When students enter the classroom, they often hold prior knowledge or conceptions about the natural world. These conceptions will influence how they come to understand what they are taught in school. Some of their existing knowledge provides good foundations for formal schooling, such as sense of number and language. Other prior conceptions, however, are incompatible with currently accepted scientific knowledge; these conceptions are commonly referred to as misconceptions (NRC 2001). Usually students derive misconceptions through limited observation and experience. Consequently, learning is not only the acquisition of new knowledge; it is also the interaction between new knowledge and prior knowledge. For example, everyday life experience leads young children to believe the Earth is flat. Learning that the “Earth is round,” some children then believe that the Earth is like a pancake—round but still flat (Vosniadou and Brewer 1992). To fully establish scientifically justifiable conceptions of the natural world, sometimes students have to experience conceptual change (Carey 1984) and transform misconceptions to complete and accurate conceptions (NRC 2001).

To facilitate students’ conceptual change toward a scientific understanding of the natural world, teachers have to (a) identify students’ current conceptions about the topic; (b) guide students to realize the limitations of those misconceptions; and (c) guide students to recognize the universality of the scientific conception. Misconceptions broadly exist in a variety of subject areas, such as physics, biology, geography, and other sciences. Among them, bringing students to an understanding of why things sink and float has proved to be one of the most challenging topics for student conceptual change.

Conceptions about why things sink and float

Why things sink and float (WTSF) is addressed in many middle school physical science curricula. Although sinking and floating is a common phenomenon in everyday life, it is a sophisticated science topic. To fully understand the fundamental reasons for WTSF requires complicated knowledge that includes an analysis of forces (buoyancy and gravity) and water pressure. That knowledge, however, is either not introduced or not sufficiently addressed in middle school curricula. Rather, some curriculum developers take a shortcut and use relative density as a simplified explanation for WTSF (e.g., Pottenger and Young 1992). Even so, relative density itself is challenging
for many students because density is a concept involving the ratio of mass to volume (e.g., Smith, Snir, and Grosslight 1992) and relative density involves comparing two ratio variables.

Despite its complexity in science, sinking and floating is such a common phenomenon that almost all students have rich experiences and personal "theories" or "mental models" for explaining WTSF. Unfortunately, many of their "theories" are either misconceptions or conceptions that are only valid under certain circumstances. Based on research literature and an experiment involving 1,002 sixth and seventh graders, we have summarized 10 misconceptions that middle school students commonly have about sinking and floating (see Figure 1) (Yin 2005).

Those conceptions are so deeply rooted in students' minds that it is very difficult for students to change them, even after they have been intensively exposed to scientific conceptions. To make things trickier, some students might be "trained" to repeat what is emphasized by the teacher and curriculum (despite what they truly believe). These students can provide scientifically sound answers to simple questions—such as "why do things sink and float"—but still hold their previous misconceptions. Authentic laboratory demonstrations or individual interviews are often used to diagnose and change misconceptions. However, these diagnostic methods are rather costly and impractical in the everyday classroom. Facing the challenge of real-world classrooms, we designed 10 multiple-choice items to help teachers diagnose common misconceptions related to WTSF.

### Diagnosing misconceptions

The diagnostic items are given to individual students at the beginning of the unit on buoyancy and density to see what misconceptions each student holds before the instruction. Students complete the diagnostic test in one 45-minute class period. During the instruction of the unit, we pay special attention to the misconceptions identified by the diagnostic tests and design activities to address each of them—these activities are presented later in this paper. At the end of the unit, the same diagnostic items are given to students again to see whether students have established a scientifically sound conception.

Each diagnostic item is designed to tap a particular misconception. The same three alternatives are allowed for each item: *float*, *sink*, and *subsurface float* (see Figure 1). To help us understand more about students' rationale for their choices, we ask students to briefly explain the *reason* for their choices. For example, students who hold misconception I—"Things sink or float due to heaviness/size"—will typically select *sink* or *subsurface float* for diagnostic item A, while students who have a scientific conception will select *float*. The short explanations of their reasoning can further illuminate the misconception diagnosis. The correct answer and answers associated with the target misconceptions are presented with each diagnostic item in Figure 1.

Our experience in the classroom has confirmed that we can use these items to accurately diagnose students' conceptions effectively and efficiently without using any laboratory equipment or individual interviews. Analyses of students' responses to these multiple-choice items have validated the effectiveness of these items in diagnosing misconceptions (Tomita and Yin 2007). In the following section, we present a number of strategies that we use to facilitate students' conceptual change.

