Overview

Why do some objects sink and others float in water? Why can an egg which sinks in water float if you add a few teaspoons of salt? Why does a great ocean ship like the Queen Mary float if it is made of steel, while a piece of steel sinks? As Piaget\(^1\) pointed out, this question is difficult for children to answer because they try to oversimplify the problem. We saw this earlier when we studied volume in Marshmallows vs. Containers. We noted then that the children often say the tallest glass has the greatest volume of water, ignoring the other two dimensions forming the cross-sectional area of the glass. If an object sinks and the child is asked why, the answer would be as Piaget noted, “Because it is heavy.” If it floats, then the response is “That one swims because it is light.” Sometimes the children answer that it floats “Because it is big” and sometimes they say it goes to the bottom “Because it is big.” These confused responses were given by children whom Piaget interviewed whose ages ranged between 5 and 12. Why? What are the children doing wrong? They are simplifying the problem so that they only use one variable, either mass or volume, to describe whether an object sinks or floats. As we shall see, it is necessary to use both variables to understand the situation properly, just as it is necessary to include both the height and the cross-sectional area of an object to determine its volume.

You can’t really blame the children for this lack of insight because they have never done an experiment which exposes and contradicts their biases. Our Sink and Float does just that.

How do we express this problem in the scientific language of variables? The type of object is the manipulated variable (Question 1). Whether it sinks or floats is the responding variable (two values, S and F) (Question 2). The type of liquid
is held fixed during the experiment. To distinguish between materials, we need two quantitative variables: mass and volume. Therein lies the problem for the children. They have to identify the object by its mass-volume relationship. They plot the mass-volume relationship of all the objects on one graph and see if they can predict which objects will sink and which will float.

**Picture, Data Table, and Graph**

Each pair of children is given several objects along with some water. They have to measure and record the mass and volume of each. Then they determine which ones sink and which ones float in water. The children should make a fairly detailed picture of this, like the one shown in Figure 1. All the variables are identified: T for type of object, M for mass, V for volume, S for Sink, and F for float. The apparatus is also clearly shown. With this picture someone can easily repeat the experiment.

A list of the objects we use at UIC are shown in Figure 2. Some of these objects — the spheres and clay—are part of the TIMS package of equipment. You can easily dig up a rock and ask your colleagues to save their fine wine corks.

One of the most important items, however, is the paraffin block. This should be available in block form from your local supermarket. The reason paraffin is so important is that you want at least one object which is heavier than most of the other objects but which still floats. This will cause unending confusion for the children because they think heavy objects sink. Yet here we have one of the heavier objects floating. *Our* paraffin block has dimensions

\[12.6 \text{ cm} \times 6.2 \text{ cm} \times 1.4 \text{ cm}\]

and has a volume of approximately 109 cc. It is important that the children measure the block’s length, height, and width to the nearest millimeter. They should use their calculators to determine accurately the block’s volume.

Also, make sure that one of the objects that sinks has more volume than at least one of the objects that floats. In our case the rock sinks even though it has more volume than the wood sphere. Again, this should raise questions because children inherently think that objects float because they have more volume. Here is one that doesn’t.

To measure the mass of water, fill the graduated cylinder with 100 cc of water (V) and measure its mass, \(M_{\text{full}} = M_{\text{water}} + M_{\text{cylinder}}\). Then, empty the water and measure the mass of the empty graduated cylinder, \(M_{\text{cylinder}}\). The mass of the water is \(M_{\text{water}} = M_{\text{full}} - M_{\text{cylinder}}\) when the volume of water is 100 cc.

The children carefully measure M and V for each object and enter that information in the data table. They then record whether the object sinks or floats in the last column of the data table.

