# Increase your *v* to lower your *D*

***by Richard H. Moyer and Susan A. Everett***

The last time you were on a boat or at the beach, what sort of life jackets—known as personal floatation devices (PFDs) to the U.S. Coast Guard—do you recall seeing? At the beach you may have seen children wearing inflatable water wings (not an approved Coast Guard device) on their upper arms. Some children's bathing suits have floatation devices built in. On a boat you may recall seeing bulky, bright-orange jackets or sleeker ski vests. By regulation, recreational boats must also carry a throw-able floatation device of some kind, usually a ring or a seat cushion. It is clear that all of these things have been designed to help keep a person afloat. Have you ever wondered exactly how PFDs work?

In the 5-E learning cycle lesson presented here, we consider life jackets—how they are designed and the physics of how they work. Different life jackets have different functions, and, therefore, engineers have had to design them for these different uses. This lesson centers on a design challenge for students to plan and construct a model life jacket for a plastic action figure that will keep the figure floating faceup using the smallest amount of life jacket material. One of the International Technology and Engineering Educators Association standards for middle-level students states, "Requirements for a design are made up of criteria and constraints" (ITEA 2007, p. 95). This same idea is also included as a middle-level grade-band end point in the new *Framework for K–12 Science Education,* which includes engineering as a core idea: "The more precisely a design task's criteria and constraints can be defined, the more likely it is that the designed solution will be successful" (NRC 2011, p. 8-3). In our design challenge, the criterion is to keep the figure floating with its face out of the water, and the constraint is to use the least amount of material.

In addition, students will learn how the overall density of the action figure changes with and without the life jacket, and ultimately realize that a life jacket essentially increases the wearer's volume while adding insignificant mass, thus resulting in reduced density. Density is a difficult property for many students to comprehend and should be visited numerous times during the middle-level years. This is due in part to the fact that density, like boiling point and solubility, is an extrinsic property; that is, it is independent of the quantity of material being considered (NRC 1996). In addition, density (mass per unit volume) is a ratio that

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First cork life jacket

increases with increased mass, but decreases with increased volume. Many students have difficulty conceptualizing the inverse part of this relationship—that increasing volume decreases density.

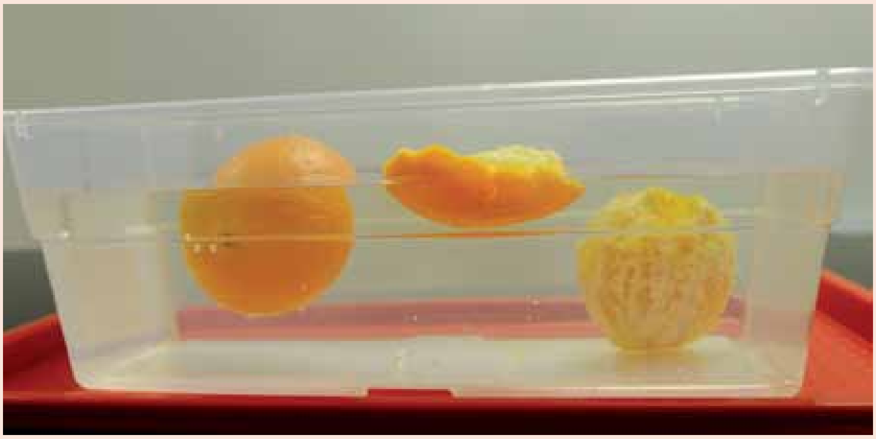
## History

The case for wearing a personal floatation device when engaged in water recreation could not be stronger. According to the U.S. Coast Guard, most drownings occur in inland waters and often close to help. The overwhelming majority of people who drown each year were not wearing a life jacket of any kind (USCG 2008). The key to water safety is simply wearing a life jacket. Many people do not because they feel the jackets are bulky or cumbersome. However, there are a number of different Coast Guard–approved types of life jackets—for offshore use, for near-shore use, vests, and for special purposes. Another type is designed to be throw-able to someone in the water. Since the more comfortable vests were introduced around 1970, the number of drownings in the United States has dropped from about 1,500 to 500 per year (USCG 2008).

Prior to modern life jackets, people made use of a variety of devices to assist in staying afloat if cast overboard. The earliest floatation devices were likely inflated animal bladders or chunks of wood. One of the earliest recorded life jackets was made of cork attached to canvas and invented by a Captain Ward in the United Kingdom in 1854 (RNLI 2011) (see opening photo). Later, a vegetable fiber known as kapok was used to make life jackets. Kapok, which does not absorb much water, made an excellent buoyant material for life jackets and was used until synthetic fibers began to dominate in the 1960s.

