Activity 1: Gravity

Materials List:

Computer with an Internet connection

Part 1: Review of Pre-Lab: Newton's First and Second Laws

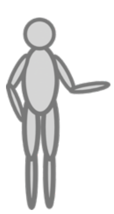
SQ1:

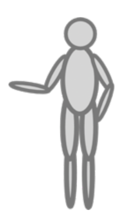
a) Suppose there are two forces acting on an object. If the object is sitting at rest and stays at rest, what must be true about the two forces that are acting on the object? Draw a sample diagram of the object and two forces acting on it. You can draw a force using an arrow and use the length of the arrow to indicate the strength of a force.

b) Suppose there are two forces acting on an object. If the object is falling at *constant* speed (i.e., it's speed is *not changing*), what must be true about the two forces that are acting on the object? Draw a sample diagram of the object and two forces acting on it.

Part 2: What's Up?

1) If you wanted to point in a straight line (the shortest possible path) from you to China and the Far East, which way would you point? Explain your answer.

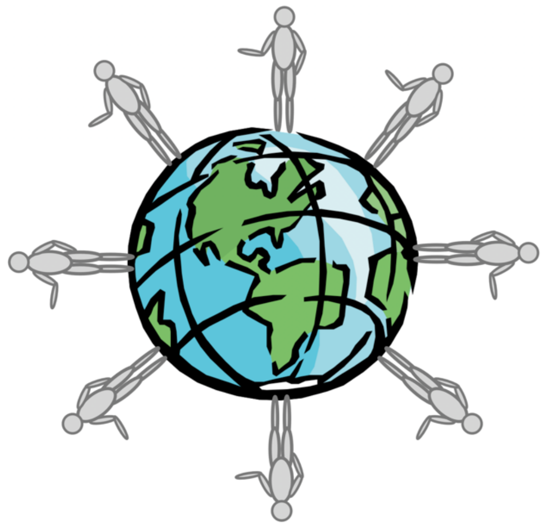
A. West 

B. East 

C. Up 

D. Down 

2) The drawing below shows some VERY tall people (actually they're drawn very tall so that you can see them, but don't take that literally; imagine they represent regular-sized people) at various points around the Earth. If each of them were to drop a rock from their outstretched hand, what happens to each of the rocks? Draw a line showing the complete path of each rock.



3) Do the lines that you drew share any common characteristics? If so, what?

4) If you were to extend your drawn lines so that they are long enough to go through the Earth, where should they all cross?

5) **SQ2** Based on your answers to the above, how would you define "up" and "down"? Come up with a single definition that will work for all people, regardless of where they are on the Earth.

Part 3: Falling Objects

STEP 1: If you were to drop a textbook and a pencil, which one do you expect would land first? Feel free to conduct a quick experiment if you like. Don't overthink it; just write down a hypothesis (or your experimental result) and move on.

Aristotle, one of the world's first scientists, believed that a heavier object would fall faster than a lighter object, and this idea prevailed for several thousand years. Then Galileo came along in the 16th century and changed our understanding.

STEP 2: **Galileo** famously performed an experiment in the late 1500's. According to the legend, he stood at the top of the Leaning Tower of Pisa and dropped two balls. The two balls had different masses.

What he found is that the balls *landed at the same time, even though they had different masses*. In so doing he had developed a new understanding of falling bodies that replaced Aristotle's idea that had reigned for thousands of years. Galileo's claim is that *all objects will fall at the same rate*. Let's examine this claim some more.

What if instead of two balls, Galileo had dropped a bowling ball and a feather? Do you think they would land at the same time? Write down your hypothesis.

STEP 3: Let's test your hypothesis from the previous question. Open a web browser and load the following video:

youtu.be/E43-CfukEgs?t=1m23s

Click Play, then stop it at around 1:35, after they perform the first experiment. Did the feather and the ball fall at the same rate?

Why do you think this happened? Was Galileo wrong about all objects falling at the same rate, or is there something else going on here? Just write down a hypothesis and move on for now; we will carefully answer this question shortly.

Let’s talk now about something called “air resistance”.

Air resistance is a form of friction that occurs when an object travels through the air. Air resistance is the slowing force caused by the object bumping into air molecules. Each collision with each air molecule slows the object down slightly, so the sum total of all of the air molecule collisions is a “drag” force on the object.

You don’t have to be falling to experience air resistance. Any object that is bumping into many air molecules, such as a car on the highway, will also experience air resistance.