The children now plot the mass-volume curve for every substance including water. The children should have done the TIMS experiment.
Mass vs. Volume before Sink and Float so they know that each substance has a unique (V,M) curve passing through (0,0) (Question 3). They also know that the best fit mass vs. volume curve (Question 4) is a straight line. Since that is true, the children only need one data point (along with (0,0) for each substance. The children can then easily draw the line through the data point and the origin, as shown in Figure 3. Have them label each curve, as we have done, placing an S or F next to the type of object.

The children should recognize the emerging pattern. The curves of all objects that sink in water lie above the curve for water. The curves of objects which float lie below the curve for water. Since each curve is determined by the relationship between mass and volume, both mass and volume determine whether an object sinks or floats in water, not just mass or volume. If we describe an object with a mass of 20 gm and ask whether it sinks or floats, you should answer, “I have no idea. What is its volume?” As illustrated in Figure 4, the object could lie at any point along the horizontal line drawn which starts at (0 cc, 20 gm). You cannot plot the point because I did not tell you the volume. After drawing in the line for water you can ask, “Is its volume less than 20 cc?” If it is, it will sink; if not, it will float. If its volume is 16 cc, then you can plot the (V,M) data point and see that the object sinks. This is illustrated in Figure 4. A similar argument holds if we give you only volume information. We explore these ideas in the first few comprehension questions.

What happens if you change the type of liquid? Although we could redo the experiment with a different liquid, we can also argue inductively as follows. If the object’s mass-volume curve lies above the line for the new liquid, the object will sink; and, if it lies below, it will float. Therefore, all we have to do is find (V,M) for the new liquid, plot its mass-volume line, and see where the (V,M) point for the object lies relative to the new liquid line. For example, if the new liquid has a mass of 24 grams when its volume is 14 cc, then its mass-volume line, as shown in Figure 4, lies above the data point for the object. Therefore, since the object now lies below the liquid line, it floats in the new liquid! It is this kind of analysis the children should carry out when answering the comprehension questions.
Liquids other than water are often messy to handle. Karo syrup is an example of a liquid that has its (V, M) line above that for water. But an object placed in Karo syrup gets yucky. Our suggestion is for the teacher to do a classroom demonstration with Karo syrup. The ratio of M/V for Karo syrup is 7gm/5cc. The children can plot the Karo syrup line and see if any of the objects now float instead of sinking. Then let them place the object in the syrup and see if they are correct. They will find the plastic object which sank in water now floats in Karo syrup. We return to this idea in the comprehension questions by studying a little geology.

The type of object could be another liquid rather than a solid. For example, what happens when you drop corn oil (nice and yellow) into water? Have the children determine the (V, M) curve for corn oil. They will find that it lies below the water line. Therefore, corn oil floats in water. To see this in a dramatic fashion, have the children pour corn oil into a beaker. Then pour some water. The corn oil, although initially at the bottom, rises to the top.

Some Magic Tricks

Let’s call the above “trick” the rising corn oil trick. You can present it to the children and see if they can explain the puzzle by asking the correct questions, like what is the mass of the corn oil, what is the volume.

Another great trick is the Mystery of the Rising Egg. Place an egg in a graduated cylinder with water already in it, say 100 cc. The egg sinks. Now add some salt, a little at a time. Soon the egg rises, as if by magic. Why? Have you changed the mass or volume of the egg? No. Have you changed the volume of the water? No, as the children can see by the unchanging water level in the graduated cylinder. Then what has changed? Have them illustrate their answer on a mass-volume plot, as shown in Figure 5. Initially the egg must lie above the water line. By adding salt the mass of the 100 cc of salt water increases, thus moving the line higher as the water becomes saltier. When enough salt has been added, the new salt water line is above the egg point and the egg floats. You can turn this into a quantitative lesson by having the children measure the mass and volume of the egg (ours was M = 57 gm, V = 46 cc), plot this data point, and draw in the salt water line which just makes the egg float. The mass of added salt is given by the difference in mass between the two lines at the volume of water you are using, as shown in Figure 5.

