Physics of Boats Unit

Jamie Berger
NSF GK-12 Fellow
Arizona State University

Unit Description:
Through scientific inquiry students learn the physical principals needed in order to build a boat.

Unit Objectives:

1. Students will understand the underlying concepts of density, buoyant force, and center of buoyancy.
2. Students will be able to implement these concepts when designing a boat.

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Lesson Plan 1: Density

Background:

Students get confused by the density=mass/volume because most of them haven't mastered ratios. Here's a more intuitive approach - do labs to define mass and volume, then show the density=mass/volume formula and do this demo.

<u>Activity 1: Packing</u>

Description: Concepts of density are related via interactive discussion and demonstration.

Time Frame: 30–45 minutes

Objectives:

1. The students should be understand the following three principles:
   a. Principle: If you pack more mass into a the same volume, it's more dense.
   b. Principle: If you pack the same mass into a smaller volume, it's more dense.
   c. Principle: Just because something has more mass doesn't mean it's more dense.
2. The students should be able to define density.

Materials:
Suitcase, clothes, tacky souvenirs, block of Styrofoam, trash bag, Styrofoam packing ships, paper clip

Procedure:

Part I.

1. Relate to the class the common experience: going on vacation, suitcase is too full to close.
2. Show an open hardtop suitcase that you're taking on vacation (full of clothes). Close it, then get a student volunteer to come up and lift it.
3. Then open the suitcase, and talk about how you always get sucked into buying stuff while on vacation while tossing a bunch of tacky souveniers and other knickknacks you've bought on vacation in.
4. Then ask another volunteer to sit on the suitcase to help cram it shut and do up the locks (you want it visibly too full, and for them to see things are getting compressed).

5. Ask the original volunteer to lift the suitcase again. Is it heavier? (yes). Ask the class - did the mass change? (let them debate it out until they come up with a consensus of yes, it increased). Then ask the class if the volume changed (no, it's the same volume inside). Is it more or less dense? (at this point, only a few students will know it's more dense, so state it is more dense - if you put more mass into the same volume, it's more dense). Write this principle down on the board.

Part II.

1. Relate to the class the common experience: crushing styrofoam (ie. everyone's put teethmarks on a styrofoam cup sometime or another).
2. Show a block of styrofoam. Get a hyper volunteer to jump on it until it's crushed a bit.
3. Then ask the class if it's mass changed. (No, it'd still weigh the same on the scale). Then ask the class if it's volume changed. (Yes, it's squished, it's smaller now). Is it more or less dense? (let people hash it out awhile then say, yes, it's more dense, and write the second principle on the board).

Part III

1. Common experience: styrofoam packing chips, paper clip
2. Preparation: stuff a big, big plastic bag with styrofoam packing chips until, to you, it feels obviously heavier than a paper clip.
3. Then get a student volunteer to hold the bag in one hand, and the paper clip in the other, and say which feels heavier. (If you have a strong bag, and some time to kill, it's fun to have the students toss the bag around the room at this point to get an idea of its weight).
4. Now ask the students which is more dense, the paper clip or the bag of styrofoam chips. (At this point, I got an almost unanimous class vote for the paper clip since it was obviously metal).
5. Then ask if you could assume something was more dense just because it had more mass. Write the third principle on the board. Ask how you could tell if some substance was denser than another substance. Try to avoid saying much here - let them debate it out and ask questions. (It depends on how much mass is packed into a volume - if you had the same volume of two things, then the one with more mass would be denser).
6. At this point, the students ruminated & asked the teacher case scenarios (ex. if I smushed the bag down to be really, really small - could it be denser than the paper clip).

Summary:

After the activity, ask students what they think the word density means. Get back answers and list point form as notes on the overhead. Restate and rewrite the three principles.

References:

Density Lesson Plan. (http://www.dun.org/sulan/ideas/density.htm)

Lesson Plan 2: **Center of Gravity**

Background: Use the following to lead an interactive discussion.

Every particle that makes up an object experiences a downward force of gravity toward the center of the earth. The sum of this force is the object's weight. If a support is placed directly below (or above) the center of mass distribution of an object or body, it will balance. Therefore, sometimes the center of gravity is referred to as the **balance point**.

