As a property of matter, density is a topic central to secondary school physical science. However, student misconceptions about the concept abound. Through interviews and open-ended questionnaires we have found that middle school students hold a number of nonscientific ideas about density that affect their science learning through high school. Some of these nonscientific ideas can be traced to experiences with buoyancy in water. Standard density experiments involve objects floating and sinking in water (Rohrig 2001), and many students mistake buoyancy-related phenomena for characteristics of density. Alternative activities allow students to explore density with solid materials and may help dispel misconceptions.
Common student ideas

Many density misunderstandings have been previously identified in literature (Stepans et al. 1986; Klopf er et al. 1992; Kohn 1993; and Smith et al. 1997), but our research suggests that secondary school students hold misconceptions about the concept of density especially as it refers to the buoyancy, or floating and sinking, of objects in water. Density misconceptions are typically over-generalizations based on actual observations and can be placed in three categories:

- Size;
- Shape; and
- Material.

Students with size misconceptions believe large objects sink in water and small objects float. Students with shape misconceptions believe objects have buoyancy properties that are a function of shape, with concomitant sorting in a water column based on shape. Students with material misconceptions believe that buoyancy behavior is a function of what a material appears to be, regardless of the actual density of the material. For example, these students assume an object that looks like metal will behave like metal, and all metals will exhibit the same density behavior.

Student responses to both open-ended questions and interviews exposed each of these common misconceptions. Students were first asked to predict sinking and floating behaviors of balls of different sizes (Figure 1). The majority of students chose incorrect responses, most commonly because of the size of the ball (Figure 2, p. 48). Occasionally, students chose the correct response (Figure 1, response D) and still demonstrated size or material misconceptions.

Size and shape misconceptions were particularly apparent when students were asked to predict and explain the behavior of a number of objects in a bowl of water (Figure 3, p. 48). Rather than drawing the objects at the bottom of the bowl, about 70 percent of the students distributed the objects based on size and shape. Most of these students drew the large cube at the bottom, the pyramid in the middle, and the small cube at the surface. Students widely varied where they placed the odd shape in their drawings; it was usually placed in the lower half of the water column. Student explanations were dominated by the idea of size, where larger objects always experienced “more” sinking than small objects. A secondary group of students also thought shape was the characteristic most closely related to sinking (Figure 2, p. 48).

Several factors other than density come into play when dealing with the two-state—water and solid—system. For instance, materials heavier than water can float on the surface because of surface tension, or if formed into boat shapes. Water also varies in its density if temperature or salinity is altered. For all of these reasons, we suggest that buoyancy is not the most effective way to teach density and propose the use of a one-state model—in this case solid-only—which may be more helpful in improving student conceptual understanding. Single-state activities using liquids such as oil and water have been proposed, but these are typically time-consuming to prepare, potentially messy, and the buoyancy involved may also confuse students about density (Stein and Miller 1998). Buoyancy is not a simple function of material density, but is rather a function of the pressure contrast between a reference column and the column being observed. Therefore, a floating boat is not a simple function of the density of the boat’s material and also depends upon the volume of displaced water and the volume and density of air existing below the water line. That said, students have difficulty conceptually differentiating density effects from buoyancy behavior.

**FIGURE 1**

Forced-response question.

Students were asked to predict sinking and floating behaviors of balls of different sizes.

Mary and Tony are in science class. They are using two balls \( \bigcirc \), made of the same material (which looks like wood). Mary puts the largest ball in the water and watches it sink:

After removing Mary’s ball, Tony puts the small ball into the water. What do you think happens when Tony puts the small ball into the water?

Circle the picture that you think best represents what will happen to the small ball.

[A] [B] [C] [D] [E]

Explain why you circled this picture.
Student responses to questions (shown in Figures 1 and 3) about floating and sinking.