Another great trick is the Mystery of the Rising and Falling Raisin. Place a raisin in a glass of clear soda, like 7-Up or sparkling seltzer water. The raisin first sinks like a rock, then rises to the top, sinks again, and rises again for several up-down passages until it seems to run out of gas and finally stays on the bottom. Why? Have the children look closely at the raisin and ask them to figure it out using their mass-volume plots. You might ask them, “Did the liquid change mass or volume? Did the raisin change mass or volume?” Certainly nothing happens to the liquid. So the liquid line does not change. Initially the raisin line must be above that of the liquid since the raisin sinks to the bottom. But then, the raisin picks up some of the gas that normally bubbles up in the 7-Up or seltzer water. If the children look closely, they can see the bubbles on the raisin. The added gas bubbles

![Figure 5](image-url)
The children can try a version of the Rising and Falling Raisin at home where they can play the part of the raisin. Have them ask their moms if they may take a bath (won’t that be a surprise!). If they lie face up and flat, as shown in Figure 7, and exhale they begin to sink in the water. If they then inhale deeply, they begin to rise. Why? Because when they inhale, they are increasing their volume by expanding their chest without increasing their mass (the air they take in has negligible mass). Their mass-volume data point moves to the right, as shown in Figure 7, until their curve of mass-volume is below that of water. Hence they float.

Density Interpretation of Sink and Float

By using a graphical approach, we have kept the material at a concrete operational level aimed at 4th and 5th graders. *Sink and Float* is still not easy because of the complicated relationship between mass and volume for both the object and the liquid. We can, however, use a quantitative approach, which although a formal operational, has the virtue of simplifying the discussion and is appropriate for 6th graders and older.

Since each curve is a straight line through (0,0), each point on the line has the same ratio of mass to volume. As we saw in *Mass vs. Volume*, this ratio is called the density of the object and is usually represented by the Greek letter, \( \rho \):

\[
\frac{M}{V} = \text{Density} = \rho
\]

Thus, we can characterize each object by a single number, its density. Density is a compound variable, since it is made up of two fundamental variables, in this case, mass and volume. Density is the slope of the mass-volume straight line. The steeper the line, the greater the density. You can pursue the concept of density through a data table in *Question 11*. The children use their calculators to determine the density of each object.
Let us look at *Sink and Float* from the point of view of density. For water, we found the density to be

\[ \rho_{\text{water}} = \frac{99 \text{ gm}}{100 \text{ cc}} = 0.99 \text{ gm/1 cc} \]

In fact, the density of water, at standard air pressure and density, is defined to be exactly 1 gm/1 cc. We usually drop the 1 in the denominator (just as we do in expressions such as 60 mi/hr) and write simply \( \rho_{\text{water}} = 1 \text{ gm/cc} \). From the experiment, we learn that all the objects that float have curves whose slopes and, therefore, densities, are less than water’s. All the objects that sink have densities greater than water’s, i.e.,

\[ \rho_{\text{sink}} > \frac{1 \text{ gm}}{\text{cc}} \]

\[ \rho_{\text{float}} < \frac{1 \text{ gm}}{\text{cc}} \]

In general, if an object sinks in any liquid:

\[ \rho_{\text{object}} > \rho_{\text{liquid}} \]

And if it floats in any liquid:

\[ \rho_{\text{object}} < \rho_{\text{liquid}} \]

This approach certainly simplifies things. We do not have to do a lot of graphing. Instead, we have to do a lot of calculating. We have several comprehension questions that give the children practice in making the calculations. The first objective, however, is that the children understand the above relationships through doing the experiments. Never just tell them the densities. They must discover it themselves by measuring the masses and volumes, finding \( \rho \) for each, and looking at the emerging pattern.

