

# Forces and Motion

## Table of Contents

Automatic Balloon Inflator.....	3
Mystery Candle .....	5
Balloon in a Bottle .....	7
Magic Card .....	9
The Power of Words .....	11
Gravity Keeps You Down.....	13
Strike a Balance.....	15
Friction Frenzy .....	17
Magnet Magic.....	19
Magnet Mania.....	21
Eddy Currents .....	23
H <sub>2</sub> Olympics.....	25
Show Me the Momentum!.....	27
Momentum Machine.....	29

## Forces and Motion

This page left intentionally blank.

## Automatic Balloon Inflator

**Passport Question:** Which takes up more space?

**Passport Answer:** Hot air or Cold air? (Circle one)

**Learning Target:** Students will learn that air expands when heated, and contracts when cooled.

### **Background information:**

We can't see air, yet it is all around us. Air takes up space and can expand and contract with changes in temperature.

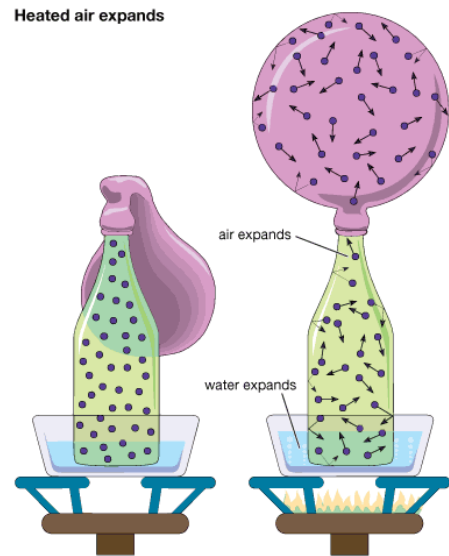
The pressure exerted by a gas is directly related to the temperature. The higher the temperature the more pressure exerted. This is because higher temperatures "excite" the molecules and allow them to move around more, and push on their surroundings. The faster they move around, the more energy they have to do work. This energy is kinetic energy, the energy of motion. When air molecules are cooled down, they have less kinetic energy; therefore they move around less, do less work, and exert less pressure on their surroundings.

### **Materials:**

- (1) Empty plastic bottle
- Balloon
- Hot water
- Ice water
- (2) clear containers

### **Procedure:**

1. Place balloon over the neck of the bottle.
2. Ask students what they think will happen if you put the bottle in the hot or cold water?
3. Place the bottle into the hot water. The balloon will start to inflate. Ask the students what they think is happening?
4. Remove the bottle from the hot water and place it directly into the ice water. The balloon begins to deflate. Ask the students what they think is happening?



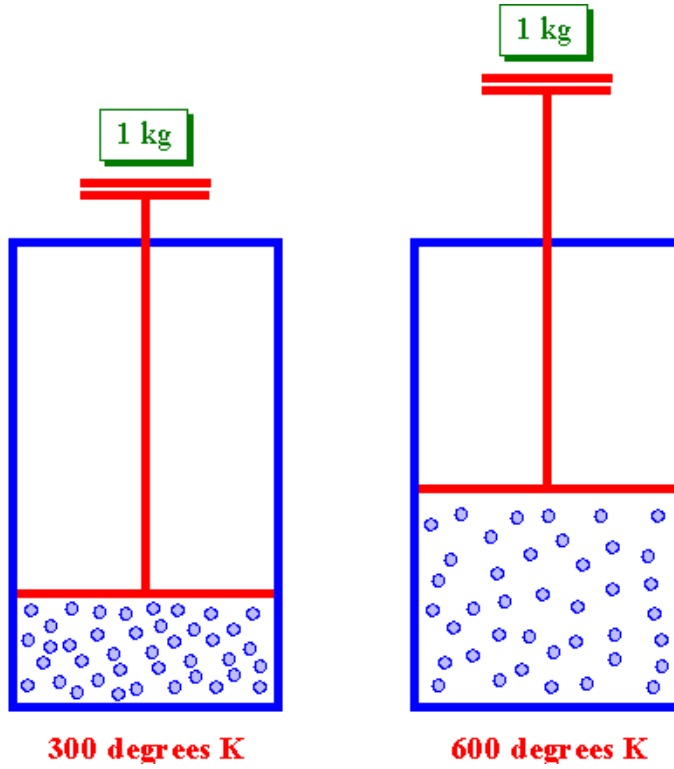
© 2009 Encyclopædia Britannica, Inc.

**Discussion:** What happened to the balloon when it was in cold water? Hot water? Why do you think this happened?

The air molecules in the bottle heat up or "excite" when placed into the hot water. When they warm up, they move around more and move out of the bottle and into the balloon, thus filling the

## Forces and Motion

balloon. When we take the bottle out of the hot water, the air molecules cool down and move less and return to the bottle, thus shrinking the balloon.



## **Mystery Candle**

**Passport Question:** Is the pressure higher or lower inside the flask?

**Passport Answer:** Higher Lower (Circle one)

**Learning Target:** Students will understand that air exerts more or less pressure on a system depending on the temperature of the gas.

### **Materials:**

- Baking pan
- Water
- Food coloring
- Candle (tea light)
- Lighter
- Erlenmeyer Flask

**Background Information:** We can't see air, yet it is all around us. Air takes up space and can expand and contract with changes in temperature. The pressure exerted by a gas is directly related to the temperature. The higher the temperature the more pressure exerted. This is because higher temperatures "excite" the molecules and allow them to move around more, pushing on their surroundings. The faster they move around, the more energy they have to do work. This energy is kinetic energy, the energy of motion. When air molecules are cooled down, they have less kinetic energy; therefore they move around less, do less work, and exert less pressure on their surroundings.

A high pressure area is a location where high force is being exerted over a certain area. Air or water prefers to move from a high pressure area to a low pressure area where less force will be exerted on it.

### **Procedure:**

1. Fill the pan with about an inch of water. Add 2-3 drops of food coloring to the water. (this makes the movement of water easier to see)
2. Place the candle in the middle of the water.
3. Light the candle.
4. Have a student cover the candle with the Erlenmeyer flask.
5. Have the students make verbal observations about what is happening to the water around the flask, the candle flame and the movement of the water.

## Forces and Motion

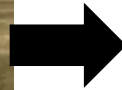
**Discussion:** *What happened inside the flask? What happened outside the flask?*

The candle flame heats the air in the vase. This hot air expands and exerts more pressure on the vase until it pushes out of the vase – which is why we see bubbles.