The center of mass is the balance point of a system, a point where you could consider the mass of the whole system to be concentrated. In a system that has moveable joints, i.e. the system can move or be moved into different configurations or positions, the location of the center of mass depends on the position of the system. For example, when a figure skater lifts his or her arms during a spin, the mass of the arms is higher up in the system than when the arms were at the side of the skater. With more mass of the skater distributed in a higher position in the body, the center of mass of the skater rises to a higher position in the body.

Methods to Increase Stability (during activity)
• Increase mass (how practical is that?) • Lower center of mass • Widen base of support • Force center of mass to be over base of support • Extend base of support toward oncoming force • Move center of mass (within base of support) toward oncoming force

Stability

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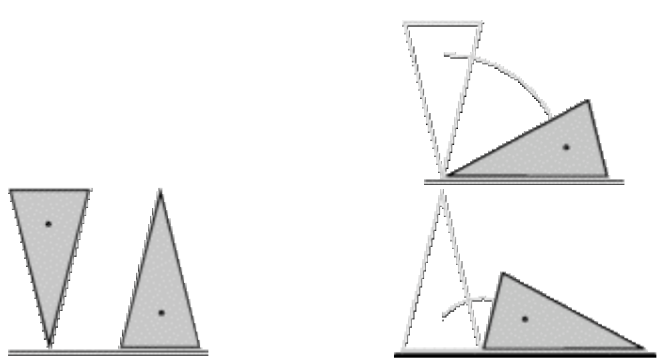


Here are two triangles on a table. The left one is perfectly balanced on its point. Why does it fall over, while the other one does not? Theoretically it is balanced, but the smallest mistake, or breeze, or vibration topples it. Let's topple them both, and see what happens (right). The one that was delicately balanced fell, and its center of mass moved downward. It lost energy. In physics, we learn about energy. Things tend to lose energy, go downhill. The right one had to be pushed over. At first, its center of mass went upward (it gained energy), and then finally it went downward. We had to supply energy to that one, to topple it over. Then it fell the rest of the way. So, the more energy it takes to tip something over, the more stable it is, and vice versa.

Activity 1: Center of Gravity of a Person

Description: Simple exercise to demonstrate the center of gravity of a person and how it helps us keeps balance.

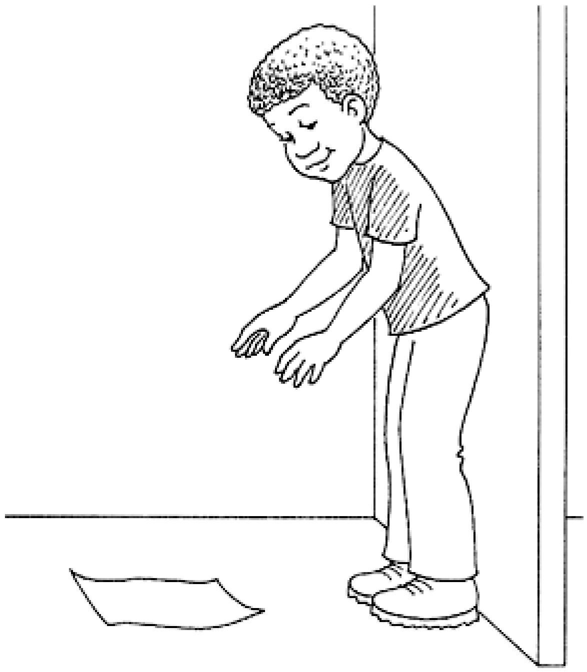
Time Frame: 5-10 minutes

Objectives: The students should be more aware of their own center of gravity and how it helps them balance. They should also begin to relate this to other objects.

Materials: A piece of paper

Procedure:

1. Ask a student to stand up against a flat wall. Place a piece of paper on the floor in front of them. Make sure their feet are together and the backs of their feet touch the wall.



2. Ask the student, “Where is your center of gravity?” Explain to the student the center of gravity of a person is over their feet.
3. Without bending their knees and without losing their balance, ask the student to try bending forward to pick up the paper.

