Elementary Astronomy Science Simulation

Intended Grade Levels

Academically advanced students in grades 4–5

Materials

- Passage on orbits, gravity videos (see Learn section)
- "Gravity and Orbits" simulation website (see Do and Analyze section)
- Handout 1: Simulation Recording Sheet
- Handout 2: Sample Student Responses

Note to Families: The purpose of the simulation lesson is to help students understand how parts of the universe interact to create motion. We suggest that the following process be used:

- **Learn** more about gravity and orbits before doing the simulation.
- **Do** the "Gravity and Orbit" using the Simulation Recording Sheet to help guide thinking.
- **Analyze** the simulation using the Simulation Recording Sheet and discussion questions. (Note that sample student responses to the simulation sheet can be found on Handout 2.)
- **Extend** your child's learning by completing one or more projects in this section or visiting other websites provided for further learning.

Learn

This simulation lesson focuses on how gravity affects the structure of the universe, and includes a number of readings and videos that support student understanding of these advanced concepts.

- Have your student(s) read through the passage on orbits, focusing on the sections that contain information about Newton and Einstein. Discuss how Newton built on Kepler's ideas about the laws of motion, Newton's three laws, and how they apply to Earth and space. Ask your student(s) to define *gravity* in their own words.
- Have your student watch videos about gravity: "Gravity Compilation: Crash Course for Kids" and "Bill Nye Gravity." After watching the video, discuss the following questions (note that those with asterisks are only answered from the Bill Nye video):
- How can you prove that gravity on Earth is directed down? Create a model or illustration to prove this. (Students may use a ball or globe to show how people in the Southern or Northern Hemisphere stay on the Earth and don't float away, or they may provide examples of things falling to the ground.)
  - » Why do heavier and lighter things hit the ground at the same time in space? Why is it harder to illustrate this on Earth? (Think feather and bowling ball vs. bowling ball and apple.)

    - How does mass affect planetary orbit? What about distance?
    - *Why do trees grow up when Earth's gravity pulls things down? What does this have to do with mass?
    - *How does gravity contribute to spherical objects? Why aren't all things spherical?

- Discuss the following questions with students to ensure background understanding:
    - What is the difference between speed and velocity? (*Note*: Speed is distance over time in any direction, whereas velocity is speed in a certain direction.)
    - What is the difference between mass and weight? (Weight is the amount of gravitational pull on an object. Weights can be different based on the gravitational pull. Mass is the amount of matter contained in an object. Mass remains the same regardless of gravity.)
    - Why might these definitions matter in space? (These definitions matter in space because there is no up or down in space so directions matter, and mass is independent of gravity.)
    - How do gravity, mass, velocity, and distance impact planetary orbits? (Stronger gravity = faster orbit; more mass = stronger gravitational pull = faster orbit; more distance = less gravitational pull = slower orbit. Velocity is interesting because if velocity of the planet increases but the planet is the same distance away from a central object [e.g., the sun] that gives a wide elliptical orbit or possibly an unbound orbit.)

- Remind your student(s) that the Earth orbits the sun, and the moon orbits the Earth. Ask them how gravity impacts this orbit. Why do they think the moon orbits the Earth instead of flying off into space? What about the Earth around the sun? Why does it stay in orbit? Provide your student(s) with a sheet of paper and ask them to draw the sun, moon, and Earth in relationship to each other, and then use arrows and words to illustrate how they think gravity, mass, orbit, and velocity (direction and speed of orbit) interact.

Do and Analyze

- Explain that scientists create simulations and models to help them predict different scenarios. Astronomers use computer simulations to help them make predictions and create different scenarios or relationships to study because it is difficult to manipulate the solar system in real life.
- Provide students with a tutorial of the simulation "Gravity and Orbits," illustrating what each of the sidebar items means. (*Note*: A tutorial and additional lesson plans are provided on the simulation website. You can access the simulation easily, but the other items may require you to create an account. There was no fee at the time this lesson was created.)
- Allow your student(s) to experiment with the simulation by adjusting the numbers and types of items, turning gravity on and off, adjusting the mass of various objects, or physically adjusting the distance by dragging an object on screen closer or farther away from one another. You may also want to discuss the benefits and issues of using scale mode versus model mode. (Scale provides a more realistic view and allows you to see more of the simulation and the effects without distortion, but because of the distances when in scale more it is harder to view up close what is happening.)
- Distribute Handout 1: Simulation Recording Sheet for your student(s) to complete. (*Note*: We suggest that students use "Model Mode" with gravity turned on. As they continue to experiment, they may conduct simulations in scale mode if preferred. Make sure that students make an elliptical orbit at some point. One way is to use the sun-Earth model and increase the mass of the sun to 1.5 suns and

run the simulation. If you want students to see that planets can make their stars move, have students work in scale mode and make highly elliptical orbits. Remind your student(s) that real life orbits are more elliptical.)