Because so many air molecules escaped, we have less air molecules inside the flask (lower pressure) compared to outside the flask (higher pressure).

Remember that air in a high pressure area prefers to be in a low pressure area; (similar to you being in a crowded room versus an empty room!) therefore it pushes down onto the water trying to get into the flask. Because the water is in the way, the water gets pushed into the flask.

\*A common misconception regarding this experiment is that the consumption of the oxygen inside of the bottle is also a factor in the water rising. While there is a possibility that there would be a small rise in the water from the flame burning up oxygen, it is extremely minor compared to the expansion and contraction of the gases within the bottle. Simply put, the water would rise at a steady rate if the oxygen being consumed were the main contributing factor, rather than experiencing the rapid rise when the flame is extinguished.



## **Balloon in a Bottle**

**Passport Question:** How do you know air takes up space?

**Passport Answer:** Because you can't blow up the balloon without a hole in the bottle.

**Learning Target:** Students will understand that air takes up space.

### **Materials:**

- (2) Plastic bottles (~1 Liter, one with a hole poked in the side, near the bottom.)
- 1 Balloon

### **Background information:**

We can't see air, but we know it is there. How? Air takes up space and exerts pressure.

### **Procedure:**

1. Slip the balloon through the neck of the bottle (without a hole in it), and stretch the opening of the balloon around the mouth of the bottle.
2. Try to inflate the balloon by blowing into it. How much does it inflate?
3. Remove the balloon, and put it into bottle two. Again try to inflate the balloon. How much does it inflate now?
4. Show students the hole in the bottle; have them place a hand in front of it while inflating the balloon to feel the air being pushed out.
5. Have a student inflate the balloon and cover the hole with their finger before taking their mouth off.

### **Discussion:**

Why doesn't the balloon in the first bottle inflate?

When we put the balloon inside the first bottle there was already air in there taking up space. The air was trapped in the bottle and couldn't get out; therefore you couldn't make the balloon any bigger. But once we poke a hole in the bottom of the bottle, the air that was formerly trapped can escape through the hole and we can successfully blow up the balloon.

Why doesn't the balloon deflate when you cover the hole and take your mouth off the bottle?

By covering the hole we block the air molecules trying to push their way into the bottle, and against the balloon. When you uncover the bottle, those air molecules can get in and push against the balloon, forcing all the air out the top!

## Forces and Motion

This page left intentionally blank.



## Magic Card

**Passport Question:** What bond is breaking when the water spills out?

**Passport Answer:** Adhesion **OR** Surface tension

**Learning Target:** Students will learn that the atmosphere exerts pressure on objects. Cohesion and adhesion are two types of strong bonds that form between water molecules and other surfaces.

**Materials:**

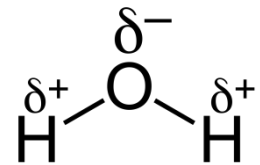
- Water
- Medium sized mason jar
- (2) Jar bands with mesh of different grades
- Note card

**Background information:**

Atmospheric pressure is defined as the force per unit area exerted against a surface by the weight of the air above that surface. The atmosphere weighs down on you with a force of 14.7 pounds per square inch, or about a ton per square foot. We're largely unaware of this tremendous pressure because it's been with us since we were born.

A low pressure area is defined as an area with few air molecules, while a high pressure area is an area with many air molecules.

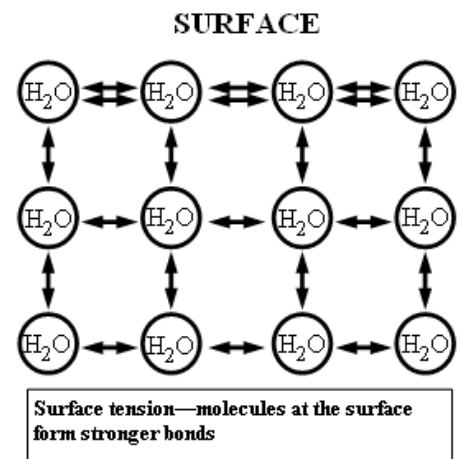
Water is a polar molecule, meaning that one end has a partial negative charge and the other end has a partial positive charge.



In a water molecule the Oxygen atom steals electrons from the hydrogen atoms creating a dipole, a molecule that has a positive end and a negative end. Think about each water molecule like it is a tiny magnet, where like charges repel each other and unlike charges attract, you'll see that there is a small attractive or cohesive force between each water molecule.

At the surface, there are fewer water molecules to cling to since there is air above, not more water. These surface molecules experience a net inward force due to the molecules below pulling down, but no molecules above pulling up to balance it out. This force is responsible for surface tension, where the molecules contract and resist being stretched or broken.

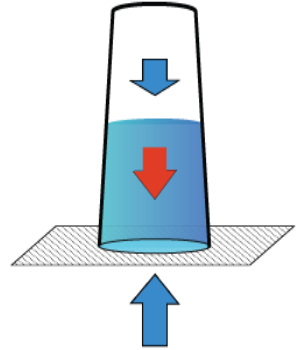
These positive and negative ends on a water molecule are also attracted to other materials, this is called adhesion.



## Forces and Motion

### Procedure:

1. Fill the lidless jar to the top. Place the card over the top of the jar.
2. Quickly turn the jar upside down, holding onto the card.
3. Carefully remove your hand from the card. The card should stay adhered to the jar.
4. Still holding it upside down, slowly slide the card off of the cup. The water will spill out.
5. Repeat steps 1-4 with the smaller grade mesh lid screwed on.
6. Remove the card. The water does not spill out!
7. While still holding it upside down, have the students gently tap the mesh. Then tilt it slowly to empty the water.
8. Fill the jar, screw on the mesh lid. Ask the students what they think will happen when you flip it WITHOUT the card?
9. Quickly flip the jar. Some water spills out but eventually stops.
10. Repeat steps 1-4 with the larger grade mesh lid screwed on.



### Discussion: How does the card stay on the cup?

The atmospheric pressure pushes up on the card, keeping it from falling. Imagine the air molecules all around us randomly colliding with the note card, continuously pushing it against the glass.

Isn't the weight of the water enough to overcome that atmospheric pressure keeping the index card up?

No, it's not. This is due to the air pocket left at the bottom (now top) of the glass. In this space, there are not very many air molecules (low pressure area). With so few air molecules present, they do not push down very much on the water. This prevents the water's weight from pushing the card down. Because there are more air molecules pushing up on the card (high pressure area), it exerts more upward force than the water exerts downward.

