Misconceptions about sinking and floating phenomena are some of the most challenging to overcome (Yin 2005), possibly because explaining sinking and floating requires students to understand challenging topics such as density, force, and motion. Using sinking and floating as an example, this article introduces a method to guide students to solve misconception problems by using scientific principles.

Researchers have proposed different approaches to address students’ misconceptions about sinking and floating. Yin, Tomita, and Shavelson (2008) present diagnostic items to identify student misconceptions about sinking and floating and further suggest two instructional strategies to address those misconceptions. One strategy asks students to provide and discuss both confirmatory evidence and counterevidence for their conceptions. The intent is to have students realize that scientific conceptions are well supported by evidence, whereas misconceptions are not. The other approach uses predict-observe-explain (POE) activities (White and Gunstone 1992). In POE, students are asked to make predictions (P) about an event, such as whether a bar of soap will sink or float. Then students are asked to observe (O) what happens. Finally, students are asked to explain (E) and reconcile their observation and prediction. By introducing anomalies to students, POE activities challenge their misconceptions and encourage students to build accurate scientific conceptions.

In both strategies, students are guided to develop inferences based on their observations either from memories of previous observations or from an investigation in the classroom. I categorize these two strategies of dealing with misconceptions as an observation-based approach. However, this approach has limitations.

Observation-based-approach limitations

The observation-based approach may be insufficient and ineffective for three major reasons. First, some phenomena may be difficult to observe. For example, it is beyond the limit of our daily capacity and perspective to observe directly air, blood circulation in the human body, and the shape of the Earth.

Second, it may be inefficient to rely fully on observations because an inductive conclusion should be based on a large number of observations, and any counterevidence will change or overhaul a conclusion. For example, when students rely only on the observation-based approach, for each conclusion, they would have to come up with a large amount of supporting evidence and counterevidence, as suggested by Yin, Tomita, and Shavelson (2008).

Third, observations may be distorted or even entirely determined by prior misconceptions because observations can be biased to fit with previously held ideas (Bloor 1991; Estany 2001; Hanson 1958). It is especially so for hard-to-detect phenomena. For example, following Newton, a heavy object and a light object dropped from the same height will hit the ground at the same time (friction negligible), yet people who believe that heavy things fall faster than light things were more likely than those who believe that heavy things and light things fall at the same speed to “see” the heavy thing hit the ground before the light thing (Chinn and Malhotra 2002).
Scientific principles about sinking and floating

Considering its limitations, I propose that in addition to using the observation-based approach, teachers guide students to apply scientific principles to solve problems. I categorize this as a principle-based approach. Besides overcoming the three limitations of the observation-based approach, the principle-based approach can help students practice abstract thinking skills and appreciate the fruitfulness of scientific principles. I elaborate this approach by using sinking and floating as an example.

Two scientific principles are typically used in U.S. science curricula to explain sinking and floating: resolution of forces and relative density. This article does not present an activity to teach the principles; instead, it introduces a method for guiding students to apply the principles to solve tricky misconception problems after students have learned the principles through proper inquiry and lessons about sinking and floating. However, to help readers better understand the principle-based approach in this article, the following are brief introductions of the principles to be used.

Resolution of forces

As shown in Figure 1, when an object (A) is placed in a medium (e.g., a liquid), two forces act on it. The buoyant force \( F_B \) pushes the object up and the gravitational force \( F_G \) pulls the object down. The maximum buoyancy that can act on the object is the weight of the maximum amount of liquid that the object can displace. For a solid object, the maximum volume of medium it can displace is equal to the maximum volume of the object, \( v_O \). That is, the displaced volume equals the volume of the object when the object is completely submerged in the medium. As the mass of the displaced medium is \( \rho_M v_O \), where \( \rho_M \) is the density of the medium, the maximum buoyancy (i.e., the maximum weight of the displaced medium) that can act on the object is \( \rho_M v_O g \), where \( g \) is the acceleration due to gravity. The gravity that acts on the object is always \( m_O g \), where \( m_O \) is the mass of the object and \( g \) is the acceleration due to gravity. Hence, whether an object will sink or float can be predicted by comparing the gravity and maximum buoyancy exerted on the object:

- If \( F_G > F_B \), object A sinks.
- If \( F_G < F_B \), object A floats.
- If \( F_G = F_B \), object A subsurface floats.