STEP 4: Use the definition of air resistance above to answer the following questions.

How do you think the air resistance would compare between two falling objects where one object has a *large area* (like a parachute) and the other object has a much *smaller area* (like a bowling ball)? Explain your reasoning. Hint: Think about the relative number of air molecules each object would be bumping into over the same period of time.

How do you think the air resistance would compare between two identical cars where one car is traveling 30 mph and the other car is traveling 90 mph? You may assume the cars are in every way identical except for their speeds. Again, think about which one is bumping into more air molecules over the same interval of time. Explain your reasoning.

How do you think the air resistance would compare between two identical balls, one that is falling at sea level where the air has standard density, and one that is falling at the top of Mount Everest where the air is much less dense (meaning there are a lot fewer air molecules)? Explain your reasoning.

An overview of *direct* and *inverse relationships*:

> If two quantities A and B are **directly related**, then when A *increases*, B *increases*. And when A *decreases*, B *decreases*.
>
> If two quantities A and B are **inversely related**, then when A *increases*, B *decreases*. And when A *decreases*, B *increases*.

Based on your above answers, how is air resistance related to an object's area? Is it a direct or inverse relationship?

Based on your above answers, how is air resistance related to an object's speed? Is it a direct or inverse relationship?

Based on your above answers, how is air resistance related to the air density? Is it a direct or inverse relationship?

If something were standing still (i.e., it had a speed of zero), what do you think the air resistance would be like for that object?

If we were able to reduce the air density almost to zero so that there are little or no air molecules remaining, such as in outer space, what do you think would happen to the air resistance?

In the case of little or no air resistance, what would happen to the feather and bowling ball demonstration we watched in Step 4? Write down your hypothesis.

STEP 5: Let's test your hypothesis. In the video we watched in Step 3, the bowling ball and feathers were in a giant vacuum chamber. A vacuum chamber is a room from which they can remove all of the air molecules (the absence of molecules is called a *vacuum*). And that's exactly what they do next: they remove all of the air from the room and then try the experiment again.

Fast-forward Video #1 to 2:45 or open this URL:

youtu.be/E43-CfukEgs?t=2m45s

Describe what happened in the experiment.

STEP 6: This same experiment was actually performed back in 1971. However, instead of using a vacuum chamber where one must evacuate the air, the experiment was done on the Moon! An astronaut from the Apollo 15 mission dropped a hammer and a feather on the moon at the same time.

Considering that the air density on the moon is very small or nearly zero, what do you think happened when the feather and the hammer were dropped? Explain your reasoning.

In your web browser, open this video that's nearly 50 years old (it's best with the sound on):

youtu.be/5C5_dOEyAfk

Did the result of this experiment agree with your prediction?

STEP 7: Since we are talking about falling objects, let's talk about *falling humans*, or in other words, skydiving! The two forces acting on a skydiver are gravity (pulling down) and air resistance (pushing up).

As long as the force of air resistance (pushing up) is less than the force of gravity (pulling down), are the forces balanced or unbalanced? And therefore what will happen to the speed of the skydiver?

As a result of your previous answer, what happens to the amount of air resistance acting on the skydiver? Hint: Look back at your direct/inverse relationships from Step 4.

Based on your previous answer, are the forces getting closer to being balanced, or are they becoming more unbalanced?

In order for the skydiver's speed to stop changing, what must be true about the relationship between the force of air resistance (pushing up) and the force of gravity (pulling down)? Based on your previous answers, do you think this situation could ever occur? Why or why not?

Suppose the force of air resistance on the skydiver is equal and opposite to the force of gravity, so that they are balanced. What will happen to the skydiver's rate of descent? Will the skydiver stop falling, or will something else happen? Think about the net force and Newton's First Law.

In the presence of air resistance, every object has a maximum speed that it can attain, which is the speed it attains when gravity and air resistance become balanced. This maximum speed is called the **terminal velocity**.

Do you think the terminal velocity will vary from object to object and from place to place? Why or why not? Hint: Look at your direct and inverse relationships that you found in Step 4.

SQ3: Imagine going skydiving on the moon. What is your terminal velocity as you fall? Recall that there is effectively no atmosphere on the moon, meaning there are no air molecules present.

STEP 8: In 1960, Air Force Colonel Joseph Kittinger set multiple records by skydiving from a balloon at an altitude of 102,800 feet, which is roughly 19 miles! For comparison, a modern jet airliner flies at an altitude of 35,000 ft, or almost 7 miles.