Discussion/Explanation:

Almost immediately, the student will know they will not be able to pick up the paper. Why? When they bend forward, they are shifting the center of gravity of their body forward. To keep their balance, their feet need to move forward.

References:

Delta Education. Center of Gravity Activities. 2001 (http://www.delta-ed.com/kids/october2001.htm).

Activity 2: Cube

Description: This is a fun hands-on activity that demonstrates how adding mass to an object alters its center of gravity and thus the orientation at which the object is more stable.

Time Frame: 30-40 minutes

Objectives: Students should begin to understand the relationship of the mass of an object and where its center of gravity is located. They should also realize that object favor positions in which their center of gravity is lowest.

Materials: Cube Templates for each student (or pairs of students), Tally sheets for each student (or pairs of students), pennies

Procedure:

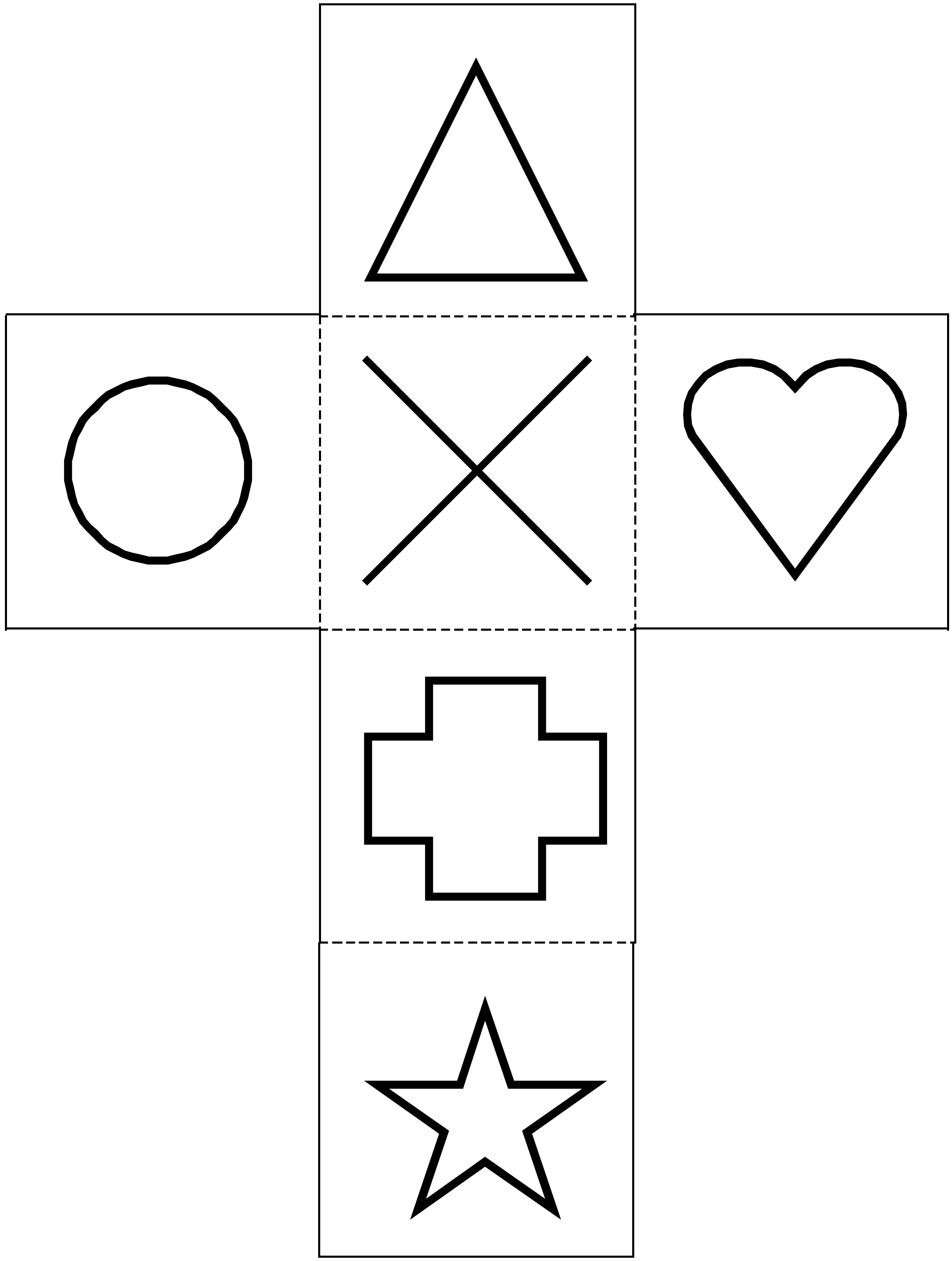
1. Distribute the Cube Template and 1 penny to each student (or in groups). Have students cut out and ask them to assemble the cube.
2. Have the students roll the cube 30 times and mark down which side the cube landed on each time on the Tally sheet.
3. Tally the results so that the class can see the results of all the groups combined. They should observe that the cube landed on each face an approximately equal number of times.
4. Now challenge the students to get the cube to land on the "X" the most number of time by taping a penny to the inside of the cube. They get to determine which side of the cube would work the best.
5. Have the students repeat step 2.
6. When they are done ask who got their cube to land on the "X" many more times than any of the other sides. Ask where they put their penny. Then ask if anyone got their cube to land on a particular side, if it wasn't the "X", many more times than any of the other sides. Ask where they put their penny. Ask the second group where they should have put their penny if they wanted it to land on the "X."