How might we explain our tricks in terms of density? Easy. For the egg and water, the density of the egg stays fixed at \( \rho_{\text{egg}} = 1.2 \text{ gm/cc} \). This is greater than the density of water, so the egg sinks. By salting the water we increase the *water’s mass* while holding its volume fixed. This increases the density of the salt water until \( \rho_{\text{egg}} < \rho_{\text{salt water}} \), and the egg floats. In the case of the raisin, initially the density of the raisin is greater than that of water, so it sinks. By picking up air bubbles, the volume of the raisin increases; and its density decreases. With enough air bubbles, the density of the new raisin becomes less than that of water, and the bubbled raisin rises. Likewise, when you inhale you take in air increasing your volume without significantly increasing your mass. Your density goes down, so you go up in the tub.

### Building Boats That Float out of Materials That Sink

Based on what we have just learned, in order for a boat to float, we must have

\[ \frac{M_{\text{boat}}}{V_{\text{boat}}} < \frac{1 \text{ gm}}{\text{cc}} \]

But how, with \( \frac{M_{\text{steel}}}{V_{\text{steel}}} = 7.8 \text{ gm/cc} \), can we achieve this? The answer is to shape the steel into a hollow container which we call the “boat.” Before we put anything into the boat all it contains is air, as shown in Figure 8. The mass of the boat is the mass of the steel plus the mass of the air inside. The latter is negligible. The volume of the boat is determined by its outer dimensions and is equal to the volume of the steel plus the volume of the air inside. The latter is not negligible. The density of the boat is thus

\[ \rho_{\text{boat}} = \frac{M_{\text{boat}}}{V_{\text{boat}}} = \frac{M_{\text{steel}} + M_{\text{air}}}{V_{\text{steel}} + V_{\text{air}}} = \frac{M_{\text{steel}}}{V_{\text{steel}} + V_{\text{air}}} \]

(Note: \( \rho_{\text{boat}} \) is NOT \( \frac{M_{\text{air}}}{V_{\text{air}}} + \frac{M_{\text{steel}}}{V_{\text{steel}}} \))

It is \( \rho_{\text{boat}} \) that must be less than 1 gm/cc if the steel boat is to float. If we make the dimensions of the boat large enough by enclosing enough air, we can easily do this. To simulate this idea, have the children take a solid piece of clay and watch it sink.
Sink and Float, page 7 of 12

Then have them hollow it out into a bowl and watch their clay bowl float. Now ask the children to find the density of their boat. The mass is easy: just put the clay boat on the equal arm balance. The volume is tricky. You need the volume of the clay and the volume of the air in the clay boat. You can find the volume of the clay by displacement. It’s easier to find before the children make the boat, as illustrated in Figure 9. Now fill the boat with water and pour the water into a graduated cylinder. The volume of the water the boat holds is also the volume of air it contains when empty. Then,

\[ \rho_{\text{boat}} = \frac{M_{\text{clay}}}{V_{\text{clay}} + V_{\text{water}}} \]

A boat is not of much use unless it carries a load. Let’s see how we can calculate how much mass our boat can hold. We call this \( M_{\text{load}} \). The important point to understand is that adding mass as a load does not change the outer dimensions of the boat. Therefore, the volume of the boat stays the same as you add mass. Only by changing the outer dimensions can you change the volume of the boat. Therefore, as you add load, the density of the boat increases:

\[ \rho_{\text{boat}} = \frac{M_{\text{clay}} + M_{\text{load}}}{V_{\text{boat}}} \]

The boat will float as long as \( \rho < 1 \text{ gm/cc} \) and sink when \( \rho > 1 \text{ gm/cc} \). At the point of just going under

\[ \rho_{\text{boat}} = \frac{M_{\text{boat}} + M_{\text{load}}}{V_{\text{boat}}} = \frac{1 \text{ gm}}{\text{cc}} \]