Why doesn't the card slide off the cup? (Like a wet cup slides on a counter top?)

Water's strong surface tension bonds helps form a seal around the glass rim. The water molecules are also attracted to the card, and adhere (or stick) to it. This keeps the card from sliding!

Why doesn't the water spill out of the cup when the card is removed a the smaller mesh lid?

The water molecules form adhesive bonds to the metal of the mesh, again forming a strong seal due to surface tension. By tapping on the mesh, you break the surface tension bonds and can feel some water spill out. But those bonds reform very quickly!

What happens when you tip it without the notecard?

The force of the atmospheric pressure in the glass plus the weight of the water molecules overcome the atmospheric pressure pushing up against them and the mesh, and some water spills out. It reaches a point, however, where the surface tension bonds form and are strong enough to overcome the force of the atmospheric pressure and weight of the water and stop leaking water.

Why doesn't the water stay in the cup with the larger grade mesh lid?

The wire squares are too far apart to allow the water to form cohesive and adhesive bonds.

## **The Power of Words**

**Passport Question:** True or False: The more surface area something has, the more atmospheric pressure pushes down on it.

**Passport Answer:** True

**Learning Target:** Students understand that surface area directly relates to atmospheric pressure exertion.

### **Materials:**

- Ruler
- Newspaper
- Table
- Weight on a string
- Air Pressure Mat
- Small stool or table

**Background information:** Atmospheric pressure is described as the force per unit area exerted against a surface by the weight of the air above that surface. The atmosphere weighs down on you with a force of 14.7 pounds per square inch, or about a ton per square foot. We're largely unaware of this tremendous pressure because it's been with us since we were born.

So, the more surface area an object has, the more atmospheric pressure is exerted on that object.

### **Procedure:**

1. Lay the ruler over the edge of the table so that it is about 1/3 of its length over the edge.
2. Ask the students what they think will happen if you hit the end of the ruler that is hanging off the table?
3. Have a student release the weight so that it drops down onto the end of the ruler. As expected, it flips off the table.
4. Ask the students how you might possibly keep the ruler on the table while you hit it? (Hopefully someone will guess that you need to exert an opposing force on the table end of the ruler – you may need to prompt them to look at the items on the table)
5. Tell the students we can only use one sheet of newspaper.
6. First, try folding a sheet of newspaper as small as possible and placing it on the table end of the ruler so that it acts as a counterweight. Get a student to hit the ruler again – still it flips off the table, this time launching the folded newspaper!
7. Ask the students how else we might be able to use one sheet of newspaper to hold the ruler down.
8. Lay a single sheet of newspaper on the table (so that the edge lines up with the table edge) and smooth it out to remove any air pockets underneath. Slide the ruler underneath, when you hit the ruler it will stay!

## Forces and Motion

### **Discussion:** How does this work?

It all comes down to air pressure. There is air pressure pushing down on the table end of the ruler, but not enough to counteract the force of the weight hitting the opposite end. The open sheet of newspaper has more surface area than the ruler for atmospheric pressure to push down on. Enough pressure, that it can counteract the force of the ruler pressing up when you press down on the other end.

It didn't work with the folded-up newspaper because the surface area over which the atmospheric pressure could act was too small and air was able to be in the space under the folded newspaper.

### **Procedure:**

1. Next, show students the rubber mat with the hook.
2. Have a student place the mat on a flat surface and then try to pull it back up again with the hook.
3. If available, have the students use the mat to pick up a stool or small table.

### **Discussion:**

This works again due to air pressure! The air is pressing down onto the mat keeping it suctioned onto the table. Remember that air can put 14.7lbs of weight on 1 square inch. If you lift one corner of the mat and let air get underneath it, that air can now break the suction by pressing up on the mat.

## Gravity Keeps You Down

**Passport Question:** \_\_\_\_\_ causes falling objects to slow down.

**Passport Answer:** Air resistance.

**Learning Target:** Students will learn that air resistance causes objects to fall at different rates depending on their size and shape.

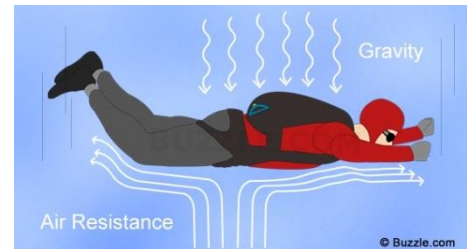
### **Materials:**

- Cardboard box
- Feather

**Background Information:** All objects (regardless of their mass) experience the same acceleration when in a state of free fall. When the only force is gravity, the acceleration is the same for all objects. On Earth, this acceleration value is  $9.8 \text{ m/s}^2$ . This is such an important value in physics that it is given a special name - the acceleration of gravity - and a special symbol: **g**. So, according to this an elephant and a feather will fall at the same rate and hit the ground at the same time. But we know this isn't the case. Why not?

Air resistance, also called drag, refers to forces that oppose the relative motion of an object through a fluid, liquid, or gas. These forces act in a direction opposite to the oncoming flow velocity.

When an object is falling, air resistance acts to push it back up. Air resistance is the opposite of gravity for an object falling down. It pushes up while gravity pulls down. This is only true for objects falling straight down. If the object is falling left or right, then air resistance will be in the opposite direction.



Terminal velocity is when the upward force of air resistance equals the downward force of gravity, the object no longer accelerates. The heavier the object is, the greater its terminal velocity is. For example, an elephant (heavy) would need to fall longer to reach its terminal velocity whereas a feather (light) reaches its terminal velocity rather quickly.

### **Procedure:**

## Forces and Motion

1. Do a demo with the feather and the box, drop them separately. \*Note that it takes the feather longer to reach the ground than the box. Ask them why they think this is? (air resistance)
2. Ask the students if they can figure out a way to drop the feather and the box at the same rate?
3. Place the feather on top of the box and drop it.