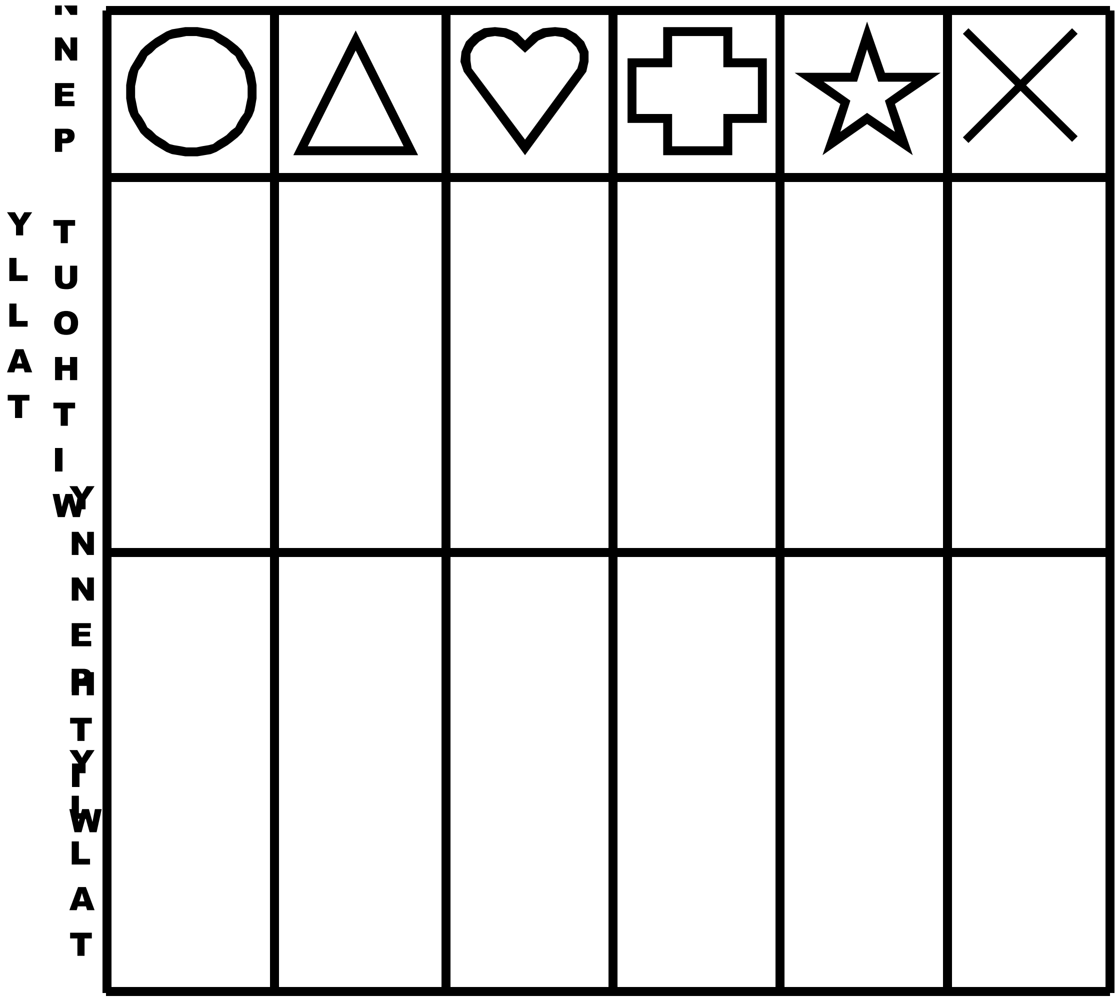
Discussion/Explanation:

The theoretical probability that any one side of a cube will land face-up is 1 in 6 (assuming a cube has uniform sides and its center of mass is located at the "center" of the cube). When students add a penny to the inside of the cube, the center of mass is no longer located in the center of the object. As the cube rolls, the side with the greater mass is more likely to be at the bottom, since the object is more stable in that orientation.

References:

Terror in Space. Nova Online. 2002.
(http://www.pbs.org/wgbh/nova/teachers/activities/2513_mir.html)




TALLY WITHOUT PENNY
TALLY WITH PENNY

Lesson Plan 3: Buoyant Force

Background: Use the following to lead an interactive discussion.

What's Buoyant Force?

Objects have weight because the force of gravity acts on them. Gravity is a downward force. Buoyant force moves upward, in the opposite direction of gravity. Buoyant force exists because of water pressure. When an object is under water, water pushes everywhere against the object--upward, downward and sideways. Instead of trying to keep track of a bunch of distributed forces engineers generally find a "centroid" or center of force. If you add together all the distributed forces and apply the result through the center of force, this one force would cause the same reaction as all the little forces acting at once.

This technique lets a boat designer combine all the weights in a boat into a "center of gravity" (CG) or "center of mass" (CM) and all the buoyancy forces into a "center of buoyancy" (CB). Since the force of buoyancy is equal and opposite to the force of gravity, the designer does not even need to pay much attention to what the actual value of the force is. Instead, they can just remember that on flat water the force of gravity is straight down and the force of buoyancy is straight up, and just look at the relative horizontal locations of the CG and CB.

With a boat in equilibrium, the centers of force will be aligned one directly above the other. This way the buoyancy is pushing straight up towards the weight that pushes straight down.

Displacing Water--The Archimedes Principle

More than 2,000 years ago, Archimedes, a Greek mathematician and scientist, discovered that an object that is *completely under water* displaces a volume of water equal to its own volume. If you have a large object that weighs the same amount as a small object, the large object will displace more water than the smaller one. The Archimedes principle also says that the buoyant force on an object is equal to the weight of the water it displaces.

Activity 1: Float or Sink?

Description: The students will participate in a hands-on activity testing whether different objects will float or sink and why.

Time Frame: 30-45 minutes

Objectives: Students will begin to grasp Archimedes Principle: 1. The buoyant force is equal to the weight of the volume of water displaced by an object, 2.

When an object sinks it displaces the amount of water equal to the volume of the object.
In general they should understand that objects that are denser than water sink and object that are less dense than water float.

Materials:

1. Assortment of non-hollow materials such as washer, nails, solid rubber balls, rocks, wooden blocks, Styrofoam, cork, etc. (Be sure they are small enough to fit into the graduated cylinder.)
2. Large transparent watertight container (an aquarium, or a large beaker).
3. 100mL graduated cylinder
4. One small beaker or cup
5. Balance

Procedure:

1. Have the students work with a partner.
2. Provide each group with a one 100mL graduated cylinder, one small beaker or cup, assortment of non-hollow materials, and a balance.
3. Instruct the students to fill their graduated cylinders to the 50mL mark.
4. Gently place the objects one-by-one into the graduated cylinder.
5. Record the level to which the water rises in a data table.
6. Subtract 50mL from each resulting level to find the displacement caused by each object.
7. Weigh (mass) each object on the balance and record their results.
8. Weigh the beaker.
9. Measure out in a graduated cylinder the amount of water displaced by object #1. Pour the water into the beaker and find its weight. Record the result in the data table, and repeat for each object.
10. Find the weight of the water displaced by subtracting the weight of the beaker from each of the weights found in step 9.