Engineers have continued to tweak life jacket design, and there are now numerous variations. A recent contest, the Innovation in Life Jacket Design Competition, had the goal of trying to improve on the basic life jacket. The winning entry was a T-shirt with a built-in inflatable bladder that greatly increases the comfort of wearing a floatation device and thus the likelihood that one does (PFDMA 2011). Life jacket design is still evolving to reduce bulk and thus encourage people to wear them while enjoying recreational activities on the water.

**FIGURE 1** Peeled and unpeeled navel oranges



## Investigating life jackets (teacher background information)

### *Materials*

Each student will need two small (about 4 or 5 cm tall) plastic action figures that are available at dollar stores in bags of 20 for $1. We used small soldiers and removed the weapons and the bases with scissors. Most action figures will have a density of just over 1 g/cm$^3$ and thus just barely sink. You should test to assure that your figures do indeed sink. Each student will also need a small piece—the exact size does not matter, but about 7 cm × 7 cm × 1 cm—of flexible (not polystyrene) foam material. We found that swimming noodles worked very well, as did the packing material used to ship new computers or electronic equipment. This material can easily be cut with scissors to any size or shape. The action figures and the foam will need to be replenished for each new class.

Each group of three to five students needs one container of water, scissors, a balance that measures to the nearest hundredth of a gram, and a graduated cylinder of sufficient width that the action figure will fit (and measures at least to the nearest milliliter). If necessary, you may need to trim the action figures in order for them to fit in the cylinder. You could have one low-temperature hot glue gun per group or choose to have just one gluing

**FIGURE 2** Floating action figures

station that you monitor. For the Engage section, you will need two navel oranges, one peeled and one not, which can be reused for subsequent classes.

### Engage

Students should wear safety glasses during this activity and use caution when working with the low-temperature hot glue gun.

To get students thinking about sinking and floating, we suggest a simple demonstration. Like many fruits, a navel orange will float in water. However, it may surprise many of your students that when peeled, the orange will sink while the peel floats (see Figure 1). In this lesson, students will discover that a life jacket aids in floating in essentially the same way that the peel causes the orange to float—by increasing the volume of the orange without substantially increasing its mass.

The engineering challenge in this lesson is for students to design a way to make the action figure float with its face out of the water, regardless of how it is dropped into the water. That is, if it goes in facedown, the life jacket will cause the figure to flip over to a face-up position. During the brainstorming session, encourage students to consider different life jacket designs with which they might be familiar. Stress to them, however, that more divergent thinking often pays off with innovative designs.

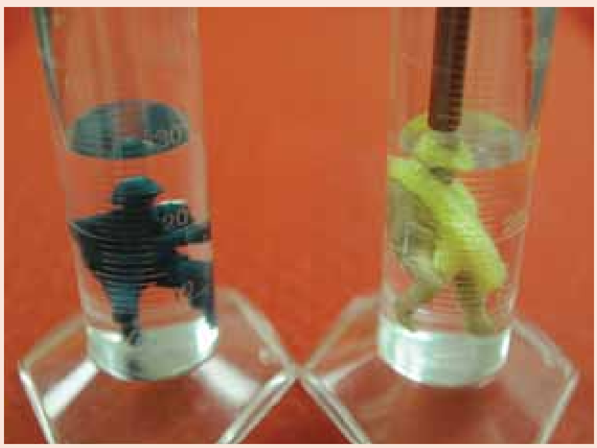
### Explore

The life preservers for the action figures can be fashioned out of the foam material, which students can safely cut with ordinary scissors. Depending on the number of glue guns you have available and the amount of supervision needed, you can either distribute one per group or set up one classroom gluing station. One station is sufficient, as there is little gluing required for this challenge. Because of the open-ended nature of this activity, you should preapprove written designs before students begin construction. Also, if digital cameras are available, you might want students to take photos of their designs in the water in order to assist in reporting results to classmates. You may wish to limit the number of times students redesign their life jacket, because they will be making another in the Extend phase of the lesson.

### Explain

Have students compare successful and unsuccessful designs (see Figure 2). They should conclude that in order for the action figure to float face up, there must be more buoyant material on the upper portion of the body and also more on the front side. The former will assure

**FIGURE 3** Measuring action-figure volume



## ACTIVITY WORKSHEET: Investigating life jackets

### Engage

Note: Students should wear safety glasses during this activity and use caution when working with the low-temperature hot glue gun.