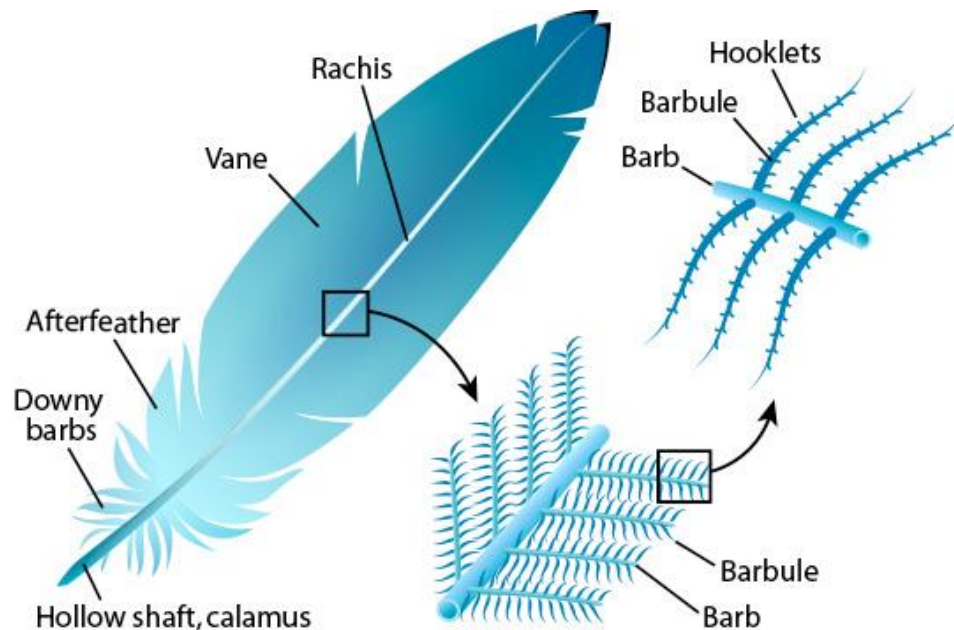
**Discussion:** Why does the feather fall slower than the box when dropped separately?

Air resistance is what makes objects fall at different rates. The more surface area and drag an object has, the slower it will fall. The feather is smaller than the box, but it has higher surface area. This is because a feather contains many barbs (like branches) and those barbs contain barbules (more branches) and each barbule contains hooklets (MORE branches) [see diagram below and on table]! Each barb and barbule increases the total surface area and slows the feather down.

When we place the feather on top of the box, the air pushes up on the box then is diverted out and around the box, but it is never able to reach the feather. So the feather and the box fall at the same rate!

Think about a sky diver with and without a parachute—how fast they fall is drastically different!

This experiment will help the students learn that without air resistance all objects will fall at the same rate. In physics we often talk about a “vacuum”. This is a space with no matter, no air that can resist movement. These vacuums do not exist in nature, and perfect vacuums are impossible to produce, but partial vacuums get close.



## Strike a Balance

**Passport Question:** What physics concept keeps objects balanced?

**Passport Answer:** The center of gravity of an object.

**Learning Target:** Students will learn that the center of gravity keeps objects from falling over.

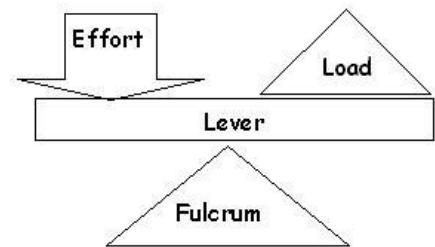
### **Materials:**

- (2) Balancing birds
- Balancing Person
- Tall item for the balancing figurine to stand on
- Wooden fulcrum
- Wooden lever
- Water bottle (optional)
- (3) Bean bags

**Background Information:** In physics, the center of gravity of an object is the average location of its weight. In a uniform gravitational field, it coincides with the object's center of mass.

Gravity causes objects to pull toward each other. In the world around us, we can best explain gravity by letting things drop to the floor or ground. Gravity pulls objects and people toward the earth. That is why things fall to the ground, and also why people and objects don't just float around in the air. The center of gravity is the factor that keeps people and objects balanced. It is the average place of the entire weight of a person or a thing. The center of gravity in an object is not always the central-most point. For example, in people, our center of gravity is slightly higher than our waist, because we hold more weight in our top half of our body than our bottom half.

A Fulcrum is the point on which a lever turns in moving an object. A simple example of a fulcrum is a seesaw.



### **Procedure A:**

1. Have the students investigate the balancing bird.
2. Have the students investigate the balancing person.

**Discussion:** Can you balance the bird on your fingertip by its wing? Where is the center of mass in the bird? If you push the person what happens? Why does the person not fall over?

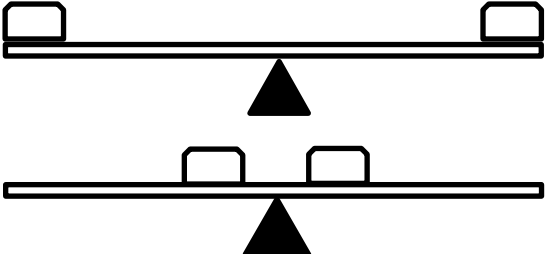
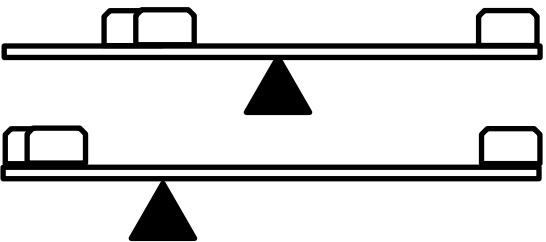
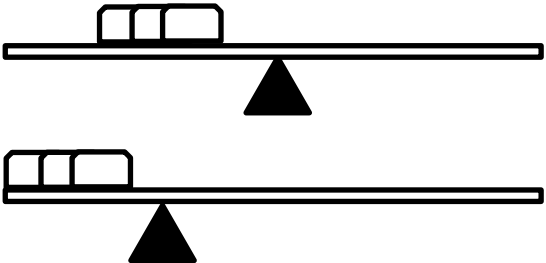
The bird's center of mass is its beak; the weight in its wings equals the weight in its body/tail allowing it to balance by the center point.

The center of gravity in the person is low due to the majority of the weight being below his feet. This allows the person to "rock" back and forth, without toppling over.

### **Procedure B:**

1. Show the students the fulcrum and explain what a fulcrum is.
2. Tell them you have 3 challenges for them.

## Forces and Motion

<p><b>Challenge 1:</b> balance the lever on the fulcrum with 1 bean bag on each side. <u>Tip:</u> The bean bags must be placed equal distance from the fulcrum.</p>	
<p><b>Challenge 2:</b> balance the lever on the fulcrum with 2 bean bags on one side and 1 on the other.</p>	
<p><b>Challenge 3:</b> balance the lever on the fulcrum with 3 bean bags on one side and none on the other.</p>	

**Discussion:** What did you need to do to balance the lever in each challenge?

In the first challenge the fulcrum is centered. If the bags placed on each side are equal distance from the center, the lever stays balanced.

