Strength of Gravitational Force: How Does the Gravitational Force That Exists Between Two Objects Relate to Their Masses and the Distance Between Them?

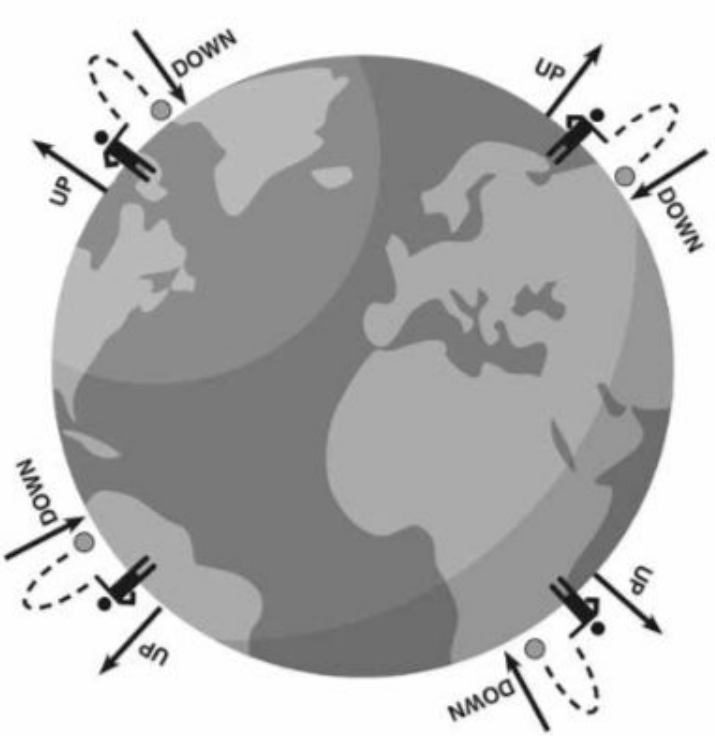
Introduction

The motion of an object is the result of all the different forces that are acting on the object. If you pull on the handle of a drawer, the drawer will move in the direction you pulled it. If a ball is rolling down a driveway and hits a curb, the force of the curb will cause the ball to stop. Applying a pull or push to an object is an example of a contact force, where one object applies a force to another object through direct contact. There are other types of forces that can act on objects that do not involve objects touching. For example, the magnetic force produced by a magnet can make a paper clip move toward it or make another magnet move away from it without touching them. Another example is static electricity. Static electricity in a rubber balloon can cause a person's hair to stand up without the balloon actually touching any of his or her hair. Magnetic forces and electrical forces are therefore called non-contact forces because they can act on objects at a distance. Perhaps the most common non-contact force is gravity. Gravity is a force of attraction between two objects; the force due to gravity always works to bring objects closer together.

Any two objects, as long as they have some mass, will have a gravitational force of attraction between them. The force of gravity that exists between any two objects is influenced by the masses of those two objects. The mass of an object refers to the amount of matter that is contained by the object. Mass is also a measure of inertia, which is the resistance an object has to change in its state of motion. All objects resist changes in their state of motion; however, the more massive an object, the more it will resist changes in its state of motion. The distance between any two objects will also influence the force of gravity that exists between them because the distance between any two objects can, and does, change. The exact relationship between these factors, however, was not well understood until 1687.

The first person to determine how mass and distance affect the strength of the gravitational force that exists between two objects was Isaac Newton. Newton described the relationship between these three factors in the book Philosophiae Naturalis Principia Mathematica (Newton 1687). The ability to describe the relationship between mass, distance, and the strength of a gravitational force was a major milestone in physics. It not only explained why objects fall toward the center of Earth (see figure above) but also explained why the planets move around the Sun, which was established by Copernicus in 1543. Before Newton put forth his revolutionary ideas about gravity, many people thought objects on Earth and objects in the sky moved because of different forces. Newton was the first person to suggest that the force of gravity is universal.

Objects fall toward the center of Earth.