1. Do you think a navel orange will sink or float? Discuss with your classmates and record your prediction. Observe what happens when your teacher puts the orange in a container of water. How does this compare with your prediction?
2. What do you think will happen to the orange if it is peeled before being placed in the water? What about the peel? Again, discuss with your classmates and record your predictions for each part of the orange. Observe what happens and compare to your predictions.
3. Predict what will happen if you place your action figure into the water, and then test your prediction. How does this compare to the orange?
4. In this activity, your challenge is to design a way to make the action figure float with its face out of the water. Discuss your ideas with your classmates.

### Explore

1. Considering the materials provided by your teacher, make a plan for a life jacket for your action figure that will keep its face floating out of the water.
2. After your teacher approves your plan, you can begin constructing the life jacket. Use caution when handling the glue gun to attach the jacket to the action figure.
3. Test your design by placing the jacketed action figure in a container of water with its face down. Take a photo or make a sketch of the action figure in the water.
4. Compare the photos (or sketches) of those designs that met the challenge criterion with those that do not. How do they differ?
5. If necessary, modify your design and retest.

### Explain

1. Share your designs and the results of your testing with your classmates.
2. Now that you have seen many designs, what can you conclude about why the successful designs work?
3. Based on what you know about density, what can you infer about the density of the action figure compared to the density of the water before you made a life jacket for the figure? After you made a life jacket for it?
4. Calculate the density of an action figure with and without its life jacket. Which changes more, the mass or the volume?

| | Mass (g) | Volume (mL) | Mass/Volume (g/mL) |
|---|---|---|---|
| Without jacket | | | |
| With jacket | | | |

5. How does the life jacket cause the density of the action figure to vary? Compare this to how the peel affects the density of a navel orange.
6. You may already know that the density of water is equal to 1 g/mL. How do the densities of your action figure compare to water's density?
7. What can you conclude about the density of things that float?