Check for Understanding:

- Ask your student to explain how gravity affects the structure of the universe. Their explanation can take the form of a written paragraph, drawing, or any other medium through which their answer can be conveyed.

Extend

Ask your student(s) to complete one or more of the following:

- Research other planets in the galaxy and discuss how their distance from the sun affects their orbit. Create a model to illustrate your findings.
- Write new lyrics to a song of your choosing to teach someone younger (a sibling, cousin, someone in the neighborhood) about the relationship between orbit, gravity, distance, and mass.
- Create your own 3-minute newscast (like one of the videos you watched) to model how simulations can help scientists answer big questions and make predictions. Include facts and examples to illustrate your points.
- Explore other simulations about gravity at https://phet.colorado.edu. Design your own simulation and share your findings in a lab report.

Additional Resources

Additional online resources for students to explore if interested include:

- https://in-the-sky.org/skymap.php
- https://stellarium.org

Name: ______________________________ Date: ______________

Handout 1

Simulation Recording Sheet

Directions: Open the simulation and select “Model” mode. Select the sun and Earth view. Make sure “Gravity” is on, as well as the “Gravity Force” and “Velocity” arrows. It may be helpful to have “Path” and “Grid” turned on as well. You may explore scale mode as you become more familiar with the simulation.

1. **Mass, gravity, and orbit:** What happens to the orbit path and gravitational pull when the mass of objects in a planetary system increases? What about if it decreases?
   a. Create a simulation that shows what happens when the Earth’s mass changes but the sun’s mass stays at the mass of “Our Sun.”

Trial 1	
Sun/Star Mass Setting:	Earth/Planet Mass Setting:
Representation/Drawing and Interactions:	
Trial 2 (With Different Settings)	
Sun/Star Mass Setting:	Earth/Planet Mass Setting:
Representation/Drawing and Interactions:	

Handout 1, continued

b. Create a simulation that shows what happens when the sun's mass gets larger but Earth's mass is back at its original value.

Trial 1	
Sun/Star Mass Setting:	Earth/Planet Mass Setting:
Representation/Drawing and Interactions:	
Trial 2 (With Different Settings)	
Sun/Star Mass Setting:	Earth/Planet Mass Setting:
Representation/Drawing and Interactions:	

c. My conclusion about how mass and gravity are related to orbit:

Handout 1, continued

2. **Distance and gravity:** How do masses and distances in a planetary system affect orbit and gravitational pull?
   a. Create several simulations using the Sun-Earth system to show what happens when you change distance and mass. Only change one, at a time for each trial. Please leave the velocity of the planet at the default value. (*Note*: You can drag the planetary structures to a distance of your choice. Use the grid to help determine distances. You may try using the "Scale" model if you have difficulties with crashing into the sun.)

Trial 1	
Sun/Star Mass Setting:	Earth/Planet Mass Setting:
Distance of Sun to Earth:	
Representation/Drawing and Interactions:	

Trial 2 (With Different Settings)	
Sun/Star Mass Setting:	Earth/Planet Mass Setting:
Distance of Sun to Earth:	
Representation/Drawing and Interactions:	

Handout 1, continued

Trial 3 (With Different Settings)	
Sun/Star Mass Setting:	Earth/Planet Mass Setting:
Distance of Sun to Earth:	
Representation/Drawing and Interactions:	

b. My conclusion about how mass, distance, and gravity impact the orbit:

3. Using any of the available scenarios, design a research question and describe the simulation(s) you use to answer it. Use the back of this handout or a separate sheet of paper to write your response if necessary.

4. Select two of the questions below and use the computer simulation to model your response. Use the back of this handout or a separate sheet of paper to write your response if necessary.
   a. How does gravity impact planetary structures?
   b. What are some of the factors that impact gravity? How do you know?
   c. What happens to the orbits if there is no gravity?
   d. What would need to happen in order for the Earth to orbit the moon? For the moon to orbit the sun? Be specific.

Name: ______________________________ Date: ______________

Handout 2

Sample Student Responses

Sample student responses for Handout 3.1 are detailed below.