Relative density

The second principle is relative density, derived from the resolution of forces. If the object has a homogeneous density (e.g., a solid object that is not hollow inside or designed in a way to displace more medium than its actual volume), \( m_O = \rho_O v_O \). The gravitational force, \( F_G \), can also be written as \( \rho_O v_O g \). As \( v_O g \) is the same in the \( F_G (\rho_O v_O g) \) and \( F_B (\rho_M v_O g) \), they cancel each other out. Whether an object will sink or float, then, can be predicted by simply comparing the density of the object \( (\rho_O) \) and the density of the medium \( (\rho_M) \):

- If \( \rho_O > \rho_M \), \( F_G > F_B \), A sinks.
- If \( \rho_O < \rho_M \), \( F_G < F_B \), A floats.
- If \( \rho_O = \rho_M \), \( F_G = F_B \), A subsurface floats.

This relative density principle can be handier than the resolution of force for an object with a homogeneous density because it replaces the force comparison with density comparison.

Density as a property of a material

Both sinking and floating principles involve density. An important property of density that students need to know and be able to apply is that the density of a material does not change with the size of the material.

Principle-based approach

Even after students learn about sinking, floating, and the property of density, many cannot apply these scientific principles to solve problems. When given problems, students tend to “forget” the scientific principles and be “tricked” by their misconceptions.
FIGURE 2 Misconception items related to sinking and floating (Yin, Tomita, and Shavelson 2008)

Note: Only some items in the original article are used as examples here. For clarity, the items are renumbered and therefore are different from their original numbers in Yin, Tomita, and Shavelson 2008.

1—Misconception: Large/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; they together will __________.
Correct answer: float
Misconception answer: sink (or subsurface float)

2—Misconception: Flat things sink.
Block A and block 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)

3—Misconception: 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 __________.

Subsurface float

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

4—Misconception: 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)

(Yin and Tomita 2008; Yin 2005). The following section illustrates how to guide students to apply scientific principles to solve problems.

After teachers have taught one or both of the two principles and the property of density through appropriate lessons or investigations, as a check on student learning, the teacher can give students diagnostic items to solve, for example, those in Figure 2, selected from Yin, Tomita, and Shavelson (2008). These diagnostic items measure common misconceptions and tend to be very challenging for students, even for some students with high achievement scores (Tomita and Yin 2008). After learning the scientific principles, if students continue to hold misconceptions and fail to answer the questions correctly, they can then be guided to apply principles to solve problems.
Applying Scientific Principles To Resolve Student Misconceptions

5—Misconception: Lightweight filler material, such as styrofoam, helps 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)

Diagnostic items involving relative density
Items 1 and 2 in Figure 2 involve objects and media with density that does not change from the initial setting (left) to the subsequent (right). In item 1, even though block A and B are glued together, their density does not change; therefore, they will still float in water as before. In item 2, even though block B is flatter than block A, the two blocks are made of the same materials. Therefore, the two blocks have the same density. As block A sinks in water, block B will sink in water, as well. If students choose the wrong answers, teachers can guide them to use the scientific principles in problem solving. Figure 3 provides sample guiding questions (under the “Questions” heading) and correct responses (under the “Item” heading). The same format is used in Figures 4 and 5. The prompts can be given to each student or each group as a worksheet or used as guiding questions in class discussion.

Similar to items 1 and 2, many items diagnosing other misconceptions in Yin, Tomita, and Shavelson (2008) can be solved by using relative density. For instance, holes will make things sink; the sharp edge of an object makes it sink; vertical things sink, horizontal things float; hard things sink, soft things float; a large amount of water makes things float. In all the items, regardless of the size, shape, orientation, or texture of the objects and the changes in the amount of the medium (i.e., water), neither the density of the object nor the medium changes. Therefore, the sinking and floating of each object do not change from the original settings.

Unlike other diagnostic items, item 3 (Figure 2) involves more than one medium. Nevertheless, students can still be guided to use relative density to solve the problem in a slightly different way, which is presented in Figure 4. In item 3, the object subsurface floating in water shows that its density is the same as that of the water. The oil floating on water shows that the density of the oil is less than that of the water. Therefore, the density of the oil is less than that of the object. Consequently, the object will sink in the oil.

Diagnostic items involving resolution of forces
Items 4 and 5 (Figure 2) are different from all the other items discussed insofar as the object does not have homogeneous density. Item 4 involves a hollow ball, and item 5 involves a container with mixed materials in it. As it is not straightforward to measure or estimate the density of the object in the two items, the resolution of forces may be used rather than the relative density. Figure 5 provides sample guiding questions and correct responses. During this process, students are guided to compare the gravity and buoyancy to make a prediction.

In item 4, both balls have equal mass and equal volume; that is, neither the gravity nor the maximum buoyancy differs for the two balls, and therefore the hollow ball will still sink like the solid one does. In item 5, the gravity increases (more stuff is added to the container) while the maximum buoyancy stays the same (the overall volume of the container stays the same). As gravity is larger than maximum buoyancy in the new situation, the object will sink.

Implementation of the principle-based approach
Examples in Figures 3 to 5 suggest how to guide students to apply scientific principles to solve problems about sinking and floating. However, attention should be paid to the following issues during implementation.