Discussion/Explanation:

Students answer orally the following questions: Is the weight of the water that was displaced nearly equal to the weight of the objects that float? (No, dependent on size of object too, i.e. density) Is the weight of water that was displaced more or less than the weight of the objects that sank? (Less) Conclude by reinforcing that the weight of water is what keeps things afloat.

References:

What Floats Your Boat. National Teacher Training Institute.

Activity 2: Foil Boat

Description: Students will participate in a hands-on activity to determine what property of an object determines whether it will float or sink.

Time Frame: 30 minutes

Objectives: Students should begin to understand the density of objects and how it relates to water and whether it will sink or float.

Materials: Foil, tubs of water

Procedure:

1. Introduce the lesson by leading a class discussion, perhaps using questions such as "Have you ever noticed that some things float and some things sink?", "Why does a giant steel ship float, yet a single steel screw sinks?", "Why does ice float on water?", "How does a submarine both float and sink?"
2. Teacher can help students generate possible hypotheses about objects that float and objects that sink through questioning (Were you surprised? How are these objects alike/different from these? Do you think size/shape has anything to do with it? etc.)
3. Give each student a piece of heavy aluminum foil.
4. Have the students fold the foil in half evenly.
5. Once in half, have the students use the fold to cut out a pair of identical rectangles.
6. Ask the students if they will agree that these two pieces are equal in weight. Be sure that the rectangles are a perfect match to create the understanding that the weight is equal. If necessary for better understanding, use a balance scale to weigh one pair of rectangles as a demonstration.
7. Challenge the students to make one of the pieces of foil sink and the other float.
8. The student should fold one rectangle into a small ball. It is very important that the ball be as tight as possible with no air pockets (sometimes it is better to fold the foil repeatedly until no more folds are possible). Fold the other rectangle into a small boat.
9. Remove the two pieces of foil from the water and ask the students if their mass is the same. Ask the class to generate solutions for why the ball sank and the boat floated if the mass of the two is the same.
10. Have the students unfold the foil and place them on top of one another to show that nothing was created or destroyed.

Discussion/Explanation:
Ask the students if how heavy an object is determines whether it will float. (NO!) Ask them why one piece of foil floated and why one sank. (Because one was

more dense, i.e. same mass but smaller volume.) Ask how dense something has to be before it sinks. (Denser than water.)

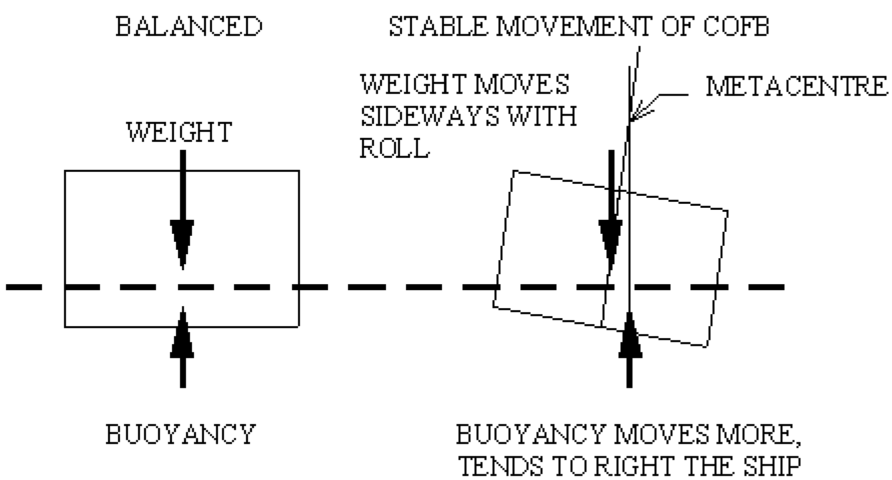
Lesson Plan 4: Center of Buoyancy

Background: Use the following to lead an interactive discussion.