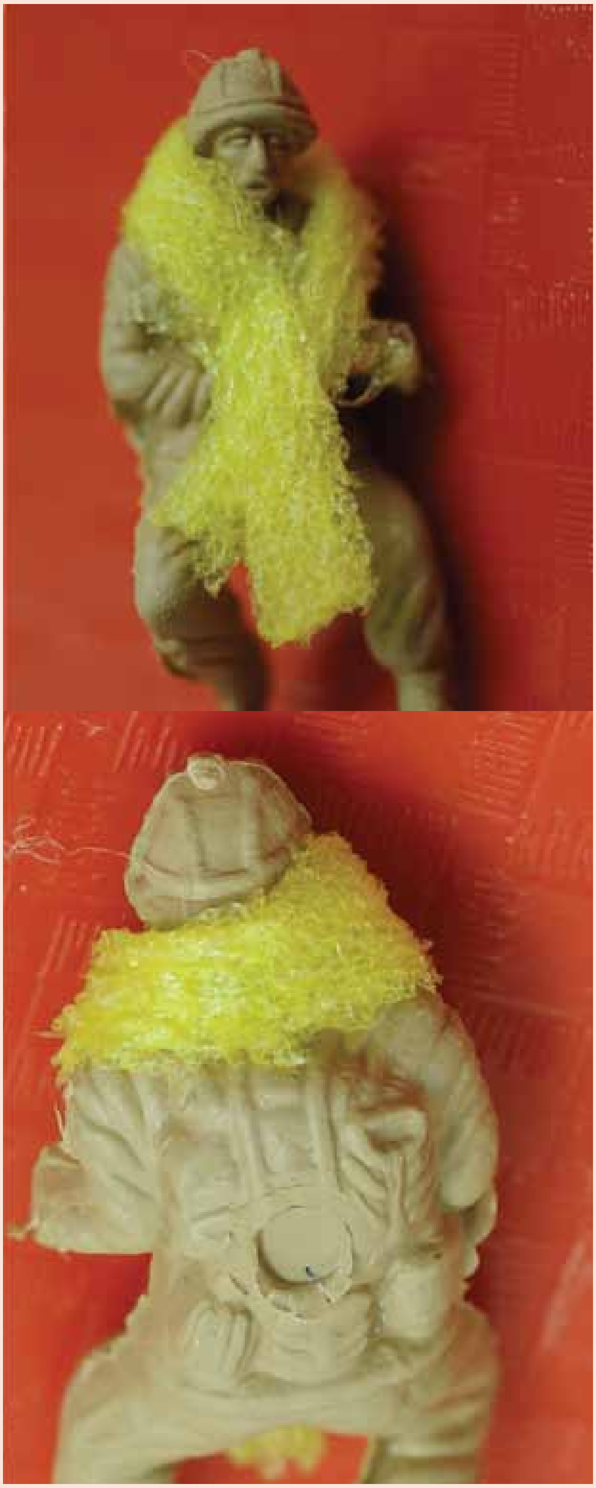
### Extend

1. One constraint an engineer has when designing a life jacket is the amount of material the design uses. Brainstorm some ideas why you think this is the case.
2. With this constraint in mind, design a second life jacket that uses the least amount of material but still meets the initial criterion of keeping the action figure's face out of the water.
3. Calculate the density of your action figure with this second life jacket design.
4. Compare this density with the density of the action figure with your first design. Which one is closer to the density of water? Why?

### Evaluate

Look at a picture of an infant life jacket. Compare this life jacket with your best design. Explain what criteria and constraints you think the engineer had to consider in the design of the infant's life jacket.

**FIGURE 4** Close-up front and back of successful design



that the head is upright and the latter that it is face up.

At this point, you may need to review the basic concept of density. Students may be able to state that objects that are less dense than water (< 1.0 g/mL) float, but likely will find it more difficult to explain why. Thus, students should calculate the density of an action figure with and without a life jacket. It is critical that they carefully measure the volume using a graduated cylinder with units no larger than 1 mL (see Figure 3). Typically, the plastic action figures will have a density very close to 1—ours were about 1.05 g/mL.

From their data table (see Activity Worksheet), students should be able to observe that the mass of the action figure with the life jacket changed very little—ours increased from 3 g to 3.15 g. Likewise, they should easily see that the volume increased a good deal—ours increased from 2.9 mL to 4.1 mL. Help students conceptualize that this increase in volume is critical to how life jackets work—they increase volume substantially with very little increase in mass. Show students the formula for density, $D = m/v$, and discuss what happens to the value of the fraction if $v$ increases. Inverse relationships, such as the one between density and volume, are difficult for many students.

### *Extend*

Most engineering problems, including the design of a life jacket, present engineers with constraints. In this case, a major constraint is the amount of material used to construct the life jacket. This is due in part to material cost, but also to try to reduce the bulkiness of the jacket, because that plays a significant role in whether people actually wear them. Thus, now that students understand the principles involved in keeping the action figure faceup in the water, they need to alter their design to use the least amount of material. Again, have students calculate the density of the action figure with the new design (see Figure 4). In this case, the density of their design will likely be higher than their first design and therefore closer to 1 g/mL. This is due to the fact that using less foam material will cause the volume to be less and therefore the denominator of the density fraction also smaller, resulting in a larger value for $D$.

### *Evaluate*

Show students a picture of an infant life jacket (see Figure 5) and ask them to analyze the criteria and constraints the engineer had to consider in its design.

The major design criterion is that the jacket needs to be virtually fail-safe in its operation because babies are essentially helpless in the water. Given the constraint that babies often have weak neck muscles results in a design criterion that the jacket has to assure the baby's head is held up and out of the water. This complicates the design, because extra material in the back of the life jacket will tend to cause the baby to float facedown. This must be compensated for with additional buoyant material on the front of the jacket. The flap behind the head helps deal with another constraint, as well—babies are a bit top heavy due to the size of their head relative to their body, as compared to an adult. Thus, the flap at the top helps assure that the baby will float head up.

## Conclusion

The new *Framework for K–12 Science Education* (NRC 2011) includes engineering as both a content idea and a practice. This lesson integrates all of the STEM disciplines, while focusing on the core ideas of criteria and constraints in engineering and the practice of engineering design. The concept of density combines both science and mathematics. The product of engineering is technology. In this case, the technology developed was a device to keep a person faceup and afloat.

So, because you float better with a life jacket, remember to wear one the next time you are in a boat and note that even something as common as a life jacket was indeed engineered. ■

**FIGURE 5** Infant life jacket design


### Acknowledgment

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### Resources


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## Sealable zipper design winners

Congratulations to the winners of our Everyday Engineering sealable zipper design contest—Ashley Cook's fifth and sixth grade classes at Ashley Hall school in Charleston, South Carolina. Inspired by the Summer 2011 Everyday Engineering column, Ashley's class rose to the challenge of designing their own innovative file-folder sealing mechanisms (pictured). Each of Ashley's classes will receive a $50 gift certificate to NSTA's Science Store (*www.nsta.org/store*), which will be carrying the Everyday Engineering compendium in early spring.