In the second challenge, there are two possibilities. One is with the fulcrum centered again. But this time we need to move the 2 bean bags closer to the fulcrum to keep the lever balanced. The other option is to place the bean bags on the ends of the lever, and move the fulcrum closer to the side with 2 bean bags.

In the third challenge, there are again two possibilities. The fulcrum and the bean bags must be closer together. This could be with the fulcrum in the center, or off-center.



## **Friction Frenzy**

**Passport Question:** What is an example of friction in everyday life?

**Passport Answer:** Examples: driving, skiing, rubbing hands together.

**Learning Target:** Students will learn what friction is and how it effects movement.

### **Materials:**

- Skateboard
- (2) Ropes (~3ft long)
- Tape
- (3) Blocks (with different grades of sand paper attached to one side, and rubber band "leashes")
- Petroleum Jelly

**Background information:** Friction happens when the rough edges of one object snag on the rough edges of another object, and some of the objects' energy has to be used to break off those rough edges so the objects can keep moving. Friction happens when any two things rub against each other. These can be solid things, like your two hands rubbing together. They can also be gases, like with the air slowing down your car. They can also be liquids, like with the water slowing down a boat.

When you rub two soft things together, like your hands, sometimes they squish into each other and get in each other's way. But even completely smooth, hard objects have some friction. This friction is the result of the molecules in both objects being attracted to each other.

We know how to make more friction or less friction, and how to predict how much friction there will be. There's more friction when the two objects are pushed together harder. If you push your hands together, it's harder to rub them up and down. If you pull the brake lever harder, your bike will stop faster. Because gravity pulls harder on things with more mass, the greater the mass the harder it is to move - a cube of iron will be harder to move than a cube of wood. Two solid things usually have more friction than two liquid things, or one liquid thing and a solid - that's why you slip on a wet surface more than a dry one.

When two things rub against each other, they both slow down. When the objects lose momentum without gaining mass, then they have to release some energy to keep the equation equal. One way for them to release that energy is as heat - loose electrons shooting off into the air. You can feel this happen when you rub your hands together and they get warmer.

The rougher the surface, the greater the friction.

The greater the weight of the objects, the greater the friction.

## Forces and Motion

### **Procedure A:**

1. Have one student sit on the ground, and another student sit cross-legged on the skateboard.
2. Hand each of the students an end of the rope (the other end is anchored).
3. Count down from 3 to signal for them to begin pulling.
4. The first student to pass the taped finish line wins!

### **Discussion:** *Which student reached the finish line first? Why?*

The student on the skateboard represents a “frictionless” system in comparison to the student sitting on the floor. The wheels move over the floor, while the student sitting down stays put because of friction. This is why the student on the skateboard reaches the finish line much quicker.

### **Procedure B:**

1. Have the students experiment with the sand paper blocks.
2. Have the students see how far they can stretch the rubber band without moving the block and compare it to the other blocks.

### **Discussion:** *Which blocks had the greatest stretch? Why?*

The greater stretch on the rubber band means there is more friction between the block and the carpet and you need to use more force to pull the block. The blocks with rougher sand paper have more friction.

### **Procedure C:**

1. Have the students rub the two sandpapered blocks together and then compare it to the 2 blocks coated in petroleum jelly.

### **Discussion:** *Which set had less friction? Why?*

The petroleum jelly fills in the low places of the surfaces of the wood and forms a coat over the surfaces. The blocks, therefore, do not touch one another and cannot interact with each other. Instead, the slippery surfaces slide against one another with less friction. Water, too, can act as a lubricant to smooth a surface. For most tools and machines, we use oil or grease to do the job the petroleum jelly did on our blocks of wood. The oil and grease smooth the surfaces so that there will be less rubbing.

## **Magnet Magic**

**Passport Question:** Magnetic fields cause magnetic \_\_\_\_\_ and \_\_\_\_\_

**Passport Answer:** Attraction and Repulsion

**Learning Target:** Students will understand that magnets create a magnetic field which can attract or repel other magnetic objects.

### **Materials:**

- Coins, paperclips, wood, soda can tab, etc
- Iron filings in plastic case
- Magnet bars, disks, etc. with polarity marked
- Magnetic Putty
- (2) Neodymium disk magnet

### **Background information:**

Magnetism- A property of certain materials that causes them to attract iron or steel.

Ferromagnetic- The property of being strongly attracted to either pole of a magnet. Ferromagnetic materials, such as iron, contain unpaired electrons, each with a small magnetic field of its own, that align readily with each other in response to an external magnetic field.

Magnet- objects that produce magnetic fields and attract metals like iron, nickel and cobalt. A magnetic field has lines of force that exit the magnet from its north pole and enter its south pole.

Permanent magnets - create their own magnetic field all the time.

Temporary magnets- produce magnetic fields while in the presence of a magnetic field and for a short while after exiting the field.

If the same pole ends of two magnets are placed near each other, they will repel, whereas if two opposite poles are placed near each other they will attract.

**NOTE:** the silver neodymium disk magnets are incredibly attracted to each other and they WILL pinch fingers! For this activity, 2 are put together, DO NOT separate them, and do not lose them!

### **Procedure:**

1. Have students investigate which materials are magnetic by using a ceramic magnet and seeing which objects it attracts or repels.
2. Have students investigate how magnets interact (repel, attract) using the polarity marked magnets and the magnets on the wooden dowels.
3. Have students investigate magnets with the iron filings.

## Forces and Motion

**Discussion: Discussion:** How do you know if something is 'magnetic'?

It 'sticks' to the magnet. These are called ferromagnetic materials; they become temporary magnets and can have other magnets or ferromagnetic materials stick to them.

Why do magnets sometimes push away from each other and sometimes pull towards each other?

Magnets have a North and South Pole, A magnetic field has lines of force that exit the magnet from its north pole and enter its south pole. Same pole ends will repel, and opposite pole ends will attract.

## **Magnet Mania**

**Passport Question:** True or False: All metals are magnetic.

**Passport Answer:** False.

**Learning Target:** Students will understand that not all materials are magnetic, magnets have magnetic fields, and students will investigate the strength of a magnetic force.

