Air has weight and so exerts pressure. The air in a room can weigh as much as 100 kilograms, which is the weight of a large person. Air can also be squeezed, or compressed into small containers. Underwater divers breathe air that has been compressed into small cylinders. You will construct several toys called cartesian divers. This toy will rise and fall exactly as a diving bell does. Diving machines that move by using air pressure are often described as "Cartesian" because the principle was first explained by Rene Descartes, a 16th century mathematician. This exercise will be divided up into four parts, which will consist of the following: "A Cartesian Retriever"; "The Cartesian Helicopter"; "A Cartesian Counter"; and "Cartesian Basketball".

Part One: An easily adjustable Cartesian diver can be made and then turned into a fun, challenging eye-hand coordination task.

Materials:
--two graduated pipets with all but 1 centimeter of the stem cut off
--two hex nuts that can screw securely onto the stems of the pipets. These should be made from stainless steel or brass.
If you take the pipet into a shop that specializes in nuts and bolts, they can usually find one that fits. Either 3/16" or 1/4" hex nuts should fit and they will thread themselves on the stem of the pipet.
--one 6-7 cm length of stiff nylon fishing line (30-50 lb test)
--one 7-8 cm length of insulated copper wire, speaker wire works really nice because it can be bent without using any pliers, 18 gauge wire will make a stiffer hook and the pliers can be used to bend it into the proper shape
--one plastic, clean, empty 2-liter soda bottle with cap
--water
--several containers with colored water
--pliers

Tools/Equipment:
--hot-melt glue gun
--candle and matches
--one 2-liter bottle with the top cut off at the point where the neck meets the side of the bottle.
Construction of the Retriever

1. Using the pliers, fashion the length of wire into a hook. (see figure 1)

2. Pass the cut stem of the pipet through the loop end of the hook, then screw one of the hex nuts over the end of the stem, as far up as it will go. The hook should now be held securely in place. (see figure 1)

3. Attach another hex nut to a different pipet, and fill about 1/2 full of colored water. Take this to the testing tank, and squeeze a few drops of the colored water out of the pipet until it just barely sinks. This pipet will eventually become the treasure.

4. Light the candle, then bend the length of fishing line into a "U" and hold the ends near the flame, until the tips just start to melt. Withdraw from the flame and push the two ends together so that they join to form a loop. Hold them together for at least 10 seconds to allow them to fuse securely. If the fishing line should catch on fire, extinguish the flame by placing it in the testing tank. (see figure 2)

5. Place the loop on the end away from the nut and attach it with a drop of glue from the glue gun. Wait 3-4 seconds for the glue to begin to cool; then push the loop down into the glue so that it completely covers the joint on the loop. This will create a secure bond. Wait for the glue to set for approximately one minute.

6. On the end of the pipet that is covered with the nut, gently squeeze the pipet and place a drop of glue into the opening and seal it. Place the "treasure" in the test tank and remover and gently squeeze the pipet to see if there are any leaks. The "treasure" is now finished.

7. Adjust the retriever so that when the treasure is attached, they will both float. If you leave too much air in the retriever, it will be almost impossible to squeeze the bottle hard enough to make it dive. The trick is to adjust the retriever so that is will be easy enough to dive, yet have enough buoyancy to lift the treasure, once it is captured.

8. A very challenging secondary puzzle can be made, if the retriever is adjusted so that when it captures the treasure, both pipets will sink.
9. Fill the plastic soda bottle with water to within about 5 cm of the top; insert the "treasure", then the "retriever", and screw the cap on tightly. The treasure should be upright on the bottom, with the loop on top; the retriever should be on top, with the hook hanging down.

Tell the students, that by squeezing and tipping the bottle from side to side, try and maneuver the retriever down, hook the treasure and bring it back safely to the surface. The degree of difficulty can easily be increased by decreasing the size of the loop and or hook.

Another variation can be tried by making a third pipet, with a loop on top and a hook on the bottom, so that it can serve as a "go-between". In order for this to work properly the loops and hooks must be made smaller, which increases the difficulty and the treasure needs to be heavy enough so that when the first retriever hooks the treasure, it is not bouyant enough to lift the treasure until a second retriever is added and then both of them working in tandem can lift the treasure.

Part Two "The Cartesian Helicopter"

Using a pipet, a hex nut, and a small pin-wheel propeller constructed from a sheet of plastic or vinyl, connect them in the following manner. (Hot-onces report covers when they are bent and cut work the best because those places on the helicopter are much brighter.)

