Paint-Stirrer Submarine

by Jocelyn Young and Kevin Hardy

After attending a workshop presented at Scripps Institute, I adapted this lab/lesson for my physical science class. The lab was conducted near the end of the year during the physics units covering motion, forces, and forces in fluids. This lab was a unique and rewarding experience for everyone involved. Students were able to design, construct, test, refine, and operate their own low-cost paint-stir-stick submarine for the pool.

The paint-stir-stick submarine fits beautifully with the National Science Education Standards Physical Science Content Standard B, and with the California state science standards for physical science, which state that the student will know how to predict whether an object will float or sink (8d); that the buoyant force on an object in a fluid is an upward force equal to the weight of the fluid it has displaced (8c); and when the forces on an object are balanced, the motion of the object does not change (2c). This lab also covers Benchmarks for Science Literacy: 3B Design and Systems.

Background information

Before beginning the lab, students need to know a variety of basic buoyancy principles. For example, you know that a rubber duck floats, but *why* does the duck float? Why doesn't it sink in the water to the bottom of your bathtub? Even if you pushed the rubber duck to the bottom, it would pop back to the surface when you released it. The buoyant force pushes the rubber duck to the top of the water.

If you have ever picked up an object under water, you know that it seems lighter in water than in air. Water exerts something called the buoyant force that acts on a submerged object. The buoyant force acts in the upward direction, against the force of gravity, so it makes an object feel lighter. A submerged object displaces, or takes the place of, a volume of fluid equal to its own volume. How do you determine buoyant force? Archimedes' prin-

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ciple states that the buoyant force on an object is equal to the weight of the fluid displaced by the object.

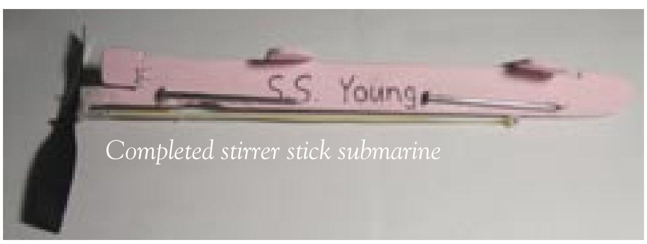
There is always a downward force on a submerged object, its weight. If the weight of the object is greater than the buoyant force, the net force on the submerged object will be downward. The object will sink to the bottom. If the weight of the object is less than the buoyant force, the object will begin to sink deep enough to displace a volume of fluid with a weight equal to its own. At that level, it will stop sinking, and float on the surface. If the weight of the object is exactly equal to the buoyant force, the two forces are balanced, and the object is neutrally buoyant, neither sinking nor rising. Since weight is simply a measure of the gravitational force on an object, you can see that buoyant force (an upward force) opposes gravity (a downward force). A successful paint-stirrer submarine voyage vividly demonstrates these opposing forces.

Setup

Bear in mine that the lab requires a good deal of teacher preparation time (see Figure 1 for materials list), and the lab materials cost about $1.50 per student group. (Grants are a great way to pay for the lab.) I did the following prep:

1. Gather materials: Most can be found at a local home improvement store. The stir sticks are free.
2. Order the propeller, prop hanger, prop shaft, and bulk rubber band material (I used Peck Polymers, Inc. in El Cajon, California).
3. You can cut the paint stirrers and drill holes for the nails beforehand to save class time, although I allowed my students to do this in class. Borrow tools from the shop teacher.

The students' interest level was at its highest when constructing and testing their submarines in a pool. If a full-sized pool is close by and doesn't require a field trip, you could use it for this activity, but be aware of safety concerns and management issues. Another alternative is to use a blow-up pool outside or even a big tub. Students do not need to get into the water, as they can launch the submarine when kneeling alongside the pool. Review your options and see what works best for your situation. Adaptability is the key to success in this lab.