Let us try an example. Suppose the clay has a mass of 40 gm and a volume of 27 cc. You shape it so that it holds 55 cc of water. Then the volume of the boat is \( V_{\text{boat}} = 27 \text{ cc} + 55 \text{ cc} = 82 \text{ cc} \). To find the maximum load you have to solve

\[ \frac{40 \text{ gm} + M_{\text{load}}}{82 \text{ cc}} = \frac{1 \text{ gm}}{\text{cc}} \]

Since both sides of the equation have to equal 1 gm/cc, we can easily solve for \( M_{\text{load}} \) by inspection. What number added to 40 gives us 82? Easy enough, \( M_{\text{load}} = 42 \) grams. If you have 6th graders or older, challenge them to solve for \( M_{\text{load}} \) using algebra. We show you how to do it here. There are just two steps. First, multiply both sides by 82 cc to obtain the algebraic equation

\[ 40 \text{ gm} + M_{\text{load}} = 82 \text{ cc} \times \frac{1 \text{ gm}}{1 \text{ cc}} = 82 \text{ gm} \]
Next, subtract 40 gm from each side, so that

\[ M_{\text{load}} = 82 \text{ gm} - 40 \text{ gm} = 42 \text{ gm} \]

It’s fun to watch the boat sink lower and lower as more and more mass is added, and as you get closer and closer to the predicted value. Usually, a big cheer will resound when a student “gets it right.” By giving the children identical pieces of clay, you can set up a boat building contest. The winner is the student that shapes the boat so that it holds the biggest load, providing the builder has correctly predicted the value of \( M_{\text{load}} \). An alternative to clay boats is plastic butter tubs. Save up the identical ones. Have the children measure \( M \) and \( V \) for a tub and predict how much mass it will hold. Then let them check it out. Here all students should get the same answer since the tubs are identical.

Building boats is hard stuff. It requires two steps of logic and good critical thinking skills. That is why the students should do it sometime before they graduate.

**Comprehension Questions**

We have made up lots of questions because the subject of \textit{Sink and Float} is so rich in concepts and applications. We have divided the questions into four sections that include a qualitative understanding of \textit{Sink and Float}, graphical techniques applied to sinking and floating, the concept of density, and building boats. We encourage you to choose only those sections and questions that you would like the children to answer. You might not want to include density and boat building. Or, you might want to try everything and include only one or two questions from each section. You might like to save some questions for a quiz. By reading over all the answers you will probably find some that appeal to you and are more appropriate for your class.

The first four questions aim to explore the children’s understanding of the two variables, mass and volume, needed to describe sinking and floating. **Question 5** concerns mass and asks the children if mass alone tells them whether an object sinks or floats. Their data should show them that the more massive of two objects does not always sink. In our case, paraffin is more massive than all of the objects yet it floats. Nor does the least massive object always float. Clay is less massive than paraffin, yet it sinks. So, mass alone cannot tell us whether an object sinks or floats. In **Question 6** we consider the same idea from the point of view of volume. Children often think the object with the biggest volume floats. Rocks can have a much larger volume than pieces of wood, yet rock sinks and wood floats. On the other hand, the wood sphere has a much smaller volume than the clay, yet wood floats while clay sinks. So, volume alone cannot help us predict whether an object sinks or floats.

**Question 7** just gives the mass as 500 gm. That’s a good-sized mass and the children may be impressed enough to stop thinking and answer, “It will sink because it is so massive.” That, of course, is wrong. We do not know whether it will sink or float until we determine its volume.

**Question 8** is supposed to “trick” the children. Block A has the bigger volume and floats. Block B has the smaller volume, so if the children are still thinking in terms of one variable, they will say B sinks. What they should answer is, “We can’t tell without knowing the mass.”

Questions 9 through 14 address the graphical techniques for determining whether an object sinks or floats. **Question 9** is also a very practical one. Which curve is grease? Since grease floats on water, curve B represents grease and curve A must be water. Why can’t you put out a kitchen grease fire with water? Dousing such a fire will not do a thing except float the burning grease on top of the water. What you should do is use a fire extinguisher that sprays foam on the fire and kills it by oxygen starvation.

