Get in the Game With Team Density

Using sports balls to confront students' naive conceptions about density

Deborah Herrington and Pamela Scott

A floating bowling ball? No way! There is no better way to get students' attention and reinforce the need for conceptual understanding than with a discrepant event like this. Density is a central concept in chemistry and physical science from middle school to college. But often, particularly at the high school and college levels, we think students understand density simply because they can solve density problems.

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However, just because a student can recite the density formula—"density equals mass over volume"—does not mean that he or she understands the concept. In this article, we describe an activity in which students explore the relationship among the mass, volume, and density of various sports balls. Students are forced to confront their naive conceptions of density and develop conceptual comprehension of this concept.

Cartesian divers.

A Cartesian diver is composed of a plastic water or soda bottle containing a neutral buoyancy object—such as a partially filled eyedropper—and filled to the top with water. As you squeeze the bottle, the "diver" goes down; and as you release it, the diver comes back up. Changes in the diver's density account for this.

Background

In our experience teaching high school and college chemistry, we have found that most students can solve mathematical density problems, but are at a loss when asked to explain how a Cartesian diver works. This is not surprising, given that density is a complex concept involving the interaction of two variables: mass and volume. Students often have several naive conceptions of density; two of the most common are that

1. more massive objects are denser, regardless of their volume (i.e., the confusion of mass and density) (Kind 2004; Schmidt 1997) and that
2. objects float because they are light (i.e., no regard for volume or density) (Krnel, Watson, and Glazar 1998).

We designed an activity to help students develop conceptual understanding of density, in which they investigate the following:

- How do mass and volume affect whether an object sinks or floats in water?
- What is the relationship between density and sinking or floating?

This activity is based on the "Floating Bowling Balls" activity (Steve Spangler Science 2010) and a series of density activities designed for grades 5–8 (Moyer, Hackett, and Everett 2007). I (Herrington) use this activity in a preparatory college chemistry course for preservice elementary teachers, but it can be adapted for middle and high school classes as well. Student and teacher guides for this activity are available online (see "On the web").

Activity design

To introduce the activity, I present students with a scenario in which a sporting goods manufacturer is considering a new production line for balls, and needs help collecting and analyzing data. Before taking any measurements, students have to qualitatively evaluate the relative masses and volumes of nine different sports balls—softballs, soccer balls, marbles, golf balls, Ping-Pong balls, racquetballs, cue balls, tennis balls, and 3.6 kg (8 lb.) medicine balls—and use this information to predict which will float in water and which will sink. Students must also explain the rationale behind their predictions. Most students base their predictions on the objects' masses or on personal experience. A few also mention density.

After making qualitative observations and predictions, I divide students into teams of two. Each pair is assigned two or three different balls and asked to measure the mass and circumference of each. They then use the circumference and the formulas provided ($C = 2\pi r$ and $V = 4/3\pi r^3$) to calculate the volume of each ball.

Teams share their data in a class table—this provides multiple trials for each ball and allows those with incorrect calculations to immediately see their errors. Figure 1 (p. 60) shows sample student data on mass and volume. Compiling data on the board or computer also provides a good stopping point for class discussion.

At this point in the activity, teachers may want to discuss significant figures for measurement. For example, I have found that students often do not read their measuring tapes to two decimal places, even though the precision of the instrument allows it. We also discuss how students' predicted order of masses and volumes compares with their measured values. Students have difficulty with the qualitative order of masses, particularly when distinguishing the difference between the cue ball and the softball. Many think the cue ball is more massive, when in fact the softball is.

This is also a good opportunity for a whole-class discussion about which balls students think will sink and which will float. Some of the balls (e.g., golf balls) have densities close to that of water, so imprecise measurements can lead to discrepant results. For example, a student group might predict that a ball will float based on imprecise measurements, only later to find (experimentally) that it sinks.

Testing

Next, students test each ball in water. A large garbage can partially filled with water works well. Students can share one garbage can, or if there are enough garbage cans and balls, groups of 8–10 students can test at stations. Large plastic storage containers also work.

After testing the balls, it is important to discuss the results as a class. For example, in my class, several teams predicted that the medicine ball would float. When asked why, one student told me she had used medicine balls in the pool during water polo practice. Fortunately, a bowl-

FIGURE 1

Sample student mass and volume data for sports balls.