Completed stirrer stick submarine

PHOTO COURTESY OF THE AUTHORS

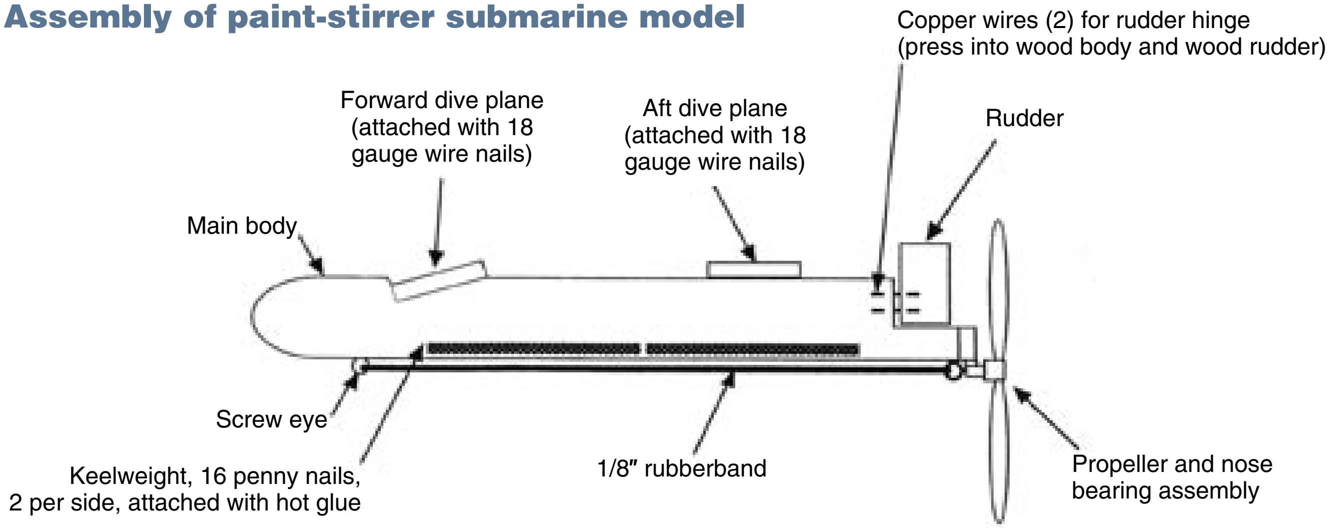
It was really interesting to see students dive into this inquiry-based activity. I saw students who had never shown any interest in science before come alive during this lab. They were delighted to find out it actually worked.

The lab took approximately 8–10 days to complete—days one and two for cutting and drilling; days three and four for sanding the submarine parts; day five and possibly six for assembling the submarine; a day for priming; a day for applying the final coat of color; and one or two days for testing in the pool. There are many safety considerations in this lab. Students use hot glue guns, a hammer, and nails. Showing students how to use a hot glue gun made for a safer experience, and the room needs to be properly ventilated. On painting days the room door can be open,

FIGURE 1 **Materials per student group**

- Paint stirrers (12" × 1-1/8" × 1/8"), two each, standard size—Sub body, dive planes, and rudder
- 16-penny finishing nails (smaller size works well also, sometimes 16 is too heavy), four each—Ballast
- M.P.C. props, 6" plastic prop with assembly, fits 1/8" × 1/4" motor stick (PA096), one each per sub—Propulsion
- Rubber bands, 3/16" (PA 6012, Peck), 1 lb box
- 1/16" copper wire pieces 3/4" long, two each—Holds the rudder on
- 18 gauge × 5/8" wire nail, four each—Attach dive planes
- Screw eye, small, one each—To secure nose end of rubber band
- Hot glue gun and glue—Attach 16-penny nails
- Sanding block, optional
- 100-grit sandpaper (medium), cut into ¼ sheets (one per student)—Sanding
- Tack hammer—Assembly
- Needle-nose pliers—Install wire for rudder
- Diagonal cutters—Cut copper wire
- Coping saw (for teacher)—Wood shaping
- Scissors—Trim prop tips
- Acrylic craft paint, various colors (do not use tempura paint, it will run when the submarine enters the water)—
- Seals wood from water, decorative
- Paintbrushes, 1" cheap ones
- Masking tape—Customizing paint
- Paper towels—Clean-up
- Newspaper—Cover work area

Assembly of paint-stirrer submarine model



Notes:

1. Rudder position may be varied to make the sub go straight, or turn slowly to port or starboard. (Subs tend to turn to starboard when rudder is set at zero angle.)
2. Wood must be painted to seal water out so it retains buoyancy.
3. Student submariners may customize the bow nose shape and dive plane shape.
4. Drill pilot holes as shown on parts pattern on next page.

