1.3 Read

The Science of Boat Design

matter: anything that has mass and takes up space.

density: the amount of matter in a given amount of space.

buoyant force: the upward push that keeps objects floating in liquid.

volume: the amount of space that something takes up.

atom: a small particle of matter.

molecule: the combination of two or more atoms.

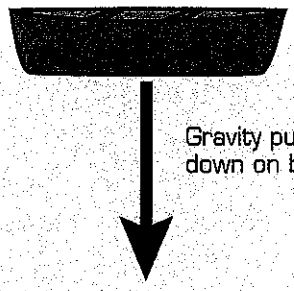
You have just finished your first attempts at building an aluminum foil boat. You also talked about the design ideas and products of other groups. You discovered some ideas that worked well and others that did not. You identified some questions that you want answered before you try again. Soon you will have another chance to build a better boat. Before you do, you will read and think about the science concepts that explain how boats work, and you can then apply this knowledge to your next boat design. To understand what makes things float, it is important to learn about three science concepts—**matter**, **density**, and **buoyant force**. They are all important to making your foil boat carry more keys.

Matter

All objects of any form (solid, liquid, or gas) are made up of matter. All matter has mass and takes up space. The amount of space that something takes up is its **volume**. The boat you are trying to build is made up of matter, and so is the water the boat floats on. Matter is made of extremely small particles called **atoms**. These atoms combine with other atoms to form larger particles called **molecules**. Molecules attach to one another to form all the objects that you see, touch, hear, taste, and smell.

Density

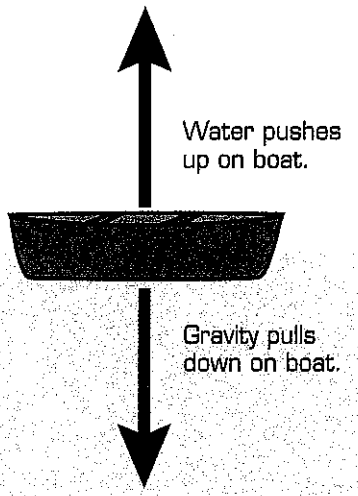
One factor that affects whether or not something can float is its density. Density is the scientific word for the amount of matter in a certain amount of space. It is a measure of how tightly the molecules making up matter are packed together in the space. The more room the molecules have in a given space, the less dense the matter will be.



If you have a cardboard box full of plastic bubble wrap, it will be lighter than the same-sized box full of books. The different materials in each box take up the same amount of space, but each contains a different amount of matter. Since a book-filled box has more matter than a box filled with bubble wrap, the box of books has greater density.

We think of books as being heavier than bubble wrap, but that is misleading. What we are really thinking about in that case is the density of the materials. A book taking up a certain amount of space will be heavier than a piece of bubble wrap taking up the same amount of space. This means that books are denser than bubble wrap. There is more matter in a book than in a section of bubble wrap of the same size as the book. That is why a box of books will be heavier than the same box filled with bubble wrap. For the same volume, the more dense material will be heavier than the less dense material.

Molecules that make up the matter in a book are tightly packed together and do not have much space between them. In the bubble wrap, the molecules have a lot of space between them because each bubble contains a lot of air—air is a gas and is much less dense than a solid. Books are solids and contain a lot less air. This makes bubble wrap less dense than books.



Buoyant Force

A force is a push or pull on matter. The upward push that keeps an object floating is called buoyant force. To understand the buoyant force that makes things float, you first have to understand gravity. You already know a lot about **gravity**. You see and feel the effects of gravity everywhere every day. Gravity is the force that holds you, and all objects, on Earth. It is a force, or pull, between any two objects. All objects have this pull toward other objects. The pull between most objects is small, and unless an object has a lot of mass, you do not feel its pull.

gravity: a pull between two objects. Gravity is the force that holds all objects on Earth.

When one (or both) of the objects is very massive (which means it has a lot of mass and, therefore, has a lot of matter), you can experience gravity's effects. Earth is very massive, and gravity is the force that pulls everything down toward the center of Earth. Because of gravity, almost everything—people, furniture, trains, and dogs—stay put on top of Earth's surface. In your activity with boats, Earth's gravity pulls on the water and keeps the water in the bucket in which you are floating your boats. Gravity also pulls down on the foil boat.