### **Materials:**

- 'Test Magnetic Strength' Board & wooden bases
- Different size/strength magnets (2 of each)
- Paperclips
- Washers
- (2) Plastic boxes with track
- (2) Large metal marbles
- (2) strong disk magnets
- (2) PVC pipes

### **Background information:**

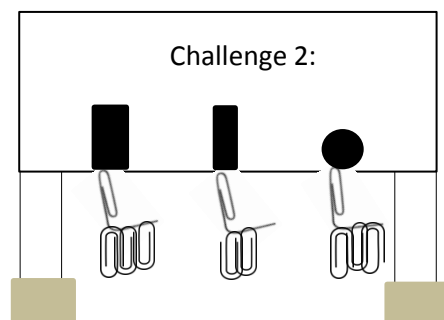
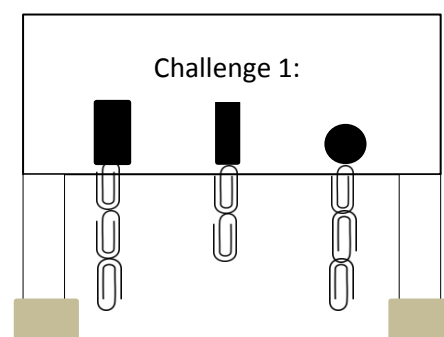
- Magnetism- A property of certain materials that causes them to attract iron or steel.
- Ferromagnetic- The property of being strongly attracted to either pole of a magnet. Ferromagnetic materials, such as iron, contain unpaired electrons, each with a small magnetic field of its own, that align readily with each other in response to an external magnetic field.
- Magnet- objects that produce **magnetic fields** and attract metals like iron, nickel and cobalt. A magnetic field has **lines of force** that exit the magnet from its north pole and enter its south pole.
- **Permanent magnets** - create their own magnetic field all the time.
- **Temporary magnets**- produce magnetic fields while in the presence of a magnetic field and for a short while after exiting the field.
- If the same pole ends of two magnets are placed near each other, they will repel, whereas if two opposite poles are placed near each other they will attract.
- Neodymium magnets (the silver disk magnets) are rare-earth magnets that are the strongest permanent magnets you can buy! **NOTE:** these magnets are incredibly attracted to each other and they WILL pinch fingers! Keep them separated, and out of the children's hands.

### **Procedure:**

1. Place the foam core into the wooden base. Attach different magnets near the bottom of the board by placing a magnet on the front and back of the board.
2. Tell the students you have 3 challenges for them to test the strength of magnets. (Have students make hypotheses before each challenge)
3. Challenge 1: Who can form the longest paperclip chain?

## Forces and Motion

4. Have each student choose a magnet and try to attach as many paperclips as they can. You can also magnetize the paperclips by rubbing it onto a magnet first.
5. Challenge 2: How many paperclips can you hang from one magnet? (You could use washers instead, but be consistent for all magnets in order to compare them.)
6. Bend one paperclip into a hook, and attach it to the magnet. Hang paperclips on this hook until the hooked paperclip falls.
7. Challenge 3: Who can finish the track fastest?
8. 2 students will guide a large metal marble through the track in the plastic boxes using the magnet underneath to move it. Have the students place the PVC pipe piece around the magnet to use to move the magnet around (the magnet should NOT be removed from the board). The student that finishes first wins.



**Discussion:** Were your hypotheses correct? Which magnet was strongest?

In challenge 1, we are testing how strong the magnetic force is in the magnet. Paperclips are not magnetic on their own, but the magnet can temporarily magnetize the paperclips by passing its magnetic force onto them. You can even remove the magnet and your chain will stay intact!

In challenge 2, we are testing how much weight a magnet's magnetic field can hold. The more paperclips (or washers), the stronger it is.

In challenge 3, we are testing how strong the magnetic force is when separated by a solid. Electromagnetic fields have the ability to go through solid objects such as plastic. But the thicker the object is, the more difficult it is to retain that magnetic attraction. Another difficulty in this challenge is the weight of the metal marble. It is heavy enough to break the magnetic field attraction if it is going fast enough.

## Eddy Currents

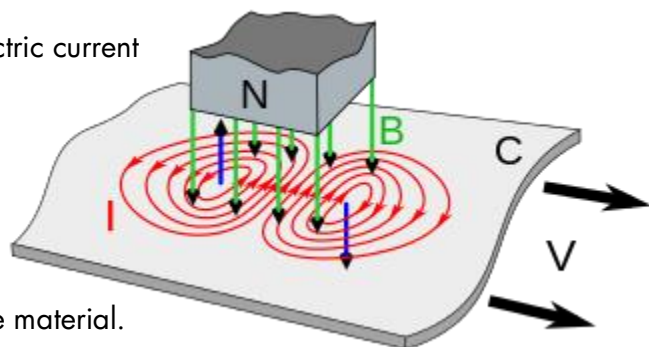
**Passport Question:** Does a magnet fall faster in a: copper tube or plastic tube? (circle one)

**Learning Target:** Students will learn that eddy currents have magnetic fields that oppose those of magnets.

### Materials:

- Strong disk magnet
- Steel metal washer
- Plastic tube
- Copper tube
- (2) Aluminum plates

**Background Information:** Eddy currents are loops of electric current induced within conductors (e.g. copper plate) by a changing magnetic field in the conductor. Eddy currents flow in closed loops within the conductors, in planes perpendicular to the magnetic field. When a current is induced in a conductor, the induced current often flows in small circles that are strongest at the surface and penetrate a short distance into the material.



These eddy currents have their own magnetic field that opposes another magnetic field.

Because of the tendency of eddy currents to oppose, eddy currents cause energy to be lost. More accurately, eddy currents transform more useful forms of energy, such as kinetic energy, into heat, which is generally much less useful.

In the photo above, eddy currents (red) are induced in a conductive metal plate (C) as it is moved to the right under a magnet (N). The magnetic field (B, green) is directed down through the plate. The eddy currents produce opposing magnetic fields (blue arrows).

An **Electromagnet** is a type of magnet in which the magnetic field is produced by an electric current. The magnetic field disappears when the current is turned off.

### Procedure A:

## Forces and Motion

1. Give the student the magnet, and ask them to find which items are magnetic (the copper tube, plastic tube, aluminum plates and steel washer). The only magnetic item is the washer.
2. Ask the students which tube they think the magnet will fall through faster?
3. Hold the plastic tube vertically. Drop disk magnet through the tube and have the students count how many seconds it takes to come out.
4. Hold the copper tube vertically. Drop the disk magnet through the tube and have the students count how many seconds it takes to come out.
5. Let the students watch the disk magnet fall through the copper tube and make observations.