Type of ball	Marble	Ping-Pong ball	Golf ball	Tennis ball	Softball	Cue ball	Soccer ball	Medicine ball	Racquetball
Average mass (g)	5.36	2.54	44.95	55.67	189.95	185.04	275.19	3,613	40.95
Average volume (cm^3)	2.54	35.40	43.40	145.4	498.2	105.6	4,537	5,996	99.33
Average density (g/cm^3)	2.11	0.0718	1.036	0.3829	0.3813	1.752	0.06065	0.6026	0.4123

(**Note:** A kilogram scale was needed to obtain the mass of the medicine ball.)

ing ball of about the same size and mass was available. Although I told students it was the same mass and volume as the medicine ball, they all thought it would sink. Their justification was that the medicine ball floated because it was made of rubber—demonstrating students' ability to rationalize observations to fit their naive conceptions. The look of shock on students' faces when the bowling ball floated was priceless! (**Note:** It is best to use a 3.6 kg [8 lb.] bowling ball because it floats fairly high. Bowling balls that weigh more than 5.4 kg [12 lb.] will sink.)

Understanding density

Students then return to their respective work areas to explain any differences between their predictions and their measurements. They are asked to look at two balls of approximately the same mass—one that sinks and one that floats—and compare their volumes. Similarly, they must find two balls with approximately the same volume—again, one that sinks and one that floats—and compare their relative masses. This exercise helps students realize that they have to use mass and volume to determine whether a ball will sink or float—the core concept of density.

After introducing the formula for density and the common units (g/ml and g/cm^3), students use their data to calculate the densities of each ball, and to compare the densities of the balls that float to the ones that sink. Students notice that the balls that sink have higher densities than the ones that float. When given the density of water, they notice that the balls that sink have densities greater than that of water, and the balls that float have densities lower than water. (**Note:** Students can also design an experiment to discover the density of water, increasing the inquiry level of this part of the activity.)

Most of my students were surprised to find that the marble was the densest ball and that the marble, cue, and golf balls were all denser than the medicine ball. When they thought about the fact that these higher density balls sank and the medicine ball did not, they realized that this had to be true.

Discussion

After students complete the activity, I give them a series of discussion and follow-up questions to answer. Some of these questions require students to use the density formula to perform calculations. For example, one question

Activity extensions.

Some possible extensions include a performance assessment requiring students to see how many pennies they can float on a piece of aluminum foil or whether they can make a piece of modeling clay sink or float. This can lead to a discussion about why ships float and be used as a precursor to an activity in which students explore the buoyant force of water, such as the one Waugh (2007) describes.

Students can also be asked to predict which soft-drink can will float in water: diet or regular? If students understand their previous investigations and the meaning of density, they will correctly predict that the diet-soda can will float; they can then test this to confirm their prediction. Or, students can design a procedure to make a golf ball float by adding salt to the water.

Still, if that is not enough, think about the importance of density in flying. If you ask students to compare the density of humid air and dry air, most will tell you humid air is denser. However, Isaac Newton discovered that humid air is less dense than dry air, a phenomenon he wrote about in his 1704 book *Opticks.* This is because, at a fixed temperature and pressure, the number of gas molecules in a given volume of air is constant. As humidity increases, heavier nitrogen and oxygen gas molecules are replaced by lighter water molecules, and the density of the air decreases.

tells students that medicine balls vary in mass but are always the same diameter, then asks them to calculate the mass necessary to sink a medicine ball. (**Note:** The same is true for bowling balls.)

Other questions are more focused on the concept of density as a measure of how much matter is packed into a given volume. For example, one question asks students to explain how and why the density of the air in a hot air balloon decreases as it is heated. (The answer is that air expands and escapes the balloon, making the air inside the balloon have less mass and therefore be less dense than the surrounding cooler air. Since the air inside the hot air balloon is now less dense than the surrounding air, the balloon floats—for the same reason that the bowling ball floats in water.)

Conclusion

The concept of density is a challenging one for students. To develop a conceptual understanding of density, they must first confront their naive ideas. Although initially some of my students think this activity is trivial, when they see the floating bowling ball, they realize they need to rethink some of their ideas about density.

After the activity, most students are better able to answer conceptual density questions. Once this activity is complete, I demonstrate—or have students construct—a Cartesian diver made of a ketchup packet inside a bottle of water and ask them to observe what happens when the bottle is squeezed. I then ask them to explain how it works. At this point, all of my students know that it is related to density, and most recognize that the volume has to be changing because the mass cannot. The bowling ball activity has been a great success! ■

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On the web

Student and teacher guides: *www.gvsu.edu/targetinquiry*

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