In designing a boat, an important consideration is why some boats stay afloat, while others do not, and sink. This is a question of how much buoyant force the boat produces.

Gravity pulls things toward the center of Earth, but objects do not continue falling toward the center of Earth. The ground, or other surfaces, resists Earth's pull. In the boat-building challenge, the molecules of the water push up on the molecules in the foil boat at the same time that gravity pulls down on the boat. If the buoyant force of the water pushing up on the boat is as strong as the force of gravity pulling the boat down, the boat will float.

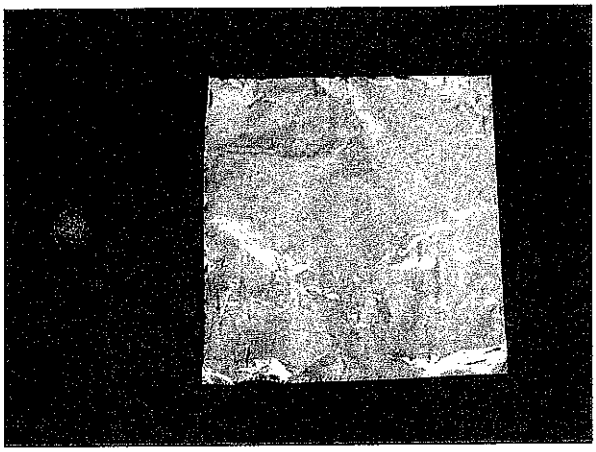
The force pulling the boat down is gravity and the water's buoyant force is the upward push helping to keep the boat afloat.

You may have thought that heavy objects sink and light objects float. But some of you might have gotten the heavy keys to float by shaping the boat in different ways. That shows that weight is not the only factor determining if objects float or sink. To illustrate what is happening in the water, look at the way gravity pulls on something that is not in water.

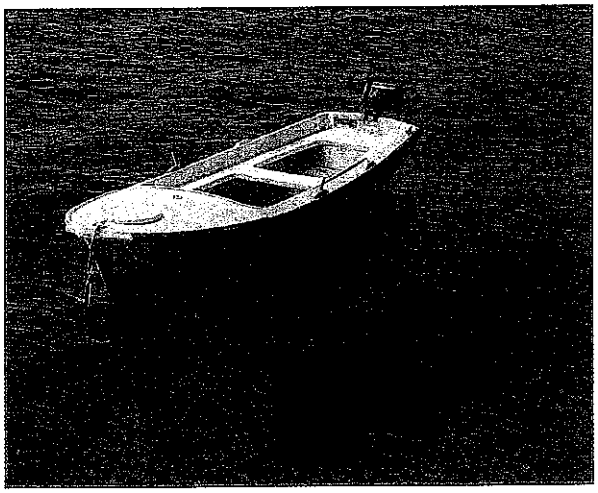
Crumple one of the 5-inch squares of aluminum into a ball, squeezing out as much air as you can. If you place it on a tabletop, you can see that all of the mass of the foil is pushing down on a very small part of the table. Set another 5-inch square of foil flat on the table, and the same mass of foil is now pushing down on a much larger area. The flat piece of foil touches more of the surface of the table. The piece crumpled into a ball touches less of the table's surface. The mass of the foil ball is concentrated into a smaller area of the table, and fewer molecules that make up the table can push back on it.

These children are able to float in the water because the gravity (downward push) of their bodies is equal to the buoyant force (upward push) of the water. Since a flotation device is less dense than the child, it causes a decrease in the overall density of the person wearing it. This means that less of an upward push by the water is needed to keep the wearer afloat.

If you were to place the foil sheet and the foil ball in a bucket of water, what do you think would happen to each? The flat sheet would float. The ball would sink (if *all* the air in the ball had been squeezed out of it). The foil ball would sink because the small area of water in contact with the full mass of the foil does not put enough buoyant force on the foil to keep it above the water. Instead, the water molecules simply slide around and over the foil ball, and it sinks.



When the foil is spread out flat, more of its surface has contact with the water. The same amount of mass from the foil pushes down on a much larger area of water. This creates a situation in which more molecules that make up the water can push up on the foil. As long as the force of gravity pushing down from the foil is equal to the buoyant force pushing up from the water, the foil will float. The flat piece of foil is better able to float because more molecules of water can apply their upward buoyant force to push up on the foil.