Center of Gravity
Objects which have a low **center of gravity** and a wide base are usually very stable. Objects with a high center of gravity, like an ice-cream cone, are not stable. If you dropped an ice-cream cone, chances are it would land scoop-side down.

Center of Buoyancy
A boat's **center of buoyancy** is the point where the force of water pushes up in a straight line with a force equal to the downward force of gravity.

Equilibrium
When a boat is motionless in calm water, the center of buoyancy (COFB) is in a straight line with the center of gravity in the middle of the boat and the boat is at **equilibrium.** Rough seas and strong winds make a boat move (heel) from side to side. As the boat moves, its center of buoyancy moves because more water is beneath that side of the boat (pushing more buoyant force against that side of the boat), and the center of buoyancy moves away from the center of gravity. If the boat is stable, gravity will work to pull down on the boat, making it more upright. If the boat is unstable, gravity may make matters worse, tipping the boat even further.



Like a rocking chair, a ship has a point of support called its center of bouyancy. When you place a steel ship in the water it will sink. Sink that is until the weight of the water displaced by the ship equals the weight of the ship and everything in it. The geometric center of that displaced volume is the ship's center of bouyancy. That is the point where the bouyant force of the water seems to act on the ship. It is similar to the point where the rocker rests on the floor in the rocking chair example.

Now if you, or some higher power, reach out and rock the ship as we did the rocking chair, the shape of the displaced volume will change to conform to the shape of the ship's now tipped hull. The hull is designed so that the center of bouyancy moves father than the center of gravity when tipping takes place. The combination of the upward force of bouyancy at the center of bouyancy and the downward force of gravity at the center of gravity tends to tip the ship back upright again.

Stability Factors

Forces Affecting Stability

- **Gravity** pulls downward on the boat.
- **Buoyancy** pushes upward on the boat.
- The **wind** and **waves** rock the boat from side to side.

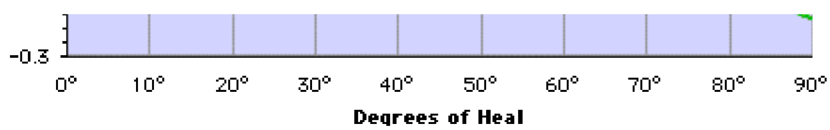
If some new condition comes along to disrupt the equilibrium, such as wind, a wave or the paddler reaching for an escaped water bottle, the boat will start to tip. As you tip, your CG moves in the direction you're tipping. Unless the CB moves in response, your weight will be hanging out beyond the buoyancy forces supporting you and you will capsize. In a stable kayak design, the action of tipping the boat rearranges the buoyancy forces to move the CB in the direction of the tilt beyond the CG, thus forcing the boat upright again. In a stable boat the center of buoyancy moves side to side faster than the center of gravity.

How Stability Works

For a kayak to be stable it should either apply a force to push you back to the upright equilibrium condition, or if you want to lean, it should apply force such that the boat finds a new equilibrium condition before it tips you over. The kayak designer controls this by manipulating the cross sectional shape of the kayak and the height of the seat.

Remember that the goal is to keep the CG vertically in line with the CB. Unfortunately, the most stable position is always going to be with the CG hanging below the CB like a rock hanging from a string. But, since you want to breathe, the CG needs to stay directly **above** the CB. When you move your body to one side, the CG is going to move to that side, away from the CB. To keep you from hanging upside down, the CB now needs to move under you before you rotate all the way over. As the boat rotates in the direction you are tipping, the hull pushes down into the water on that side while the other side lifts out of the water. This action of adding volume (buoyancy) on the side you are tipping and subtracting volume on the other side will cause the center of buoyancy to move toward the side you are tipping. If the boat is shaped to be stable, the CB will move out to the side faster than the CG.

The following is an extended advanced background. This part is not necessary to understand the lesson but might provide some clarification to students with questions about the shape of the boat and its relation to stability.



ɔoats with their stability curves. Although the boats have varying widths, the waterline width and shape is the same in all b
· zero is nearly identical regardless of the different shapes above and below the waterlines. This is because initial stability i
at, only the waterline width and shape.

xpect a round bottomed (**red**) boat to be the least stable, in this case it has the highest overall stability because it flares out
ough the "flared" (**blue**) shape has similar overall width, the volume distribution of the rounded shape gives it more stabili
rline will tend to have more secondary stability.