Before opening his parachute, Kittinger free-fell for 4 minutes and 36 seconds (setting the record for longest free fall ever by a skydiver) and he reached a speed of 614 miles per hour!

Courageous missions like Kittinger's helped pave the way for the space program. Kittinger wore an early model of a space suit because, at an altitude of 19 miles, he was at the edge of space where the air density was very low.

Given that the air density was so low at this altitude, what does that mean about the air resistance at that altitude?

Kittinger's record was broken in 2012 as part of a scientific mission and publicity stunt funded by the energy drink company Red Bull. The mission was named *Red Bull Stratos*. Austrian skydiver Felix Baumgartner jumped out of a balloon at an altitude of about 24 miles!

He free-fell for 4 minutes and 19 seconds before deploying his parachute. During that time, he reached 834 mph, which is faster than the speed of sound. He is the *first person to ever break the sound barrier without a vehicle*. His body produced a sonic boom.

To watch a video of this death-defying jump from 2012, open the following URL:
youtu.be/FHtvDA0W34I

In the video, you can see Kittinger cheering for Felix from mission control, and giving him a hug at the end of the video. Kittinger was one of the advisors on the Red Bull Stratos mission which broke his own records.

These two record-breaking skydives are summarized here:

	Altitude of Jump	Free Fall Time	Maximum Speed
John Kittinger (1960)	102,800 ft	4m 36s	614 mph
Felix Baumgartner (2012)	127,851 ft	4m 19s	834 mph

SQ4: Kittinger free-fell for a longer time than Baumgartner, but Baumgartner reached a higher maximum speed. Why? Use what you've just learned about air resistance.

Part 4: Force of Gravity

In the 1660's (almost 100 years after Galileo), Isaac Newton famously sat under an apple tree and, according to legend, when an apple fell out of the tree and hit him in the head, he had a realization: Gravity, the force that pulled the apple to the Earth, is the same force that keeps the Moon in orbit around the Earth. Let's explore this idea.

In the previous Part, we studied what happens when two objects are falling because they're being pulled down by the gravity of the Earth (or the Moon). But, what if the Earth (or the Moon) is not involved? For instance, imagine two lonely asteroids floating past each other in space. Does gravity still exist, and if so, what is its behavior? Let's investigate.

STEP 1: Open the simulation at the following URL:

phet.colorado.edu/sims/html/gravity-force-lab/latest/gravity-force-lab_en.html

Or, go to the PhET website (phet.colorado.edu), click "Play with Simulations", select "Physics" in the left-hand menu, select "Motion" in the left-hand submenu, and scroll down to find the simulation called "Gravity Force Lab". Click on it to start it.

STEP 2: Take a minute to familiarize yourself with the simulation. Explore the things that you can change, move, etc. Be sure everyone in your group gets a chance to see the simulation as it's being used.

STEP 3: Think about what the arrows above each ball represent. In the space below, draw the two balls, the two arrows, and label what each arrow is.

An arrow contains two kinds of information: it has a direction and it has a length (i.e., it's a "vector").

What do you think is indicated by the direction of each arrow in the simulation?

What do you think is indicated by the length of each arrow in the simulation?

STEP 4: Set both masses to 200 kg and then start to increase Mass 1. What happens to the force with which *Mass 1 pulls* on Mass 2? How can you tell from the simulation, either graphically or numerically?

What happens (while still increasing *Mass 1 only*) to the force with which *Mass 2 pulls* on Mass 1? How can you tell?

STEP 5: Set both masses back to 200 kg and then start to increase Mass 2 this time. What happens to the force with which *Mass 2 pulls* on Mass 1? How can you tell?

What happens (while still increasing *Mass 2 only*) to the force with which *Mass 1 pulls* on Mass 2? How can you tell?

How does gravitational force relate to the amount of mass present? Is it a direct or inverse relation? Justify your answer.

STEP 6: Use the simulation to answer the following question: Can one object experience a different gravitational pull than the other object, or does each one always experience the same amount of gravitational pull as the other? Make sure to experiment with changing both the masses and the distance.

SQ5: With only two objects present, … (choose one)

one object *can* experience a different gravitational pull than the other object.

each object *always* experiences the same gravitational pull as the other object.

The above behavior is seen over and over in nature and is called *Newton's Third Law.*

Newton's Third Law states that, for every force-at-a-distance (like gravity), there is always an identical but opposite force-at-a-distance.