### Realizing the limitations of misconceptions and the universality of scientific conceptions

**Provide supporting and counter-evidence for the conceptions**

One of the most obvious limitations of a misconception is its lack of universality. That is, those conceptions might work well in some situations but not in others. Take for example the conception "Holes will make objects sink (in water)." This conception works for floating objects that are made of material denser than water, e.g., a boat made of metal. Although a solid metal block sinks in water, the container shape of a metal boat will increase its capacity to displace water and its buoyancy, which allows a boat made of metal to float on water. When a hole is made in the boat, however, water flows into the boat; the boat's capacity to displace water and its buoyancy will be reduced. As a result, the boat will sink when its gravity is greater than its buoyancy. However, holes made in objects made of material less dense than water—e.g., a plastic strainer—will not sink in water.

To help students realize the limitation of their misconceptions, we encourage them to discuss and fill in a worksheet that asks them to provide both supporting and counter evidence for the common misconceptions (Figure 2). Seeing that all the misconceptions have counter evidence, students realize these conceptions are not universal scientific rules. In contrast, scientifically sound conceptions, such as density, do not have counter evidence, and can therefore be used...
A. Misconception I: Big/heavy things sink, small/light things float.
Block A and Block B both float in water. Suppose that we glue them firmly together and place them in water; together they will ____________ .

Correct answer: float
Misconception answer: sink (or subsurface float)

B. Misconception II: Hollow things float; things with air in them float.
Ball A and Ball B are made of different materials, but they have the SAME mass and the SAME volume. Ball A is solid; Ball B is hollow in the center (see the pictures below). Ball A sinks in water. When placed in water, Ball B will ____________ .

Correct answer: sink
Misconception answer: float (or subsurface float)

C. Misconception III: Things with holes sink.
Block C floats on water. Suppose we make a hole in it. When placed in water, Block C will now ____________ .

Correct answer: float
Misconception answer: sink (or subsurface float)

D. Misconception IV: Flat things float.
Blocks A and B are made of the SAME material. Block B is flatter than Block A. Block A sinks in water. When placed in water, Block B will ____________ .

Correct answer: sink
Misconception answer: float (or subsurface float)

E. Misconception V: The sharp edge of an object makes it sink.
If Block A (below left) is placed in the water, it will float. If Block A is turned upside down (below right) and placed in the water, it will ________ .

Correct answer: float
Misconception answer: sink (or subsurface float)

F. Misconception VI: Vertical things sink; horizontal things float.
Block A sinks in water if we place it in water as shown on the left. If we place it in water as shown on the right, Block A will ____________ .

Correct answer: sink
Misconception answer: float (or subsurface float)
G. Misconception VII: Hard things sink; soft things float.

Ball A and Ball B have the **SAME** mass and the **SAME** volume. Ball A is made of something soft. Ball B is made of something hard. Ball A floats in water. When placed in water, Ball B will ________.

Correct answer: float
Misconception answer: sink (or subsurface float)

H. Misconception VIII: Floating fillers help heavy things float.

A tightly sealed container is half filled with rocks and it sinks in water. If we fill the other half of the container with foam peanuts, tightly seal it again, and place it in water, it will ________.

Correct answer: sink
Misconception answer: float (or subsurface float)

I. Misconception IX: A large amount of water makes things float.

Block D sinks in the water in Container 1. When Block D is put in a big container with more water (Container 2), Block D will ________.

Correct answer: sink
Misconception answer: float (or subsurface float)

J. Misconception X: Sticky liquid makes things float.

Block A subsurface floats in water (see 1). Cooking oil floats on water (see 2). If Block A is placed in cooking oil, it will ________.

Correct answer: float
Misconception answer: sink (or subsurface float)
Student worksheet—sample counter evidence is provided, but the column should be left blank when distributed to students