ıull shapes below are the curves when overall widths are the same. Now, the round bottom is much less stable because the
ıstrates why knowing the overall width of a kayak is not that informative. You will learn more by asking for both the overa

<u>**Activity 1: Tipping The Boat**</u>

Description: Students will participate in hands-on activity with cardboard boats moving the center of gravity around to determine the most stable position for the center of gravity.

Time Frame: 20-30 minutes

Objectives: Students will learn how the placement of the center of gravity in a boat effects the stability of the boat.

Materials: several shoeboxes wrapped in aluminum foil (one for each group), a set of gram weights (if you do not have gram weight substitute objects of various weights), a large tub of water, tape

Procedure:

1. Distribute the shoeboxes and weights to each group.
2. Instruct the students their boat are about to be taken over by a violent wind storm and they need to make their boat as stable as possible by using the weights. The weights may only go **inside** the boat and they may be taped down so they don't move. Let them know that you are going to be the wind and test their boat by pushing it side to side.
3. Have the students put their boats in the water and let the students experiment with the placement of the weights for some time. The
4. When all the students are satisfied with the stability of their boat go around testing each one.

Discussion/Explanation:
Ask the students how the placement of the weights related to the stability of the boat. Explain that as they moved the weights around they were changing the location of the center of gravity, and thus the center of buoyancy when the boat was in equilibrium. When the boat was tipped the center of buoyancy shifts the side of the boat tipped into the water in order to correct the boat. If the center of gravity is to far off the center of the boat then the center of buoyancy will not be able to shift far enough to correct the boat and the boat will tip over. Diagrams often help explain this concept better.

References:
Kerr, Steve. Balance of Racing Rowing Boats. Furnivall Sculling Club Home Page. 13 November 1998. (http://www.btinternet.com/~furnivall.sc/fscbrb.htm)

Lesson Plan 5: Games with Buoyancy

The following are interactive websites the students can explore to learn more about buoyancy.

1. Animations with Buoyancy

http://www.thirteen.org/edonline/gallery/animations_buoyancy.html
For each animation discuss what it is happening and how it relates to buoyancy.

2. Buoyancy Mix & Match

http://surfnetkids.com/games/buoyancy-mm.htm

3. Buoyancy Games

http://www.rogersmagnetschool.org/id158.htm

4. Brain Pop

http://www.brainpop.com/science/forces/buoyancy/

5. Density Lab

http://www.explorescience.com/activities/Activity_page.cfm?ActivityID=29

6. Floating Log

http://www.explorescience.com/activities/Activity_page.cfm?ActivityID=30

Lesson Plan 6: Synthesis of Physical Principals Using Boat Design

Use the principals learned above to design your own boat. The following are five ways these principals can be implemented when building a boat:

1. Where to put the rowers?

Use the center of gravity and buoyancy principals. Situate the rowers so that the center of gravity is as close to the center of the boat as possible.

2. How many rowers?
   Use the center of gravity and density principals. Depending on the size of you boat determine the weight of the rowers that can be in the boat before the density of the boat exceeds that of water. Also note that the more rowers you put in the boat, the lower the center of gravity and thus the more stable the boat.
3. How deep should the boat be in the water?
   Use the density and Archimedes principals. The depth of the boat in the water depends on the size and density of the boat relative to the water.
4. Size of the boat?
   Use the density and Archimedes principals. Depending on the amount of rowers you plan to have determine the size of the boat that would make the density of the boat less than that of water.
5. What happens if the boat fills with water?
   Use the density and Archimedes principals. If you are unfortunate enough to have the boat begin to fill with water determine how much water the boat can take on before it starts to sink. This is found by determining how much water will equate the density of the boat to the density of water.

Let it be known that there are many other principals to be explored outside the realm of this lesson plan than contribute to the success of a boat. This was learned from personal experience! Be sure the construction of the boat is adequate and that the rowers have a lesson in how to row. There are also other aspects that can be added to a boat that were not examined in this lesson plan, such as a sail, a rudder, etc. Good Luck!