FIGURE 2 **Assembly notes**

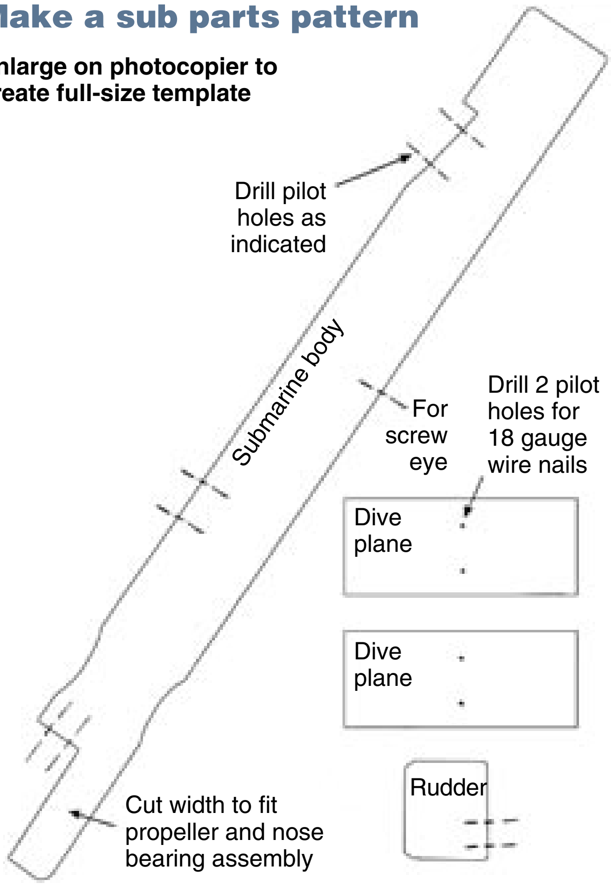
1. Sand nose of sub to desired shape.
2. Sand leading edge of dive planes and rudder to rounded shape.
3. Sand trailing edge of dive planes and rudder to tapered shape.
4. Hot glue 16-penny nails to bottom of sub body, two on each side.
5. Use a tack hammer to nail dive planes on. This must be done very carefully!
6. Use needle-nose pliers to attach the rudder using the copper wire. Adjust rudder angle by bending wire.
7. Twist the screw eye into the pilot hole.
8. From the side, ensure that the leading edge of the propeller is flat, the trailing edge is curved. Make sure the leading edge faces the prop hanger.
9. All wood parts must be primed and painted to seal wood against absorbing water, or loss of buoyancy will result and cause your submarine to sink to the bottom (yikes!). Students can custom paint their individual submarines.
10. Place the propeller assembly at the end (aft) of the submarine. If it doesn't fit, sand the wood until it does.
11. Trim with diagonal cutters to 4″ if desired.
12. Attach the rubber band from the propeller to the screw eye.
13. Wind the rubber band by twisting the propeller. Release the propeller and check that the air blows away from the sub body. This ensures that the propeller will propel the submarine forward.
14. The finished submarine is now ready for testing in the pool!

but usually there is no problem since craft paint is used instead of latex paint. Painting outside the classroom is another alternative. Direct supervision of students' hammering the nails into place reduces the risk of injury. It works best to distribute the rubber bands at the time students are ready to install them. Wear safety goggles for the entire construction phase! Also, I cover my tables with newspaper and tape it down. There will be some mess, but either a good sweeping or vacuuming can fix that. It might be nice to let the custodians know ahead of time and possibly give them a special gift for helping to clean your room during the experiment.

My students had a difficult time sanding all the pieces in one day because their hands got tired, so two days were allotted for sanding. Students will need safety glasses. The sand from the submarine is minimal, but you should always open the windows and door for fresh air and turn on the fume hood if available. Assembling the submarine should be

Make a sub parts pattern

Enlarge on photocopier to create full-size template



done after all the pieces have been primed and painted to seal the wood from absorbing water. Discuss which primer to use and how much, how to handle the priming, and proper cleaning of the brushes. Bring tools to the pool at launch time so students can make any necessary adjustments to their submarines.

The construction of the submarine seems intricate, but it really is simple (see Figure 2). Students found it easy to assemble when we tried to accomplish just one or two tasks each day, which allowed plenty of time for success. Some students may get frustrated with hammering such small nails. If a nail pokes out through the side of the submarine body, it can be covered and secured with hot glue.

Space in the classroom needs to be reserved for each class that is building a submarine. Place some newspapers down on a counter with the class period labeled so students know where to place their submarine when done for the day.

Testing the subs

Once the submarine is in the water, it moves forward due to the propeller. If students positioned the nails (ballast) correctly it will travel the length of the pool at mid-depth. If the nails are too heavy, either forward or aft, then the submarine will sink. If it sinks, a pool net can be used to bring it up. Students can reposition the nails and try again.

After their submarine test runs, students answer the following questions:

- What is buoyancy?
- How did you compensate for buoyancy when you assembled your submarine?
- Explain Archimedes' principle.
- Why does your submarine work? (Hopefully it did!) Explain.
- What changes/modifications did you make to get your submarine to work? (Hint: If it didn't work the first time it entered the water, what did you do?)
- What is your opinion of the lab? Did you like it? What would you improve if you were to do the lab over?

Students turn in the answers individually for final assessment. Additionally, informal assessment during the construction phase and students' written analysis of the sub's performance allowed me to evaluate their learning.

Conclusion

In today's fast-paced, technological world, it is a constant struggle for teachers to find new and exciting ways to challenge and engage our students. The paint-stir-stick submarine is a unique and challenging laboratory exercise that keeps the students enthralled. They won't even realize they are learning because they will be having too much fun. This hands-on experience in building a submarine allows the students to learn about buoyancy, buoyant force, Archimedes' principle, and motion in an active engaging manner. There are many safety precautions during this laboratory exercise, but if care is taken there should not be any problems. Students are able to take their submarine home and continue the learning exercise. It will be an experience neither you nor your students will ever forget. ■

Acknowledgments

Michelle Hardy converted Kevin's first drawings for the paint-stick sub into a useful lesson plan. Kevin just likes building things, and claims, "There's a lot of science to be learned in a toy store."

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