1. Using a fifty cent piece as a pattern, and a wooden block underneath the sheet of plastic, cut out a circle with an exacto knife or similar sharp object.

2. Punch a hole in the center of the circle with a paper punch.

3. Place the punched circle on the pipet, and secure it with the hex nut.

4. Using a pair of scissors, cut the punched circle, to the point on the hex nut where two sides meet. You will be making 6 cuts.

5. Adjust the density of the pipet with water, until it barely floats.

6. The ends of the propeller may be bent so that when the pipet dives, it will rotate on the way down. See figure 5. (It will rotate in the opposite direction on the was back up.)
Students can hold a propeller design contest, trying to design a propeller that produces the most rotations as it sinks. When a reference dot is placed on one of the propellers, will make determining the number of rotations much easier. There are several parameters for the students to consider. The number of blades, the shape of each blade, pitch or angle of each blade, size of the propellers, etc. Note the propellers may be larger than the mouth of the bottle, for the plastic will flex back and forth. Another teacher suggested that she could teach fractions by having the students make several propellers and cut them in thirds, quarters, fifths, etc. The students can also make two divers, one which twists in a clockwise direction and the other in a counter clockwise direction.

Part Three "The Cartesian Counter"
1. Construct seven or more Cartesian Divers using the pipets and hex nuts, and adjust the densities so that they all float, with differing degrees of buoyancy. If you place them in the testing tank, they will all be at the same depth in the water.

2. The easiest way to give them all different bouyancies is to number the pipets from 1 to 7 first. Starting with # 7, leave it full of air. Take # 6, and squeeze two bubbles of air from the diver while it is in the test tank. Squeeze four bubbles from # 5, six bubbles from # 4, 8 bubbles from # 3, 10 bubbles from # 2, and 12-13 bubbles from # 1.

3. If you line up the divers in numerical order, #1 should be floating the lowest, and # 2 should be a little higher, and # 3 higher still, until # 7 is floating the highest.

4. Place them all in the same 2-liter bottle, screw on the cap, and squeeze the bottle. The divers should decend in order. If they don't, then minor adjustments need to be made in the bouyancy by either adding a little more water, or squeezing some out.

You can play this up quite a bit, by announcing that while # 4 is decending, okay # 5, its your turn. . . and sure enough there goes # 5. One can also use this as a carnival-type "strength-tester". With my high school classes, it is the "Whimp tester". I tease the gals who are strong enough to get all seven to dive, that they don't have to worry about getting home from a date if they have car trouble, they can push and the guy can steer. Several teachers suggested that their students could use these to add and subtract. If 3 divers are on the bottom? How many are left on top? With the students help, several bottles can be used in series. The other students can then add the number of divers on the bottom, and the number of divers on the top.
Part Four " Cartesian Basketball"

1. Using a fifty cent piece, wrap a piece of fishing line around it and cut the line where it meets the end.

2. Heat the cut ends in the candle, make a loop and join them together.

3. Select another pipet, fill it with colored water and cut about 1 inch from the bottom off. Attach the hex nut, and adjust the buoyancy until the basketball standard is on the bottom and floating upright. Seal the open end with a drop of hot glue.

4. Place the loop on the side of the basketball standard near the middle of the bulb. Glue the loop to the pipet so that it is parallel with the ground.

5. A "basketball" can be made from a 2 inch square of aluminum foil that has been rolled into a ball. Some air is trapped in the foil and it will float. As the ball descends it does not go straight down but rather weaves back and forth.

The rules of the game are quite simple, while maintaining a constant pressure, the students are to try and maneuver the basketball into one of the loops on the basket. The smallest loop is worth 3 points, the next smallest 2 points. If the pipet touches any part of the basket without going through the hoop, it is considered a missed shot, and it is the other person's turn or if the basketball touches the bottom or sides of the testing tank.

I hope that you have enjoyed today's workshop! If you have other variations to the ones that you were shown today, please write to me at the following address. We would love to hear from you. The original idea for the cartesian retriever and helicopter was developed by Robert Becker of St. Louis, Missouri. Last summer at the Chem Ed meeting, a first grader who wasn't strong enough to get the diver to dive gave us the idea of the cartesian counter. My students suggested the basketball game after I left several of the cartesian retrievers in the lab. Many of the other extensions were suggested by other teachers who participated in various workshops that I have done since.