<table>
<thead>
<tr>
<th>Figure</th>
<th>Student response</th>
<th>Misconception</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A: “Because if you compare it to the big ball it will probably be light enough to float.”</td>
<td>Size</td>
</tr>
<tr>
<td>1</td>
<td>E: “Because it will have more buoyancy.”</td>
<td>Size</td>
</tr>
<tr>
<td>1</td>
<td>C: “It is roughly half the size of the large ball so it will float at about half the depth.”</td>
<td>Size</td>
</tr>
<tr>
<td>1</td>
<td>D: “I think it will sink because it is round.”</td>
<td>Shape</td>
</tr>
<tr>
<td>1</td>
<td>C: “I think that it would float...since the object is made out of a material that looks like wood.”</td>
<td>Material</td>
</tr>
<tr>
<td>1</td>
<td>A: “I did this because wood floats on water.”</td>
<td>Material</td>
</tr>
<tr>
<td>1</td>
<td>D: “Because wood is heavy and the second object isn’t much smaller than the first.”</td>
<td>Material/Size</td>
</tr>
<tr>
<td>3</td>
<td>“Because bigger objects sink.”</td>
<td>Size</td>
</tr>
<tr>
<td>3</td>
<td>“The square seems to weigh more so it would be at the bottom. The triangle seems to weigh a little less so it would be higher than the square. The other items look light so they would float up at the top.”</td>
<td>Shape</td>
</tr>
<tr>
<td>3</td>
<td>“The small square is light so it stays at the top the large square is heavy so it sinks, the odd shape is a little lighter so it will float a little.”</td>
<td>Size/Shape</td>
</tr>
<tr>
<td>3</td>
<td>“Because the bigger the object the farther down it will go, and sometimes it depends on the shape.”</td>
<td>Size/Shape</td>
</tr>
<tr>
<td>3</td>
<td>“I think the square and the triangle and the other shape will stay up because they are big and different shaped but the small square will sink because it’s small.”</td>
<td>Size/Shape</td>
</tr>
<tr>
<td>3</td>
<td>“I drew them like this because they are different shapes and sizes.”</td>
<td>Size/Shape</td>
</tr>
</tbody>
</table>

Open-ended question.

Students were asked to predict and explain the behavior of different objects in a bowl of water.

The teacher walks by and hands Tony and Mary four objects made of the same material as the large and small balls:

- Mary reminds Tony that the large ball sank earlier when they put it in the water.

Draw each of the four objects in the water-filled container below based on whether you think they will sink or float:

Explain why you have drawn the objects this way.

Solid activities

Using only solid materials in the activities described below avoided the student misconception that water was necessary for density separation. (This view was proposed by one of the students in our study who, when asked if solid materials in a bottle might separate if the bottle were shaken, responded, “No, you need water!”) The solid materials had to have very different densities for sorting based on density to occur and to avoid issues of packing-related size sorting when additional objects were added. The following supplies were used in the activities:

- 450 g plastic or glass bottle with cap (clear spice bottles work well);
- Two sets of solid balls or beads of different material, but of same shape and size. One set should be low density (e.g., wood or plastic); the other set should be high density (e.g., metal, such as steel). Enough of each type of bead to fill the bottle one-half to two-thirds full. If beads are used, both sets should have similar structure—using different types of beads causes students to use structural differences (such as holes) to explain density contrasts;
About three each of high- and low-density balls or beads of different shapes and sizes, but the same materials as in previous bullet point; and

Two sets of balls or beads of a common material (such as plastic) and size, but different shapes.

**Activity 1: Sorting of solid materials**

The first activity compared two materials of the same shape and size to allow students to observe the separation of solid materials. We filled the bottle about two-thirds of the way with stainless steel ball bearings and plastic beads of the same shape and size, each about 0.5 cm in diameter, leaving enough room for separation to occur. Other materials, such as wood or plastic foam, also work but the density contrast between the two materials must be great enough to allow separation to occur. For example, using two metals such as copper and lead would not work because the densities are too similar.