**Discussion:** Why does the magnet fall slowly through the copper tube?

As the magnet falls, the magnetic field around it constantly changes position. As the magnet passes through a given portion of the metal tube, this portion of the tube experiences a changing magnetic field, which induces the flow of eddy currents in an electrical conductor, such as the copper or aluminum tubing. The eddy currents create a magnetic field that exerts a force on the falling magnet. The force opposes the magnet's fall. As a result of this magnetic repulsion, the magnet falls much more slowly.



In the photo on the right, we can see that the red induced currents form an electromagnet which slows the progress of the magnet. The upper magnetic field attracts the magnet and the lower magnetic field repels the magnet (opposite poles attract, same poles repel), therefore slowing the magnet. These currents die away due to resistance, allowing the magnet to continue falling, slowly, as it continues to get caught in these currents.

**Procedure B:**

1. Hold one of the aluminum plates at an angle.
2. Place the washer at the top and let it slide down the length of the plate. Place the Magnet at the top and let it slide down the length. Compare the speed of the falls.
3. Next, hold the two aluminum plates together, with enough space between them for the magnet.
4. Drop the magnet between the two plates; observe the speed of the fall.

**Discussion:** What made the magnet fall slowly?

Again, this is due to eddy currents, but this time we can really see it happening! The opposing magnetic fields created by the eddy currents are slowing down the magnet as it falls.



## H<sub>2</sub>Olympics

### Passport Question:

Cohesion is the attraction between water molecules and other water molecules.

Adhesion is the attraction between water molecules and other materials.

Surface Tension is the strong bonds formed between water at the surface.

Capillary Action is the movement of water molecules within materials.

**Learning Target:** Students will learn basic properties of water including cohesion, adhesion surface tension and capillary action.

### Materials:

- Pennies
- Pipette
- (1) square tin baking dish
- Water
- Forks
- Paper clips
- 2 different paper towel brands, cut into strips
- Wide mouth, tall Mason Jars
- Ruler

### Background information:

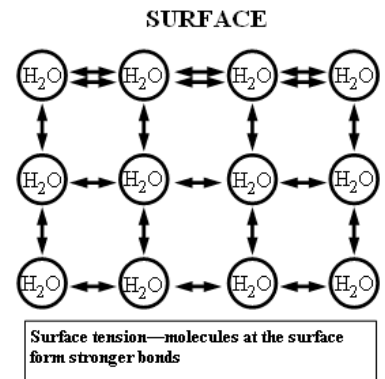
In a water molecule the Oxygen atom steals electrons from the hydrogen atoms creating a dipole, in this case a molecule that has a positive end and a negative end. If you think about each water molecule like it is a tiny magnet, where like charges repel each other and unlike charges attract, you'll see that there is a small attractive or cohesive force between each water molecule.

At the surface, there are fewer water molecules to cling to since there is air above, not more water. These surface molecules experience a net inward force due to the molecules below pulling down, but no molecules above pulling up to balance it out.

This force is responsible for surface tension, where the molecules contract and resist being stretched or broken.

These positive and negative ends on a water molecule are also attracted to other materials, this is called adhesion.

Capillary action is movement of water within the spaces of a porous material due to the forces of adhesion, cohesion and surface tension.



### Procedure A: PENNY DROPS

1. Students use a pipette, to carefully place as many drops on the penny as possible, before it spills.



## Forces and Motion

**Discussion:** What happens to the water drops as you add them?

They form one large, dome-shaped water drop. This shape is due to surface tension. The strong, cohesive bonds of surface tension can break and form easily, which is why we see one drop getting bigger and not many separate water drops.

### **Procedure B: FLOATING PAPERCLIPS**

1. Use a fork to suspend paper clips on top of water.
2. See how many you can suspend! Use a magnet to remove the paperclips from the water.

**Discussion:** Why do the paperclips sometimes sink and other times float?

They're not actually floating! Cohesion can be seen through water's surface tension. Surface tension acts a 'skin' and can be strong enough to hold small objects such as paper clips and even insects.

Adhesion can be seen where the water and the metal of the paper clip are touching.

### **Procedure C: SOAK IT UP**

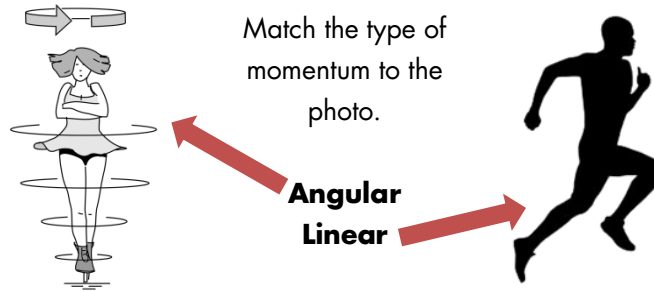
1. Make a hypothesis of which paper towel will absorb more.
2. Fill the mason jars with about an inch of water dyed with food coloring.
3. Have the students dunk the paper towels into the water and count to 30.
4. Measure the height absorbed for each towel.

**Discussion:** How does the water 'climb' the paper towels?

Capillary action! This movement occurs when water molecules attract the molecules of other things (like a paper towel, or your shirt) and to each other. But the molecules can only travel so far before the force of gravity stops them from continuing.

## Show Me the Momentum!

### Passport Question:



**Learning Target:** Students will learn what linear momentum is and how it can be transferred between two objects (i.e. two balls colliding).

### Materials:

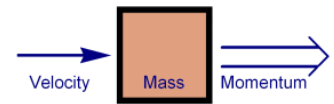
- Ramp
- 1 canister filled with cotton balls
- 1 canister filled with rice
- Newton's Cradle
- Plastic tube
- (2) tennis balls
- Color wall chart

### Background Information:

Linear Momentum ( $p$ ) depends on an object's mass ( $m$ ) and velocity ( $v$ ). The more linear momentum an object has, the more difficult it is to stop that object.

$$p = m \times v$$

Force, a push or pull that gives an object linear momentum.



If the Force acting on an object is removed, the momentum on the object is conserved and remains constant. The momentum can still be changed by changing the mass or the velocity of the object.

Linear Velocity ( $v$ ) is the distance traveled ( $x$ ) over time ( $t$ ).

$$v = x / t$$

### Procedure A:

1. Have the students to pick up the canisters and observe the differences between them.
2. Ask them which canister they think will hit the bottom *harder* (not faster)? The one that hits harder will be harder to stop.
3. Ask them which canister will have more momentum. The canister that hits harder will have more momentum.