The air that fills the open parts in the boat decreases the boat's overall density, making it possible for the buoyant force (upward push) of the water to keep it afloat.

Density and Buoyancy Force

Buoyant force and density work together to affect whether or not something will float. When a boat sits in water, it pushes some of the water away, or displaces it. The water that was pushed away has a certain density. If the boat, including the air in it, is less dense than the water it pushes away, the boat will float. If it is denser than the water it pushes away, the boat will sink. As the density of any object increases, it sinks lower into the water, always displacing an amount of water equal to its weight. The weight of the water that is pushed away, or **displaced**, by the boat is equal to the weight of the boat.

displace: to take the place of.

This is a complicated idea to think about. You will have more opportunities to investigate the effects of gravity, buoyant force, and density. For now, think about your challenge. You are trying to figure out how to make the weight of the keys spread out over a large enough area of the surface of the foil boat so that the buoyant force of the water can keep it afloat. Even as you add more keys, the boat will stay afloat as long as you can find ways to spread the weight of the boat and keys over a larger space.

Reflect

You are going to get another chance to design a boat. You will use the same materials. Think about how your group could design your next boat to better meet the challenge by considering what you now know about gravity, density, and buoyant force. Answering the following questions should help.

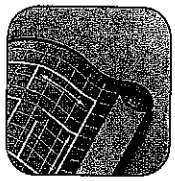
1. Think about some of the boat designs that held the most keys. What decisions did the students who designed these boats make that improved the buoyant force of the boat?
2. Did your boat float? If it did not float, why do you think it sank? Discuss *buoyant force* and *density* in your answer.
3. How could you make the boat better able to stay afloat? Remember that you have to float six keys. Use what you have learned about gravity, buoyant force, and density to answer this. Also, take advantage of what you can learn from other groups' designs.

What's the Point?

All objects are made of matter, which is made up of atoms. Atoms combine with other atoms, becoming molecules. All matter, including water and air, is made up of atoms and molecules. Density is the amount of matter in a given amount of space. It is a measure of how tightly the matter is packed together in the space.

For something to float, the force (gravity) pulling down on it cannot be greater than the force (buoyant force) pushing up from the water. To increase the buoyant force pushing up on a boat, you can spread the mass of the object over a greater area of water. This is similar to placing both the flat piece of foil and the crumpled ball of foil in a bucket of water. The flat piece floats, while the crumpled piece, if all the air has been removed, will sink.

When the foil is spread out, more of its surface has contact with the water. The same amount of mass from the foil pushes down on a much larger area of water. More molecules that make up the water can push up on the foil, or any size boat. The greater the surface of an object that touches the water, the more molecules of water can apply their buoyant force and push up the object.



Learning Set 1

Back to the Big Question

How do scientists work together to solve problems?

Over the past few days, you and your classmates have been working to create a boat that can carry six or eight keys for at least 20 seconds. The last boat you built was probably a lot better than the first one. During this activity, you took part in several practices that scientists use when they solve problems. Think about some of the things you did in this *Learning Set*.

You identified the criteria and constraints of your challenge. Criteria are the requirements your solution must meet. Constraints are the factors that put limits on your solution. You also saw how criteria and constraints could change as you attempt to solve the problem.

You learned that there is a difference between copying and building on the ideas of others. You saw some designs of other groups that may have looked very good. In your next attempt, you may have used some of these ideas. Others might have used some of your ideas. This is how scientists work and how science grows as a field. Science builds on the ideas of others.

Scientists work together. They support each other. Working together to build ideas and understanding is called collaboration. In this class, you will collaborate to solve problems or meet challenges. As you collaborate, you will share ideas with others. Others will share ideas with you. One way you collaborated was to participate in a *Solution Briefing*. Scientists often present solutions or ideas while they are trying to solve problems.

Iteration can help you achieve a challenge or solve a problem. You probably saw that it is not always easy to achieve success the first time you try something. But once you shared and saw the ideas of others and learned some scientific concepts, you were able to plan and build a better boat. Scientists also use iteration when solving problems.

In this *Learning Set*, you probably approached problem solving differently than you have in the past. You now have a better idea of how scientists work together to solve problems.

Reflect

Define or describe the following ideas and why they are important to working together as student scientists. Be prepared to discuss your answers with your class.

- criteria and constraints
- iteration
- collaborating
- building on the ideas of others
- record keeping
- asking questions
- using science knowledge