Newton's Law of Gravity and Kepler's Laws of Planets

PURPOSE:

To learn about the force of gravity and the orbital mechanics of our solar system.

Part A - Gravitational Force

Go to https://phet.colorado.edu/sims/html/gravity-force-lab/latest/gravity-force-lab_en.html

Use this simulation to do the activity below.

1. Set Mass 1 to 50 kg and Mass 2 to 70 kg. Set the masses at 1.0 meter apart. This is similar to the mass of you and the mass of another student in a desk next to you.
2. Fill in the top half of the table to the right, where an **Action** causes the **Gravity Force** to increase or decrease.
3. What is the ratio of the force on the Mass 1 to the force on the Mass 2? What law explains this ratio?
4. In what direction are the gravitational forces acting on the objects?
5. (a) What happens to the **force** between the objects if you *double* the Mass 1? (Fill in the lower part of table).
(b) What happens to the **force** between the objects if you *double* the Mass 2?
(c) What happens to the **force** if you *double* the **distance** between objects?
(d) What happens to the **force** if you *triple* the **distance** between objects?

Action	Gravity Force
Mass 1 and Mass 2 closer together	▢ Increase ▢ Decrease
	▢ Increase ▢ Decrease
	▢ Increase ▢ Decrease
	▢ Increase ▢ Decrease
	▢ Increase ▢ Decrease
	▢ Increase ▢ Decrease
(a) Double the Mass 1	
(b)	
(c)	
(d)	

6. If you multiply Mass 1 (50 kg) with Mass 2 (70 kg), divided by distance between them (1 m) squared, you get ______ N. This is *not* the actual force (it would be a lot!). Instead, the Law of Universal Gravitation includes a constant, *G*. Click on Show Values to view force from the PhET simulation, then solve for the value of *G*. Include the units in the calculation.

$$F_g = \frac{Gm_1m_2}{r^2} \Rightarrow G =$$

The value of *G* isn't the *reason* that the Gravity Force is very small for ordinary objects, but it's a reminder that gravity is a relatively weak force!

7. The Law of Universal Gravitation follows the inverse square law. What does this mean, and which other law is similar?

8. The Law of Universal Gravitation can be equated to the familiar equation for weight, $F_g = mg$, where m_1 is m, and m_2 is the mass of the Earth ($M_E = 5.97 \times 10^{24}$ kg), and the distance is the radius of the Earth ($R_E = 6.37 \times 10^6$ m). Solve for g.

Part B – Orbital Motion

Go to PhET: https://phet.colorado.edu/sims/html/gravity-and-orbits/latest/gravity-and-orbits_en.html

1. Newton proposed that artificial satellites could orbit the Earth. His idea was to launch a cannonball at high velocity atop a mountain (often called Newton's Cannon). Using the PhET simulation, explore this idea. Set the simulation to "Model" and select the 4th model, which shows the Earth and the Space Station (ISS). Fill in the table below.

How can you…	Explain what you changed	Draw the path of motion	Other changes noticed?
Make the ISS orbit elliptically			
Make the ISS escape the Earth			
Make the ISS crash into Earth			

2. Looking at the initial velocity vector for ISS, what would happen to the ISS path if gravity were "turned off"? Why?

3. Set the simulation to "Scale". Select Star and Planet (top choice). Note: Star Mass = Our Sun, and Planet mass = Earth. Select options: Velocity, Path, Grid, and Measuring Tape. Click the Play arrow. Click the Fast Motion and Slow Motion arrows to see their affect. Use these buttons as needed. Click the Stop button. Click the grey reset button in upper right.

4. Using the Measuring Tape for distance and the Earth Days for time, determine the speed of the Earth in m/s when in the initial orbit of two grid boxes from the Sun. Show your work below.

5. Use the general formulas for gravitational force $F_g = GmM / r^2$ and centripetal force $F_c = mv^2 / r$ for circular orbits, to derive an equation for orbital speed v in terms of orbital radius r. Show the equation you derived to your teacher.

6. Mars orbits the Sun at about 1.5 times the Earth's orbital radius. The Sun's mass is 1.99×10^{30} kg. Use the previous equation to calculate the orbital speed of Mars. Adjust the simulation to these values; see if the orbit of Mars is circular.

Part C – Kepler's Laws

Go to http://astro.unl.edu/naap/pos/animations/kepler.html To enable flash, go left of the URL & select "Not Secure" (or the *lock* symbol), go to **site settings**, go to **flash** and "allow" it. Refresh the website (Ctrl r).

1. ORBITAL OBSERVATIONS

In the lower right corner go to the **Visualization Options** and check on the first three boxes below (**show solar system orbits**, **show solar system planets** and **label the solar system orbits**). Select **start animation**. Using the Orbit Settings, you can also change the **semimajor axis**, **eccentricity** and the **animation rate**. Then make 4 distinct observations about orbits below.

(a)

(b)

(c)

(d)

2. VECTOR OBSERVATIONS

In the upper right hand corner select **reset**.

Newtonian Features:

In the lower left corner select **Newtonian Features** and check on the **vector** and **line** boxes for velocity and acceleration. Select **start animation**.

Acceleration:

(a) Where is the acceleration vector pointing at all times?

(b) At what point in the orbit is the acceleration vector the longest? (Refer to the data in the graph if needed.)

(c) Using the Law of Universal Gravitation, explain why.

Velocity:

(a) Describe the velocity vector's orientation to the orbit the planet is making.

(b) At which point in the orbit is the planet moving the fastest? The slowest?

(c) In the table below (and on the next page), you will draw and describe the orientation between the velocity and acceleration vectors, and explain at how the magnitude and direction of the velocity of the planet changes.

DECREASING VELOCITY	INCREASING VELOCITY
Draw a picture of the orbit and show the planet in a position where its velocity is decreasing. Label the vectors	Draw a picture of the orbit and show the planet in a position where its velocity is increasing. Label the vectors

At which point does the velocity vector switch from increasing to decreasing?	At which point does the velocity vector switch from decreasing to increasing?
Using the velocity and acceleration vectors explain why the planet slows down in its orbit	Using the velocity and acceleration vectors explain why the planet speeds up in its orbit

3. KEPLER'S 1ST LAW - Click on Kepler's 1st Law and check on all the boxes.

(a) What do you notice about $r_1 + r_2$ during the planet's orbit?

(b) Increase the eccentricity of the planet's orbit. Does this affect $r_1 + r_2$? What do you think Kepler's 1st Law states?

4. KEPLER'S 2ND LAW - Click on Kepler's 2nd Law and check **sweep continuously** and click **start sweeping.**

(a) Each sector of the ellipse corresponds to how much time? To how much area? (Use sound effect if needed.)

(b) Erase sweeps, and then adjust the size of the sweeps using the slider bar. What do you observe happening to the sectors?

(c) What do you think Kepler's 2nd Law states?

5. KEPLER'S 3RD LAW - Click **erase sweeps** then click on Kepler's 3rd Law

(a) "*a*" is the semimajor axis in AU (this is the Earth/Sun distance, called an Astronomical Unit). "*P*" is the period in years. In **Orbit Settings**, select different planets and hit OK. What is the ratio of P^2/a^3 for each planet? (Note: *P should* be *T* !)

(b) In **Orbit Settings** change the semimajor axis to a new setting that none of the planets have and calculate from that its period in years. Show work below.

(c) What happens to the period as the semimajor axis changes? What do you think Kepler's 3rd Law states?