<table>
<thead>
<tr>
<th>Misconceptions</th>
<th>Supporting evidence</th>
<th>Counterevidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>I Big/heavy things sink; small/light things float.</td>
<td>A boulder sinks, while a leaf and a feather float.</td>
<td>Small rocks or coins sink, although they are small. Objects made of floating wood will float in water regardless of size. Two pieces of floating wood bundled together still float. A piece of soap sinks in water. If cut into two unequal pieces, both pieces still sink in water regardless of size.</td>
</tr>
<tr>
<td>II Hollow things float; things with air in them float.</td>
<td>Balloons, beach balls, and basketballs float.</td>
<td>A submarine sinks although it has air in it all the time.</td>
</tr>
<tr>
<td>III Things with holes sink.</td>
<td>A boat or ship with a hole in it sinks, e.g., Titanic.</td>
<td>Objects made of floating materials (e.g., wood and foam) will float in water even if there is a hole in them.</td>
</tr>
<tr>
<td>IV Flat things float.</td>
<td>Water rafts and surfboards float.</td>
<td>A flat piece of iron and a ceramic plate sink.</td>
</tr>
<tr>
<td>V The sharp edge of an object makes it sink.</td>
<td>Things with an edge are easier to push in snow, soil, and other solid materials.</td>
<td>A piece of clay made into an edge shape will sink in water no matter how it is placed in water.</td>
</tr>
<tr>
<td>VI Vertical things sink; horizontal things float.</td>
<td>When we stand in water, we sink; when we lie on water, we float.</td>
<td>If we put a piece of wood pencil in water, no matter how you put it in, it floats.</td>
</tr>
<tr>
<td>VII Hard things sink; soft things float.</td>
<td>Rocks sink, while balloons float.</td>
<td>A piece of clay sinks in water although it is soft. A piece of wood floats in water although it is hard.</td>
</tr>
<tr>
<td>VIII Floating fillers help heavy things float.</td>
<td>Life preservers help people float in water.</td>
<td>If a sealed container sinks, adding foam peanuts and resealing the container won’t make it float.</td>
</tr>
<tr>
<td>IX A large amount of water makes things float.</td>
<td>Boats float in the ocean.</td>
<td>Some things sink in the ocean although the ocean is huge.</td>
</tr>
<tr>
<td>X Sticky liquid makes things float.</td>
<td>A clay ball floats in corn syrup.</td>
<td>Objects that sink in water will sink in cooking oil, although the oil is very sticky.</td>
</tr>
</tbody>
</table>

as a universal rule to explain sinking and floating. The worksheet can be completed and discussed in a small group then further discussed with the whole class, so that students can have a rich and wide range of evidence and counterevidence to consider. About one 45-minute class period is needed to complete and discuss the worksheet.

Predict-Observe-Explain
In addition, when students have trouble coming up with counterevidence for their misconceptions, we prepare some predict-observe-explain (POE) activities to guide them. POE is an instructional strategy to promote students’ conceptual change (White and Gunstone 1992). In POE activities, students are asked to (a) predict what will happen if a certain action is taken in an event (e.g., an experiment); (b) observe what actually happens; and (c) finally explain what has happened. Due to students’ misconceptions, their observations often conflict with their predictions. By creating cognitive dissonance and surprise, POE helps students realize the limitation of their misconceptions and get ready to learn scientific theories.

In one of our POE activities, we manipulate a piece
FLOATING AND SINKING

of clay into different shapes to help students see the limitations of their misconceptions about WTSF. For example, students believe that heavy things sink and light things float. We show them two clay balls—one is large, the other is tiny. We ask students what will happen if the two balls are placed in water. Students who have the misconception “Heavy things sink” predict that the big one would sink but the small one would float. We then show students that both balls sink. After the observation, students are asked to explain why they both sink. When students discuss their explanations, we guide them to consider the differences and commonalities of the two balls—Volume? Mass? Density? Students then realize that density, rather than volume and mass, determines whether an object will sink or float.

Similarly, we use POE to show students the counter-evidence for the misconception “Flat things float.” We show students a clay cube sinking in water. We then reshape the cube into a flat clay sheet and ask students what will happen if the flat clay sheet is placed in water. After seeing that the flat clay sheet also sinks in water, students realize that flatness does not determine sinking and floating. The purpose of the POE activities is to present students with sensory experiences that they can rely upon to establish scientific conceptions. POE activities are conducted as demonstrations for the whole class to view and discuss. Again, the activities and discussion are designed to be completed within one 45-minute period.

Practically, these two strategies are implemented in stages that scaffold students in identifying their own conceptions and internalizing the evaluation of those conceptions. Initially, students are asked to record their own ideas. Then students share their ideas in small groups and share group ideas in the class. Students then view a demonstration or are otherwise provided evidence that may counter common misconceptions. Finally, students are asked to reevaluate their conceptions in light of new evidence.

The effectiveness of the two strategies relies on students’ challenging their own misconceptions, often through argumentation and social construction of justifiable explanations. Rather than simply correcting students’ misconceptions and telling students which conception is the correct one, we guide students to establish a firsthand scientific conception of sinking and floating through their activities and examples (Tomita and Yin 2007). In this way, students develop an understanding of the limitations of their conceptions and begin to appreciate the robust scientific conception.

Conclusion

We have found these diagnostic items designed to identify students’ misconceptions and classroom activities designed to treat those misconceptions effective and efficient instructional tools (Tomita and Yin 2007). We expect that similar approaches can be taken to address common misconceptions and help students establish scientific conceptions in other content areas of science education.

References


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