**Question 10** refers to the Mystery of the Rising Egg. The tap water line must lie below that of the egg and salt water above. Therefore, B is tap.
two mass-volume lines that pass through (0,0). If they do this carefully, they find that liquid B floats on A.

The next section deals with density. You might want to hold off on this for a while or plunge on ahead. Although density is more formal operationally, the children should be able to handle it.

We start with a “trick” question. In **Question 15a** we ask which is heavier a pound of feathers or a pound of lead. Hopefully the children will not be fooled, and will say, “Neither, they have the same mass.” **Question 15b** is not a trick but it may be tricky. The volume of a pound of feathers is much greater than a pound of lead; so, the density of lead is much greater than the density of feathers.

**Question 11** was taken from a 1986 national assessment test given to 9-, 13-, and 17-year-olds. Since B and C float and A sinks, the mass-volume line for A must be above those for B and C. Since all the blocks have the same volume, and A is above the other two, then it must have more mass. So the only statements you know are true are the first one and last one. This is illustrated in Figure 10. As in Question 6, we have no idea about the masses of B and C. All we know is that they both float and have the same volume. This does not mean that they have the same mass nor is this enough information to tell us whether B or C has more mass. Statements 3 and 4 are both false since B and C have less mass than A. **Question 11** requires the children to think. Only 27% of the 9-year-olds and 53% of the 13-year-olds got this type of question correct on the national test!

If the children use their graph correctly in **Question 12**, they find the data point lies below the water line and so the object floats. In **Question 13**, we try a different liquid. The children have to plot the data point for the liquid and the data point for the object. Drawing lines through each point and (0,0) they should find that the line for the liquid lies below that for the object; so, the object sinks. As we mentioned earlier, one liquid can float on another. Corn oil and water nicely illustrate this. Again, the children can use their graph to plot the two sets of data points in **Question 14** and draw the

---

**Density Tables**

<table>
<thead>
<tr>
<th>Object</th>
<th>Density in g/ml/cc</th>
</tr>
</thead>
<tbody>
<tr>
<td>rock</td>
<td>2.83</td>
</tr>
<tr>
<td>clay</td>
<td>1.48</td>
</tr>
<tr>
<td>steel</td>
<td>7.76</td>
</tr>
<tr>
<td>glass</td>
<td>2.35</td>
</tr>
<tr>
<td>plastic</td>
<td>1.17</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Object</th>
<th>Density in g/ml/cc</th>
</tr>
</thead>
<tbody>
<tr>
<td>wood</td>
<td>0.71</td>
</tr>
<tr>
<td>paraffin</td>
<td>0.83</td>
</tr>
<tr>
<td>cork</td>
<td>0.22</td>
</tr>
</tbody>
</table>
In **Question 16** we ask the children to complete the density table. Figure 11 illustrates our answers to this question.

**Question 17** was also taken from the national assessment test. By inspection, you can eliminate answers A and D since their densities will be less than one. For answers B and C the children will have to calculate the respective densities. For \( \rho_B \) we have a density of 11 gm/9cc. For a sense of comparison we want to place this over a common denominator, and so we write \( \rho_B = \frac{1.22 \text{ gm/cc}}{1 \text{ cc}} \) or \( \rho_C = \frac{1.37 \text{ gm/cc}}{1 \text{ cc}} \), so answer C is correct. Another way to do the mathematics of Question 17 without a calculator is to write each density with a common numerator. For the two cases of interest

\[
\rho_B = \frac{11 \text{ gm}}{9 \text{ cc}} \\
\rho_C = \frac{5.5 \text{ gm}}{4 \text{ cc}} = \frac{11 \text{ gm}}{8 \text{ cc}}
\]

We can easily see that \( \rho_C > \rho_B \) because for the same mass C has the smaller volume.