In this investigation, you will have an opportunity to explore the relationship between mass, distance, and the strength of the gravitational force that exists between two objects in order to learn more about the behavior of gravity. This type of investigation can be difficult, however, because identifying the exact nature of the relationship that exists between several different factors is challenging. Take mass as an example. There are many potential ways that the strength of a gravitational force between two objects can be related to the mass of those two objects. The strength of the gravitational force between two objects may depend on the mass of the larger object or the mass of the smaller object. The strength of the gravitational force could also be related to the total mass of the two objects. In addition to mass, there are many different ways that the strength of a gravitational force between two objects can be related to the distance between the two objects. The strength of a gravitational force may increase as the distance between the two objects increases, or it may decrease as the distance between the two objects increases. It may also increase or decrease exponentially as the distance between the two objects changes. All of these different relationships are possible (along with many others). Your goal is to figure out the actual relationship.

Your Task
Use what you know about forces, motion, patterns, and proportional relationships to design and carry out an investigation using a simulation to determine the relationship between mass, distance, and the strength of a gravitational force.

The guiding question of this investigation is: ***How does the gravitational force that exists between two objects relate to their masses and the distance between them?***

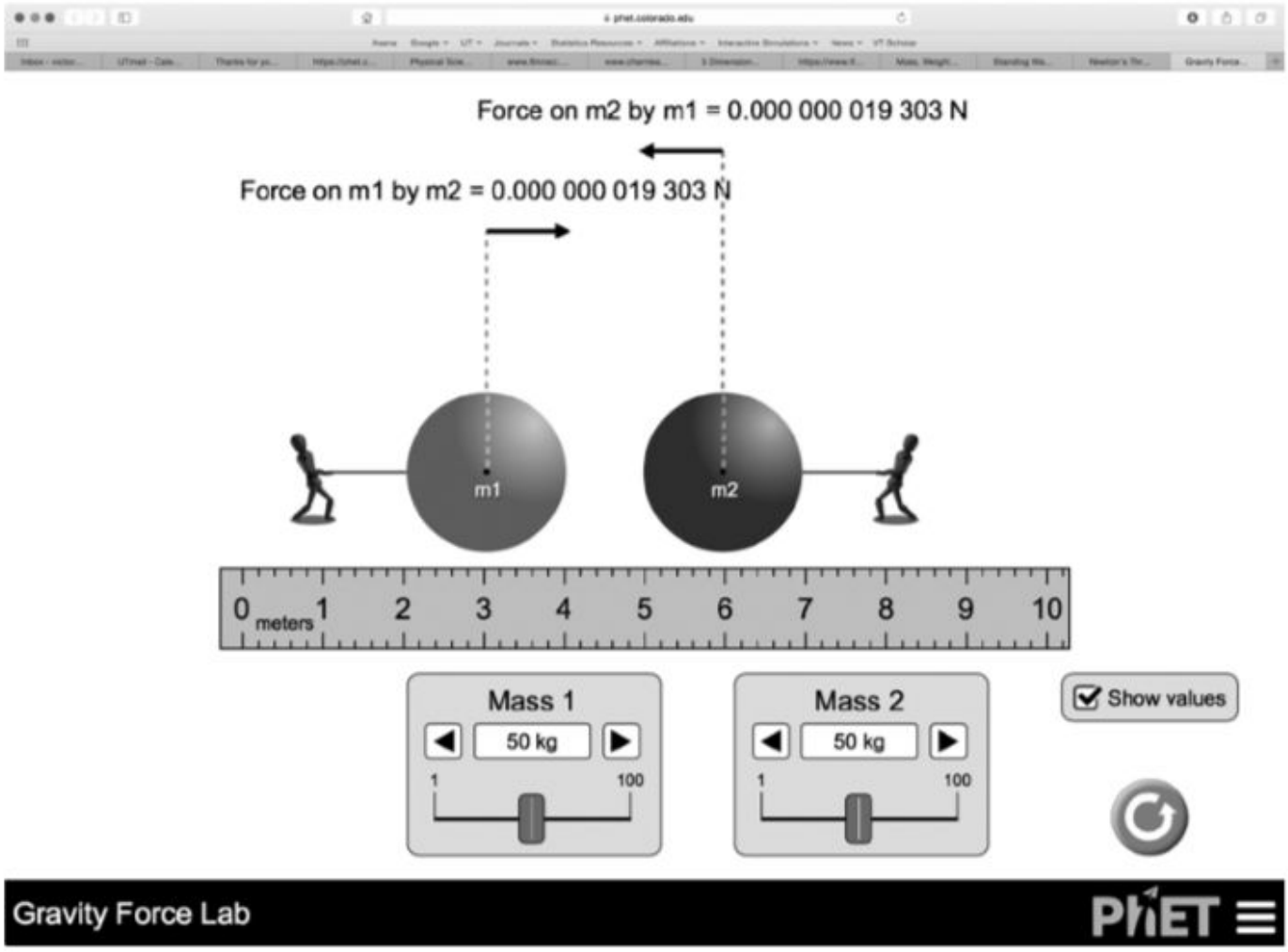
Materials
You will use an online simulation called *Gravity Force Lab* to conduct your investigation. You can access the simulation by going to the following website:
https://phet.colorado.edu/en/simulation/gravity-force-lab