1. **Mass, gravity, and orbit:**
   a. Create a simulation that shows what happens when the Earth's mass changes but the sun's mass stays at the mass of "Our Sun."

Trial 1	
Sun/Star Mass Setting: **Always 1**	Earth/Planet Mass Setting: **1.01 to 2**

Representation/Drawing and Interactions:

Note: If you have a computer for every student, you can have one student have the "original" scenario (1 sun mass and 1 Earth mass) and another have the changing one, or you could put the "original" scenario on a projector screen.

Students may struggle slightly with this one because they do not really get to see anything happening and they think there should be something dramatic:

- *The orbital period of a heavier planet does not change (still 365 days—easily seen when you have "Grid" on).*
- *The orbital shape of a heavier planet does not change (still basically circular).*
- *The force of gravity arrows are bigger with a bigger planet and you can see the slight elliptical-ness of the orbit because the arrows get closer (and overlap) at different parts of the orbit—it's just easier to see with bigger arrows.*
- *The velocity arrow does the same thing it did before—it's always tangent to the orbit and is always about the same length.*

Note that no matter what mass students have the planet at (or orbiter if they use different scenarios given), they will not get much change in the orbit. It will still be circular and still be the same number of days because the mass of the central object (the star) is so much greater than the planet (the only exception is the Earth-moon scenario—it changes slightly, but they're closer in mass anyway). The equation that describes how orbiting bodies interact is Newton's version of Kepler's Third Law.

If your students are interested in more, here is a version of the equation:

P = orbital period
M_{star} = mass of the parent star
a = semi-major axis
M_{planet} = mass of the planet
G = the gravitational constant

$$P^2 = \frac{4\pi^2}{G}\frac{a^3}{\left(M_{star} + M_{planet}\right)}$$

Handout 2, continued

b. Create a simulation that shows what happens when the sun's mass gets larger but Earth's mass is back at its original value.

Trial 1	
Sun/Star Mass Setting: **1.1–2**	Earth/Planet Mass Setting: **Always 1**
Representation/Drawing and Interactions: *Note*: When using "Model Mode," if students set the star mass to 2.0, the planet will always crash into the star (can switch to scale mode or just decrease mass to 1.9). ■ *The planet starts making an elliptical orbit.* ■ *This elliptical orbit is faster than 365 days!* ■ *In this elliptical orbit, the velocity arrow changes size (faster when close, slower when far) but is still always tangent to the orbit.* ■ *In this elliptical orbit, the force of gravity arrows vary widely in size but are always pointed toward each other. They are biggest when the planet is closest to the star.* ■ *If you're doing this with the sun, Earth, moon scenario and make the sun's mass 2.0, the planet crashes into the sun, and the moon flies away!* ■ *The mass is deliberately chosen to be increased because then the planet is always in orbit and doesn't become "unbound."*	

c. My conclusion about how mass and gravity are related to orbit:
- *Orbits can be circular or elliptical.*
- *Mass of the orbiter doesn't seem to matter in the Sun-Earth case even though the force of gravity between the two objects changes (Note:* it does matter when the objects are more closely matched in mass—if you want to see it, look at the Earth-moon simulation).
- *When the mass of the star increases, it changes the shape of the orbit, which affects the speeds and force of gravity during the orbits—both will get bigger when closer to the star.*
- *Just because the gravitational force is greater, it doesn't mean that the orbit will change (even though you can increase the planet mass to increase the gravitational force, it doesn't really change the orbit shape).*

2. **Distance and gravity:**

   a. Create several simulations using the sun-Earth system to show what happens when you change distance and mass. Only change one value at a time for each trial. Please leave the velocity of the planet at the default value.

Handout 2, continued

<table>
<tr><th colspan="2">Trial 1</th></tr>
<tr><td>Sun/Star Mass Setting: 1 (Default)</td><td>Earth/Planet Mass Setting:</td></tr>
<tr><td colspan="2">Distance of Sun to Earth: Changes</td></tr>
<tr><td colspan="2">Representation/Drawing and Interactions:
In the default mass scenario, we just change the distance. Note that it is best to change the distance along the same grid line that the planet starts on because then the velocity is tangent to the orbit and one won’t crash into the sun as often.
If the planet is CLOSER than default:
■ gravitational force arrows get bigger.
■ the planet’s orbit will be elliptical—when elliptical, the gravity arrows and velocity arrow change (bigger when closer, smaller when farther).
■ the orbit is shorter than the original 365 days.
■ when in “Model Mode,” if move you closer than one grid line from default, then it will crash into sun on an elliptical orbit. The limit is about 0.8 squares away from the original start.