**Question 18** was taken from the same section of the national assessment test as **Question 17**. The question is exactly our experiment! All the children have to do is plot the water line, say, at the data point (4 cc, 4 gm). One can then immediately see that A and B will sink while C and D will float.

Questions 17 and 18 seem like a pair of relatively straightforward questions. Yet only 2% of the 13-year-olds got the questions at this level correct. All of your students who do the density part of **Sink and Float** should obtain the right answers. It shows how little hands-on experimental work children do around the country.

**Question 19** is an easy generalization of their experiment. The liquid is no longer water, but the results are the same. If the object sinks, its density is greater than the liquid’s; if it floats, the density is less. Comparing an object and a liquid in **Question 20**, the density of the object is greater than the density of the liquid so the object will sink.

Can the children construct the mass-volume line from a given density? In **Question 21** this is made even more difficult because the data points of \( M = 4 \text{ gm} \) and \( V = 1 \text{ cc} \) are really not accessible. What should the pupils do? They should use proportional reasoning to get to a mass and volume they can accurately plot. For example,

\[
\rho = \frac{M}{V} = \frac{4 \text{ gm}}{1 \text{ cc}} = \frac{40 \text{ gm}}{10 \text{ cc}}
\]

Having drawn the line through (10 cc, 40 gm) and (0,0), the children can now easily answer the next part of the question. Plotting the data point (20 cc, 60 gm) they should find that it lies below the line of the liquid, and so the object will float. Or, one could have found the density of the object

\[
\rho = \frac{600 \text{ gm}}{20 \text{ cc}} = \frac{3 \text{ gm}}{cc}
\]

and seen that it is less than the density of the liquid.

A more difficult variation of **Question 18** is presented in **Question 22**. The liquid is no longer water but has a density of 1.5 gm/cc. It is hopeless to plot the data point (1 cc, 1.5 gm) because all the lines come together there. So the children really have to use some formal operational thinking and find a convenient data point well out on the graph. Let’s say we find the mass of the liquid when its volume is 4 cc. Using our definition of density and proportional reasoning we have

\[
\rho = \frac{M}{V} = \frac{1.5 \text{ gm}}{1 \text{ cc}} = \frac{M}{4 \text{ cc}}
\]

\[\therefore M = 6 \text{ gm}\]

Plotting the data point (4 cc, 6 gm) we see that B, C, and D all float in the liquid.

**Question 23** explores one of the most interesting floating bodies of all, our continent. Made of granite (a substance containing mostly silicon—see **Mass vs. Volume**), our continents (and oceans)
literally float on a material called basalt, also made of silicon, aluminum, and iron. The density of basalt has to be greater than 2.65 gm/cc to support the continents. Indeed, the density of basalt is close to 3 gm/cc. We know the density of basalt because it pours out of volcanoes and from cracks in the mid-oceanic ridges. It is the basalt pouring out of the mid-oceanic ridges that pushes the continents as they float on the basalt below. As moving continents collide, they create mountains, like the Rockies and the Himalayas. Of course, this is a slow process, but it is ongoing. The basalt can certainly support the oceans.

Long ago, the continents were once loaded with ice. This extra mass pushed the continents deeper into the basalt, just as a loaded boat sinks deeper into the water. This caused the oceans to cover more of the continents than they do now. The ice then melted and the continents rose. Indeed, geologists think that the continents are still slowly rising, exposing more land. In terms of density, the extra ice adds mass but not volume to the continents.

Our last section deals with building boats. The children have shaped and molded their clay until it floats and have seen just how much mass it can carry. Let’s see how well they understand it.