Getting Started
The *Gravity Force Lab* simulation (see screen shot below) enables you to measure the amount of gravitational force that two objects exert on each other. You can adjust the mass of the two different objects in the simulation and the amount of distance between them. As you change mass and distance, you will be able to see the amount of force, in newtons, that each object exerts on the other one. To use this simulation, start by clicking on the "Show values" box in the lower-right corner of the window. This will allow you to see the amount of force exerted by the blue object (m1) on the red object (m2) and the amount of force exerted by the red object (m2) on the blue object (m1). You can change the masses of the blue and red objects by using the sliders at the bottom of the window. To change the distance between the red and blue objects, you can simply drag and drop each one to a different spot above the ruler. This simulation is useful because it allows you to measure the force of gravity under different conditions, and perhaps more important, it provides a way for you to design and carry out controlled experiments so you can focus on one factor at a time.

You will need to design and carry out at least three different experiments using the *Gravity Force Lab* simulation in order to determine the relationship between mass, distance, and gravitational force. You will need to conduct three different experiments because you will need to be able to answer three specific questions before you will be able to develop an answer to the guiding question:

1. How does changing the mass of the red object affect the amount of gravitational force?
2. How does changing the mass of the blue object affect the amount of gravitational force?
3. How does changing the distance between the two objects affect the amount of gravitational force?

A screen shot of the *Gravity Force Lab* simulation



You will also need to determine what type of data you need to collect, how you will collect it, and how you will analyze the data for each experiment, because each experiment is slightly different.

To determine *what type of data you need to collect,* think about the following questions:

- What type of measurements will you need to record during each experiment?
- When will you need to make these measurements or observations?

To determine *how you will collect the data* using the simulation, think about the following questions:

- What will serve as your dependent variable for each experiment?
- What will serve as your independent variable for each experiment?
- How will you vary the independent variable during each experiment?
- What will you do to hold the other variables constant during each experiment?
- What types of comparisons will you need to make using the simulation?
- How many comparisons will you need to make to determine a trend or a relationship?
- How will you keep track of the data you collect and how will you organize it?

To determine *how you will analyze the data*, think about the following questions:

- What type of calculations will you need to make?
- What type of graph could you create to help make sense of your data?

Once you have carried out all your different experiments, your group will need to use your findings to develop an answer to the guiding question for this investigation. Your answer to the guiding

question will need to be able to explain how the gravitational force that exists between two objects is related to the masses of the objects and distance between them. For your claim to be sufficient, your answer will need to be based on findings from all three of your experiments. You can then transform the data you collected during each experiment into evidence to support the validity of your overall explanation.

Report

Once you have completed your research, you will need to prepare an investigation report that consists of four sections (be sure to have section headings):

1. Introduction: Give some background information on the topic. Explain what question were you trying to answer and include a hypothesis. (Background info, research question and hypothesis)
2. Procedure: What did you do during your investigation and why did you conduct your investigation in this way? (How you collected and analyzed data)
3. Data: Include a data table and/or graph to show your results. Be sure to include a title for your table or graph with labels for the variables.
4. Conclusion: What is your argument? (Claim - Evidence - Reasoning)

Your report should answer these questions in two pages or less. The report must be typed, and any diagrams, figures, or tables should be embedded into the document. Type your report on Google Docs (12 point font, double-spaced) and share it with your teacher. Your report will be graded based on the rubric in the class syllabus.