If the planet is FARTHER than default:
■ gravitational force arrows get smaller.
■ the planet’s orbit will be elliptical—when elliptical, the gravity arrows and velocity arrow change (bigger when closer, smaller when farther).
■ the orbit is longer than the original 365 days.
■ if you move farther than one grid line from default, then it will have an unbound (yet curved) orbit. The limit for our purposes is about 1.2 squares from the original start—you do have to zoom out to see the whole, orbit.</td></tr>
<tr><th colspan="2">Trial 2 (With Different Settings)</th></tr>
<tr><td>Sun/Star Mass Setting: Changes</td><td>Earth/Planet Mass Setting: Variable</td></tr>
<tr><td colspan="2">Distance of Sun to Earth: Changes</td></tr>
<tr><td colspan="2">Representation/Drawing and Interactions:
Students have already experimented with how changing the mass of the central star and how changing the mass of the planet affect the orbits, so they likely will start with the planet distance changed and then change the mass of one or the other.
■ Changing the planet mass won’t really do anything (as learned above).
■ Changing the star mass will change the orbit, and students do like trying to figure out if they can get a more circular orbit with a different distance and a different star mass (teachers may need to nudge students in that direction).

For instance, students can get basically circular orbits with these different settings (they may need to be zoomed all the way out to see full orbit):
■ Sun = 0.5 Suns, Planet = whatever, Distance = 1 square from center of star
■ Sun = 1.5 Suns, Planet = whatever, Distance = 3 squares from center of star
■ Sun = 2.0 Suns, Planet = whatever, Distance = 4 squares from center of star

Students should discuss the length of time to complete orbits in whatever scenario they chose.</td></tr>
</table>

b. My conclusion about how mass, distance, and gravity impact the orbit:
   - *Changing masses does the same as discussed in the previous scenarios (planet mass doesn't matter; star mass does).*
   - *Changing the distance has a huge effect on the shape of the orbit—you can make circular, elliptical, and unbound orbits.*
   - *Unbound orbits tend to happen with a smaller-massed star or a farther distance.*
   - *Elliptical orbits tend to happen with a higher massed star or a closer distance.*

3. Using any of the available scenarios, design a research question and describe the simulation(s) you use to answer it.

Students may need some assistance here. Some suggestions for prompting are:

- remind them there are different scenarios to use,
- do a comparison of the default values with changing various things,
- remind them of changing the velocity arrow ("How does changing the direction/size of the velocity change the orbit?"),
- do a comparison of Sun-Earth versus Earth-Moon scenarios, or
- see if they can get any scenarios that show the central object moving when the orbiter gets close (this happens especially in the Earth-Moon scenario).

4. Select two of the questions below and use the computer simulation to model your response:
   a. How does gravity impact planetary structures? *Gravity dictates how planetary structures move in orbits. The closer two objects get, the greater the gravitational pull and the faster the orbiting object will go.*
   b. What are some of the factors that impact gravity? How do you know? *Masses of the objects involved and the distance between them. I know because of the "Gravity Force" arrows shown in the model. When you change the mass of any of the objects, the "Gravity Force" arrows change size (get bigger when increase mass and smaller when decrease mass). When you change the distance between objects, the "Gravity Force" arrows change size (get bigger when get closer and smaller when farther apart).* Note that some students may say velocity but that's not actually something at affects the gravitational force—velocity does affect the shape of the orbit though.
   c. What happens to the orbits if there is no gravity? *There is no orbit if there is no gravity! The orbiter just keeps going in a straight line.*
   d. What would need to happen in order for the Earth to orbit the moon? For the moon to orbit the sun? Be specific. *So we can't actually show Earth orbiting the moon in any of the scenarios, but in order to do so, the moon would have to have more mass than Earth. For the moon to orbit the sun, it would have to be*

separated from Earth, enough so the moon wouldn't get pulled into Earth orbit by Earth's gravity.

Note: Some of your more precocious students may state they've heard that the moon is orbiting the sun, and Earth is just perturbing the moon's orbit. But really, the moon is orbiting Earth more than it's orbiting the sun (see this article for a nice discussion: http://blogs.discovermagazine.com/badastronomy/2008/09/29/the-moon-that-went-up-a-hill-but-came-down-a-planet/#.WVCy1h2Qy2w).