## Forces and Motion

4. Have one student place the canister filled with cotton balls at the top of the ramp, and hold it in place with the insert. Have another student place their hand on the outside of the finish line.
5. Remove the insert to let the canister roll down.
6. Repeat procedure with the canister filled with rice. Which one hits the bottom hardest?

**Discussion:** Which canister hit the bottom harder?

The canister full of rice hit harder, because it is heavier. Therefore, it had a higher linear momentum.

### **Procedure B:**

1. Hold the acrylic tube upright in front of the color chart and drop the pink rubber ball. Measure the height that it bounces and remove the ball.
2. Next, drop the small yellow ball and measure the height it bounces. Remove the ball.
3. Place the yellow ball on top of the pink ball and drop them through the tube simultaneously. How high do the two balls bounce?
4. Using the Newton's Cradle, hold one ball up in the air, but do not drop it. Ask the students what they think will happen when you let it go?
5. Have a student drop

**Discussion:** When the balls were dropped together, How high did the yellow ball bounce? How high did the pink ball bounce?

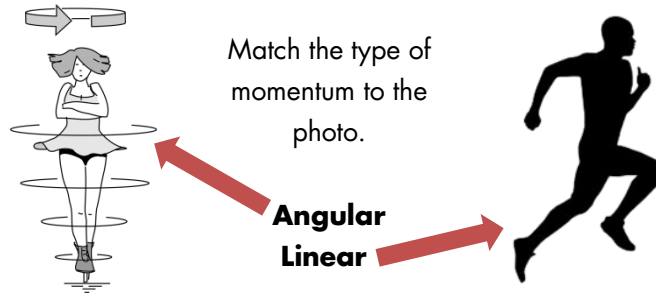
The pink ball hardly bounces at all while the yellow ball bounces much higher than it originally did.

When they are dropped together, most of the pink balls momentum is not lost, but is transferred to the yellow ball. The yellow ball now has greater momentum and thus increases speed which allows it to travel higher. Remember the equation for linear momentum,  $\mathbf{p} = \mathbf{m} \times \mathbf{v}$ , we aren't changing the mass of the balls, but we are changing the momentum, which affects the velocity.

In the Newton's Cradle, we see momentum being transferred through multiple balls. When one ball is lifted and dropped it collides with the second ball. The next three balls seem to stay still, while the fifth ball, on the opposite end, is set into motion. The momentum of the first ball (from being lifted and dropped) is transferred to through the center balls and into the fifth ball where we see it get thrown up. That ball comes back down, and sends the momentum back through the line, and this process is repeated!

## Momentum Machine

### Passport Question:



**Learning Target:** Students will learn what angular momentum is and that it depends on how fast an object is rotating and how its mass is distributed.

### Materials:

- Hand weights (2-3lbs)
- Lazy Susan

### Background Information:

Angular Momentum (L) depends on an objects mass ( $m$ ), velocity ( $v$ ; perpendicular to radius), and distance from its center of rotation ( $r$ ). The greater the angular momentum of an object is, the more difficult it is to stop that object from rotating.

$$\mathbf{L} = \mathbf{m} \times \mathbf{v} \times \mathbf{r}$$

Torque ( $\tau$ ) is a measure of how much force acting on an object causes that object to rotate about an axis.

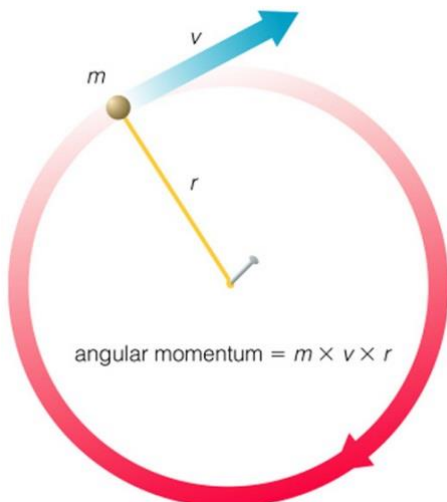
Every rotating object has an Angular Velocity ( $\omega$ ) and a Linear Velocity ( $v$ ).

Angular velocity is the ratio of the angle travelled ( $\theta$ ) over time ( $t$ ).  $\omega = \frac{\theta}{t}$

Linear Velocity ( $v$ ) is the distance traveled ( $x$ ) over time ( $t$ ).  $v = \frac{x}{t}$

Angular Velocity ( $\omega$ ) and Linear Velocity ( $v$ ) are related in this formula.  $v = r\omega$

By combining and rearranging the equations (below) for Angular Momentum and Angular Velocity, we can see that  $r$  and  $\omega$  are inversely related. Therefore, if the object is moved further from the axis, or  **$r$  is increased**, then the angular velocity ( $\omega$ ) **decreases**. And vice versa.



$$\begin{aligned} L &= m \times v \times r \\ L &= m \times r\omega \times r \\ L &= m \times \omega \times r^2 \\ r^2 &= \frac{L}{m \times \omega} \end{aligned}$$

If the Torque ( $\tau$ ) acting on an object is removed, the momentum on the object is conserved and remains constant.

## Forces and Motion

The momentum can still be changed by changing the distance from the axis.

### Procedure:

1. Have a student sit cross legged on the lazy susan.
2. Give the student the hand weights to hold in each hand. Have them hold their arms out.
3. Give them one small push so that the student begins to spin slowly.
4. On command, have the student bring the two weights to his or her chest. The student's rotation rate will dramatically increase. Tell the student to extend the weights again, and the rotation rate will decrease.
5. Ask students their observations, focus in on how fast they are rotating when do move their arms inwards and outwards.

### Discussion: What happens when the student brings their arms in?

They spin faster.

We set the student in motion using Torque, or a push, giving the student and the lazy susan angular momentum. By not pushing the chair continuously, we removed the Torque, yet the angular momentum was conserved, or stays the same. At least until the student brings their arms in.

Because angular momentum is conserved, if one factor of the equation is changed, another must change in the opposite direction in order to keep things balanced.

Angular momentum depends on mass, velocity, and distance from the axis. Did we change the mass? No. Did we change the velocity after the first push? (To change it would require more pushes or to stop the chair) No. Did we change the distance of the mass from the axis? Yes! By pulling their arms in, they reduced the distance of the weights from the axis (the student's body) which increases their angular momentum which in turn, increases angular velocity.

Check for understanding by asking, what would happen if we changed mass or velocity?



Mass is further away from axis of rotation  
→ Lower angular speed



Mass is closer to axis of rotation  
→ Greater angular speed