First, the guiding questions and the correct responses are only examples, and although they are among the most straightforward and logical routes, they are not the only possibilities. In addition, the guiding questions should not be used as scripts; in reality, students might
not respond in the expected way. When students have difficulties, the teacher should reteach some content or provide more scaffolding. For instance, if a teacher finds that students have trouble understanding or applying the rule that the “density of a material does not change with the size of the material,” the teacher may spend time helping students to understand the rule first (e.g., by using equations, schema, or activities). It is also possible that some students might skip steps and solve the problems more quickly than shown or use other approaches. For example, students may use the resolution of forces to solve problems that could have been solved by using relative density, and vice versa. There is no one-size-fits-all strategy, and the teacher should make adjustments based on students’ responses. Teachers should be flexible and engage students in discussion whenever possible.

Second, only symbols are used in the current guiding questions and responses to fit the nature of the original misconception diagnostic items (Yin, Tomita, and Shavelson 2008). If the symbols are too abstract for some students (especially at lower grades), the teacher may replace the symbols with specific numbers in both the items and the guiding questions to reduce the cognitive load for students. For example, density less than that of water may be specified as 0.9 g/cm³, density greater than that of water may be specified as 1.2 g/cm³, and specific mass and volume information may be provided to help students conceptualize the problem in a concrete way. On the other hand, when possible students should be encouraged to think about science problems by using symbols, because using scientific language is an important component of science training.

Third, as suggested earlier, the guiding questions can be handed out to individual students or groups as worksheets or used as guiding questions in class discussion. In addition, the guiding questions can be used in a combined manner to engage all students. For example,
### FIGURE 5
**Force-analysis guiding questions and sample correct responses to items 4 and 5**

<table>
<thead>
<tr>
<th>Steps</th>
<th>Questions</th>
<th>Item 4</th>
<th>Item 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observation</td>
<td>Does object A sink or float in water?</td>
<td>Sinks</td>
<td>Sinks</td>
</tr>
<tr>
<td>Inference</td>
<td>Compare the gravity ($F_g$) and the maximum buoyancy ($F_B$) exerted on object A. Which one is greater, or they are the same?</td>
<td>$F_g &gt; F_B$</td>
<td>$F_g &gt; F_B$</td>
</tr>
<tr>
<td>Inference</td>
<td>How does the force of gravity exerted on object B ($F_g'$) compare with the force of gravity exerted on object A ($F_g$)?</td>
<td>$F_g' = F_g$</td>
<td>$F_g' &gt; F_g$</td>
</tr>
<tr>
<td>Inference</td>
<td>How does the maximum buoyancy exerted on object B ($F_B'$) compare with the maximum buoyancy exerted on object A ($F_B$)?</td>
<td>$F_B' = F_B$</td>
<td>$F_B' = F_B$</td>
</tr>
<tr>
<td>Inference</td>
<td>Compare the gravity ($F_g'$) and maximum buoyancy ($F_B'$) exerted on the object B. Which one will be greater, or they are the same?</td>
<td>$F_g' &gt; F_B'$</td>
<td>$F_g' &gt; F_B'$</td>
</tr>
<tr>
<td>Prediction</td>
<td>Will object B sink or float in the water?</td>
<td>Sink</td>
<td>Sink</td>
</tr>
</tbody>
</table>

The teacher may encourage students to respond to the prompts individually, then discuss in small groups to arrive at a consensus, and finally discuss different ideas in class. It is also helpful to give students some time and opportunities to think and talk about challenging questions with any prompts before they are guided to the correct direction so that they are not limited to one approach and can compare different ones.

Fourth, once students learn how to use the principles to solve sinking and floating problems, the teacher does not have to guide them to solve every one. Instead, the teacher may encourage students to transfer their analytical skills to solve problems in new scenarios. For example, the teacher could provide less and less direct scaffolding when students are given similar problems.

Fifth, the principle-based approach does not exclude the observation-based approach. In fact, the two compensate for each other. For example, if the objects involved are available for demonstration, the teacher may employ a POE activity, asking students to discuss the questions first and then demonstrating what happens to examine different predictions and highlight the advantage of the scientific conception over the misconception. That is, observation supports the prediction guided by scientific principles rather than by misconceptions.

Finally, this article discusses how to use scientific principles to deal with misconceptions about sinking and floating. A similar approach can be applied to other types of questions (e.g., real-event application of sinking and floating) or misconceptions (e.g., phase change of water) as well. Teachers need to design the guiding questions intentionally so that students can learn to apply scientific principles to solve problems and realize the limitation of misconceptions and the fruitfulness of the scientific principles so that the application of the scientific principles becomes as intuitive as their misconceptions used to be.

### References


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