In Questions 24, 25, and 26, we turn to harder, more quantitative questions that require a deeper understanding of the concepts. Still, the questions should be solvable by most of the children. In Question 24 the mass of the boat is $M_{\text{boat}} = 150$ gm. Its volume is $V_{\text{boat}} = 5 \, \text{cm} \times 10 \, \text{cm} \times 10 \, \text{cm} = 500 \, \text{cc}$. To float in water, the boat’s density must be less than $1 \, \text{gm/cc}$. We set up our algebraic equation; and, by inspection, solve for $M_{\text{load}}$:

$$\rho_{\text{boat}} = \frac{M_{\text{boat}} + M_{\text{load}}}{V_{\text{boat}}} = \frac{150 \, \text{gm} + M_{\text{load}}}{500 \, \text{cc}} = \frac{1 \, \text{gm}}{1 \, \text{cc}}$$

$\therefore M_{\text{load}} = 350$ gm

**Question 25a** is the same basic idea only now we determine the volume of the inside of the clay boat so that it floats. Setting up our equation, we have

$$\rho_{\text{boat}} = \frac{M_{\text{clay}} + M_{\text{load}}}{V_{\text{clay}} + V_{\text{air}}} = \frac{20 \, \text{gm}}{13 \, \text{cc} + V_{\text{air}}} = \frac{1 \, \text{gm}}{1 \, \text{cc}}$$

$\therefore V_{\text{air}} = 7 \, \text{cc}$

Thus, the boat must have at least 7 cc of inside volume to add to that of the clay if it is to float. Of course, the boat could not hold any load, but it would just float with its top barely above the water. **Question 25b** is a variation of part (a): we want the clay boat to hold 8 gm. So it must be rounded and thinned out some more. How much more? Setting up our equation, we have

$$\rho_{\text{boat}} = \frac{M_{\text{clay}} + M_{\text{load}}}{V_{\text{clay}} + V_{\text{air}}} = \frac{1 \, \text{gm}}{1 \, \text{cc}}$$

$$\frac{20 \, \text{gm} + 8 \, \text{gm}}{13 \, \text{cc} + V_{\text{air}}} = \frac{1 \, \text{gm}}{1 \, \text{cc}}$$

$\therefore V_{\text{air}} = 15 \, \text{cc}$

The last question (Question 26) is tough. The game is to fold a 12-cm aluminum foil square into the shape of a rectangular boat with the bottom of the boat always a square. Children like games, so see who can fold the aluminum boat so that it holds the most mass. Now, the key idea is that to hold the most mass the aluminum box has to have the biggest volume. The problem, really, is to decide how to fold the aluminum into the biggest volume. Since the bottom is a square, the height of the boat, $h$, and the width of the square, $w$, is limited by the relationship $w + 2h = 12 \, \text{cm}$. This problem is a perfect extension of the algebra the children should be learning. The above equation is an algebraic equation that relates width to height. If you know
one, the other is determined. How do you find the biggest volume? Trial and error is good enough. Systematically try different values for $h$. Each value of $h$ will give a value for $w$ and one gets $V = w \times w \times h$. In Figure 12 we show a few trials.

Clearly, the answer must lie near $h = 2$ cm. Now we can try a $\frac{1}{2}$ cm on either side of $h$ and close in on the maximum volume. This is shown in Figure 13.

So, it looks like $h = 2$ cm is the winner. Your children will be winners, too, if they can learn to solve these kinds of problems.

**Summary**

*Sink and Float* is a wonderful experiment filled with all kinds of practical problems, yet loaded with basic math including graphing, proportions, and simple algebra.

The experiment also gets to the heart of some of the intrinsic problems children face when dealing with a compound variable system.

**Materials per Team**

- 1 steel sphere, 2.5 cm (1") in diameter
- 1 wood sphere, 2.5 cm (1") in diameter
- 1 glass sphere, 2.5 cm (1") in diameter
- 1 cork
- 1 graduated cylinder (at least 150 cc) with 5 cc per division
- 1 equal arm balance
- 1 paraffin block (12.6 cm $\times$ 6.2 cm $\times$ 1.4 cm)
- 1 rock
- 1 metric ruler
- 1 large container
- paper towel
- water

**References**