How does the behavior of the simulation support Newton's Third Law?

The simulation allows a minimum mass of 1 kg. What do you think would happen to the gravitational forces if you could set the mass of one or both balls to 0 kg?

Therefore, what is required for there to be a gravitational pull of exactly zero?

Do *you* have a gravitational pull? How do you know? Use your previous answer to help you answer this one.

Can you feel a gravitational pull between you and a person sitting near you? Why or why not?

In the grand scheme of things, gravity is actually a fairly weak force! This makes it especially difficult to study gravity in a laboratory. That's why we used a computer simulation to conduct our investigation of gravity today.

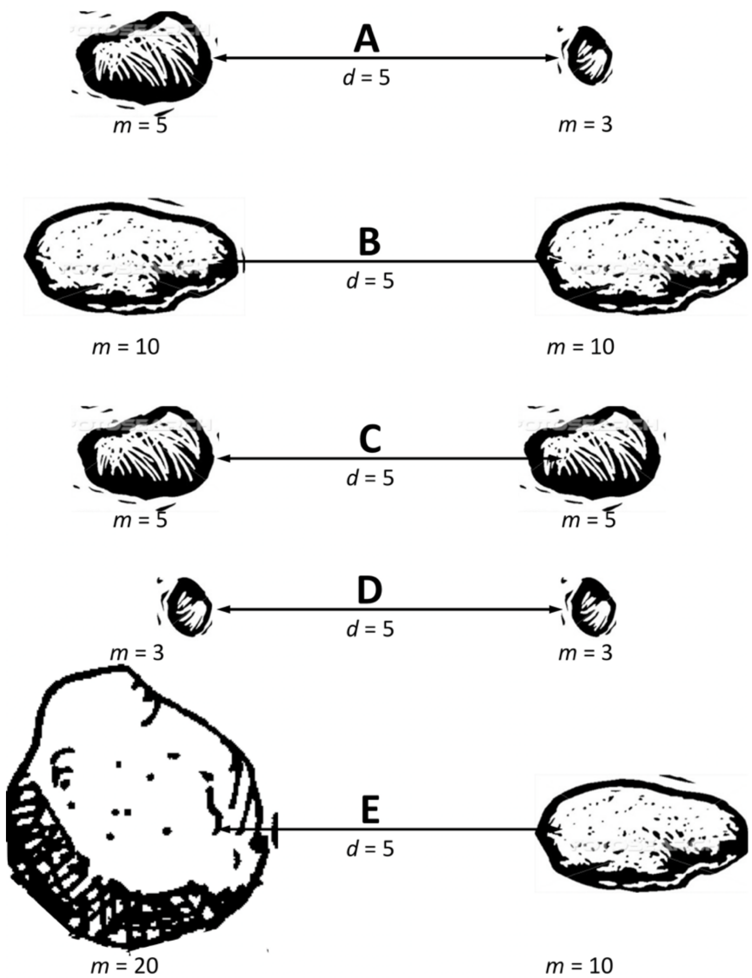
When you hold a book out at arm's length, what is the object that is most obviously pulling on the book gravitationally?

The Earth's mass is about 6,000,000,000,000,000,000,000,000 kg (i.e., $6x10^{24}$ kg). So *that* much mass is pulling on the book via gravity, and yet it's still not strong enough to overcome your muscles' ability to prevent the book from falling. Apparently, you should pursue a career as an Olympic weightlifter! And/or, gravity is very weak.

Say the book is being pulled downward with a force of 5 pounds ("pound" is actually a unit of *force*, not mass). With what force (in pounds) is the *book pulling upward* on the Earth? Hint: Remember what we learned with Newton's Third Law.

SQ6: If the gravitational forces between the book and Earth are equal and opposite, then why when you release the book does the book drop to the Earth, rather than the Earth "falling upward" to the book? Which of Newton's Laws did you use to answer this?

SQ7: The drawing below shows pairs of asteroids with a mass *m* (in some units of mass) and separated by a distance *d* (in some units of length).



(a) Consider the gravitational pull that's felt by the asteroid on the right in each pair. Which asteroid on the right is experiencing the greatest gravitational pull from its left neighbor? If it's a tie, list all that are tied.

(b) Now consider the gravitational pull that's felt by the asteroid on the left in each pair. Which asteroid on the left is experiencing the greatest gravitational pull from its right neighbor? If it's a tie, list all that are tied.