The filled bottle was capped, held horizontally, and gently shaken from side to side (Figure 4a). The plastic balls separated perfectly from the stainless steel balls (Figure 4b). This demonstrated that the materials were separating based on some property although students were still not aware that density, an intrinsic property of the material, was causing the separation. Students tried to explain the demonstration by saying that the metal was harder than the plastic, the metal was attracted to the bottom magnetically, or even that the difference in color between the two materials was affecting the separation. In order to effectively demonstrate the concept of density, additional elements were needed.

As shown in Figure 2, students believed that large objects sink and small objects float in water, and materials behave differently as a function of shape. Therefore, students needed to observe the behavior of objects of different size and shape. We chose objects about four times the volume of the initial beads. Leaving the initial beads in the bottle, other objects were added one at a time, and students were asked to predict what would happen when the bottle was shaken. The majority of students thought the larger objects would be at the bottom of the bottle. Other students thought the objects would be side by side based on size, although they weren’t sure where in the bottle the objects would come to rest. Even students who adamantly claimed that sinking or floating in water was a function of material or density were unsure how these objects would behave outside of water. As before, plastic objects separated to the top, with steel objects beneath, regardless of size and shape (Figure 5).
Repetition of this demonstration with several different objects helped students focus on the point that objects of like material behave in a similar fashion. Some size sorting occurred, such that large objects tended to come to rest at the top of the layer of identical material. This was simply a function of packing wherein smaller objects slipped into spaces below larger objects, essentially moving and pushing larger objects toward the top. Because of this effect, if the two materials used were too close in density, all of the larger objects, regardless of material, would end up on top, seemingly contradicting the concept of density. Because of this, if the two materials used were too close in density, all of the larger objects, regardless of material, would end up on top, seemingly contradicting the concept of density. Using materials with a large density contrast avoids this complication.

**Activity 2: Shape doesn’t matter**

Although the first activity clearly showed that object behavior is independent of shape and size, many students believed that additional sorting based on shape would occur if enough objects of differing shape were added to the bottle. To combat this belief, we developed a second, very simple activity. Two sets of beads—the same size and composition, but one set was spherical while the other was cubic—were put in a second bottle (Figure 6). Students again predicted what they thought would happen when the bottle was gently shaken. Although all students determined from the previous activity that shape did not affect separation, many students still reverted to their initial misconceptions. For example, some thought the objects would layer; students were evenly split on which type of bead would be on top. Explanations for this layering included gravitational attraction between the round beads and the Earth, the “pushing” of the round beads out of the way by the square beads, and possible magnetism. Only a few students, about 10 percent, declared that the beads would remain mixed after shaking. Of course, this was the case! After this demonstration the majority of students were able to pinpoint composition, not shape or size, as the factor most likely to determine sorting behavior. Additionally, all students were convinced that water was not a necessary component of a density sorting experiment.

Although most students abandoned their misconceptions based on these two demonstrations, a few students thought we were tricking them. After shaking the bottles for themselves and observing layering in the first activity and mixing in the second, the hesitant students were also convinced that separation was independent of size and shape. Further discussions with students led them to the conclusion that separation was not occurring naturally, but rather was a property of the material. We were then able to continue with a discussion of density as an intrinsic property.

Based on student comments throughout the activities, we found this approach, including student prediction of object behavior and student manipulation of the bottles, to be an effective way to directly teach the concept of density. Additionally, the easy availability of the needed materials makes this an ideal activity for the classroom. After engaging secondary students in these activities, teachers interested in discussing buoyancy behavior can do so without also combating common misconceptions about density.

*Figure 6*

Shape has little control over material sorting.

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**Acknowledgments**

We wish to thank our colleagues Harold Coyle, Anila Asghar, and Francine Rodgers for their help with this research. Our entire team of consulting teachers helped us create and test our ideas in a classroom setting. This work was supported by the DESIGNS project funded by the National Science Foundation (NSF) Materials Development Grants ESF-9452767 and ESI-9730469. An NSF Postdoctoral Fellowship in Science, Mathematics, Engineering, and Technology Education (DGE-9906479) supported Libarkin during the course of this study.

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