Building a Steam Powered Boat

A lesson in thermodynamics

Subject: science
Grade: 9-12
Time required: one class period

Content standards:
Grades 9-12: Physics 1b, 2c, 2e, 2f, 2h, 3a-g

Key concepts:

- A transfer of heat energy occurs when substances having different temperatures are allowed to mix.
- A heat engine, such as a steam turbine, is a device that converts heat energy into mechanical work.
- The quantity of heat transferred to a system is equal to the work done by the system plus the change in the internal energy of the system (total amount of energy remains constant). This is called the Law of Conservation of Energy, or First Law of Thermodynamics.
- Whenever two substances at different temperatures are allowed to mix, heat travels from the hotter substance to the colder one. The quantity of heat given off by the hotter substance is equal to the quantity of heat energy gained by the cooler object, provided that heat energy does not escape to the surroundings. The transfer of energy will continue in this way until both substances reach the same temperature. This is called the Principle of Heat Exchange.
- heat energy lost = heat energy gained ⇔ $E_H\,(lost) = E_H\,(gained)$

Background Information: *Laws of Thermodynamics*
Energy exists in many forms, such as heat, light, chemical energy, and electrical energy. Energy is the ability to bring about change or to do work. Thermodynamics is the study of energy.

The First Law of Thermodynamics states that energy can be changed from one form to another, but it cannot be created or destroyed. The total amount of energy and matter in the Universe remains constant, merely changing from one form to another. The First Law of Thermodynamics (Conservation) states that energy is always conserved, it cannot be created or destroyed. In essence, energy can be converted from one form into another.

The Second Law of Thermodynamics states, "in all energy exchanges, if no energy enters or leaves the system, the potential energy of the state will always be less than that of the initial state." This is also commonly referred to as entropy. A spring-driven watch will run until the potential energy in the spring is converted, and not again until energy is reapplied to the spring to rewind it. A car that has run out of gas will not run again until you walk ten miles to a gas station and refuel the car. Once the potential energy locked in carbohydrates is converted into kinetic energy (energy in use or motion), the organism will get no more until energy is input again. In the process of energy transfer, some energy will dissipate as heat. Entropy is a measure of disorder: cells are *not* disordered and so have low entropy. The flow of energy maintains order and life. Entropy wins when organisms cease to take in energy and die.

Introduction: *Building a simple heat engine*
Heat engines take many forms, from the internal combustion engine in the family car to giant boilers that make steam to spin the giant turbines that generate electricity for our homes. What they have in common is they steal some of the energy moving between something hot and something cold, and convert it into motion.

When you heat a gas like air or steam, the molecules in the gas move around faster. The faster they move, the harder they hit anything that is in the way. If we put something in the way, such as a propeller or a pinwheel, we can make them spin (this is how turbine generators spin to create electricity). If we confine the gas in a container with a lid, we can pop the lid off (this is how the piston in a car engine works). If we let the fast moving molecules push on one side of a container, and escape through a small hole on the other side (so they are pushing on one side more than on the other) then we have a rocket or a jet, which moves in a direction away from the side with the hole.

Materials:

1. 13-15 inches of copper tubing (1/8 diameter), for each group of 2-3 students (You can use the easier to find 1/4 inch soft copper tubing, but the 1/8 works best with the candle's small heat source, and weighs less, so it is less likely to tip the boat.)
2. 1 tealight for each group of 2-3 students (make sure to use the ones in aluminum cups)
3. assorted containers for boat hulls--#2 plastic bottles (water bottles work well), soda cans, aluminum potato boats,
4. nail to pierce simulated boat for each group of 2-3 students (1/8 diameter)
5. masking tape
6. plastic tub filled with 6 inches of water
7. lighter (for teacher)

Preparation:
Cut copper tubing into 6-inch lengths, one for each group. The best way to cut the copper tubing is with a tubing cutter (get it at the hardware store when you get the tubing). You can use a hacksaw, but you will have to clean the debris out of the cut with a knife or sandpaper.
For the boat hull, obtain soft plastic bottles and/or soda cans, cut in half lengthwise using an Xacto knife, other sharp utility knife or scissors. Students can choose what type of boat they want to build from these materials. See pictures for details on how to construct boat.

Procedure:
The students will begin by constructing a boat that has no valves or no moving parts:

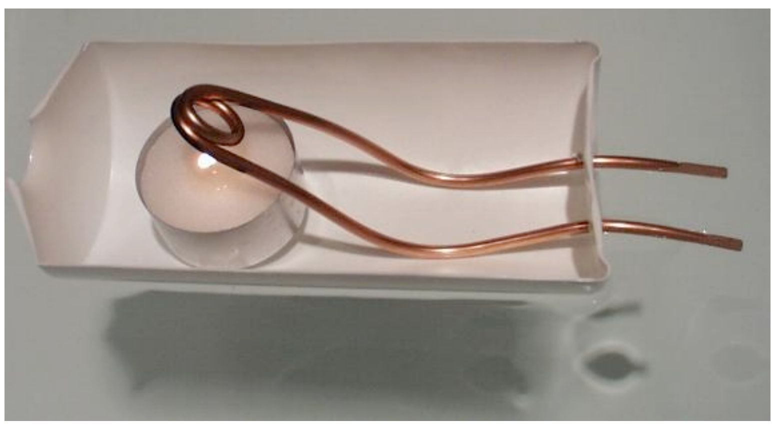
1. Allow the student to choose what type of boat they want to build by selecting

one of the pre-cut boat hulls.

2. Gently bend the tubing around a large pen or pencil to form the coil in the center.
3. Place the tealight in the boat and attach the bottom to the boat with masking tape.
4. Bend the tubing so that the coil is positioned directly above the tealight and the open ends are submerged when attached to the boat and placed in water.
5. Poke two holes in the back of the boat with a nail, and force the copper tubes through the holes. The holes in the soft plastic will close around the tubing, forming a water-tight fit. If a soda can is used for the boat, use the masking tape to cover the holes and to hold the tubing in place.

The boat is now finished, and ready to launch:

6. The copper tubes must be full of water, and both open ends must be under water. The easy way to fill the tubes is to hold one end under water, and suck on the other end.
7. When the tubes are full of water, and the boat is resting in the water with both ends of the tubing under the water, light the candle.



When the coil of copper tubing is hot enough to boil the water inside, the boat will jerk ahead suddenly and then start moving evenly forward. If you put your fingers in the water just behind the tubes, you can feel little pulses of water, about 5 or 10 pulses per second. These pulses are pushing the boat along, creating ripples in the water behind the boat. The ripples in the water are caused by the pulses that the engine makes as it operates. The easiest way to view this is to watch the reflection of a bright light on the surface of the water.

Discussion: *How does it do that?*

When the water in the coil boils, the steam expands. This pushes the water out of the tubes. The reaction pushes the boat forward. As the steam continues to expand, it encounters the section of tubing that used to be full of water. This tubing is cold, and the steam condenses back into water. This causes a vacuum to form, which pulls more water back into the tubes.

You would expect that the water moving back into the tubing would cause the boat to go backwards. However, the water doesn't get very far before it hits the end of the tube (the two streams of water in the two tubes meet each other in the coil).

Any motion caused by the water being sucked into the tubes is reversed by the water hitting the front of the tube (the coil) and pushing the boat forward again. As you saw when you put your finger near the tubes, this back and forth water motion is fairly rapid, and the comparatively heavy boat never actually moves backwards at all.

Conclusion:
Once the students have designed their boat, have a contest using the tub of water where the students race their designs for a prize!