# Modeling Gravity

**GRADE RANGE**
**6th-8th**

**GROUP SIZE**
**Entire class (two groups for large class)**

**ACTIVE TIME**
**40 minutes**

**TOTAL TIME**
**40 minutes**

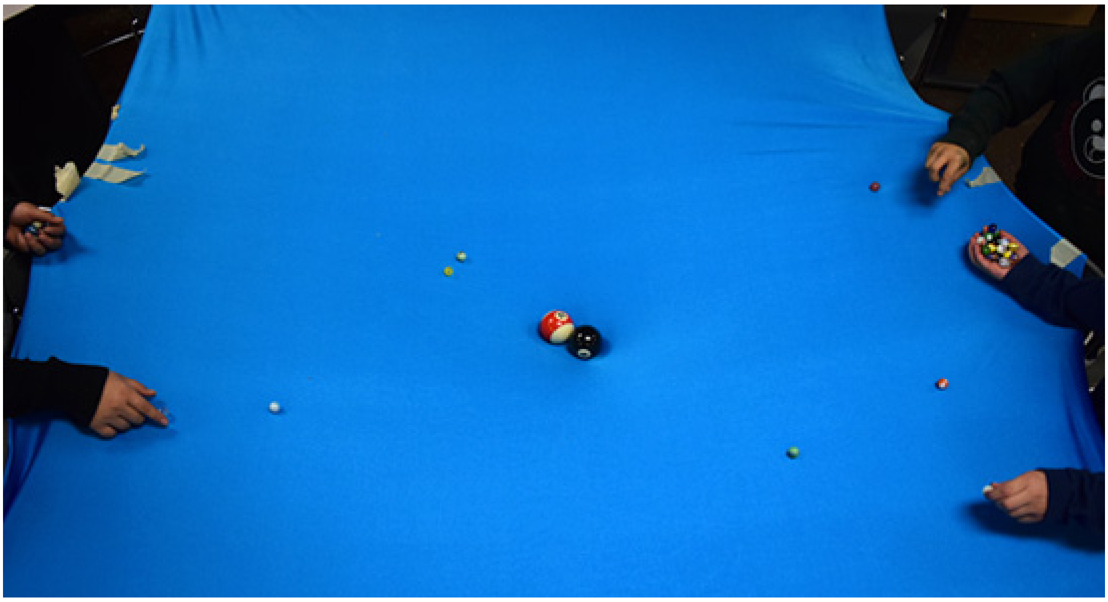
**AREA OF SCIENCE**
**Astronomy**
**Physics**

**KEY CONCEPTS**
**Mass, gravity, orbit**

**LEARNING OBJECTIVES**

- Explain why, on Earth, we can only feel gravity pulling us down, and not sideways towards other objects.
- Explain how gravity influences the motion of planets in our solar system.
- Understand the usefulness of models as well as their limitations.

**CREDITS**
**Ben Finio, PhD, Science Buddies**



## Overview

Why can we feel gravity pull us down towards the Earth, but not sideways towards other big objects like buildings? Why do the planets in our solar system orbit the sun instead of flying off into space? In this lesson plan your students will develop a model for gravity and use it to explore answers to these questions.

## NGSS Alignment

This lesson helps students prepare for these Next Generation Science Standards (http://www.nextgenscience.org/) Performance Expectations:

- **MS-PS2-4**. Construct and present arguments using evidence to support the claim that gravitational interactions are attractive and depend on the masses of interacting objects.
- **MS-ESS1-2**. Develop and use a model to describe the role of gravity in the motions within galaxies and the solar system.

This lesson focuses on these aspects of NGSS Three Dimensional Learning:

| Science & Engineering Practices | Disciplinary Core Ideas | Crosscutting Concepts |
|---|---|---|
| **Developing and Using Models.** Develop and use a model to describe phenomena. Evaluate limitations of a model for a proposed object or tool. | **PS2.B: Types of Interactions.** Gravitational forces are always attractive. There is a gravitational force between any two masses, but it is very small except when one or both of the objects have large mass—e.g., Earth and the sun.<br><br>**ESS1.B: Earth and the Solar System.** The solar system consists of the sun and a collection of objects, including planets, their moons, and asteroids that are held in orbit around the sun by its gravitational pull on them. | **Scale, Proportion and Quantity.** Time, space, and energy phenomena can be observed at various scales using models to study systems that are too large or too small.<br><br>**Systems and System Models.** Models can be used to represent systems and their interactions. Models are limited in that they only represent certain aspects of the system under study. |

## Materials

These materials will be enough to set up the activity for the entire class. For a large class, you may want to split into two groups, so you will need twice as many materials. The following supplies are available from Amazon.com (https://www.amazon.com?ie=UTF8&tag=sciencebuddie-20):

- Large sheet of stretchy fabric (https://www.amazon.com/gp/product/B01G9FU99Q?ie=UTF8&tag=sciencebuddie-20) (polyester/spandex/lycra etc.), approximately 2 yards by 2 yards.
- Marble set (https://www.amazon.com/gp/product/B01L8GHS8G?ie=UTF8&tag=sciencebuddie-20) that includes larger "shooter" marbles in addition to regular marbles.
- At least one pool ball, which you can purchase as a set (https://www.amazon.com/gp/product/B0060BCLB4?ie=UTF8&tag=sciencebuddie-20) or individually (https://www.amazon.com/s/ref=nb_sb_noss?url=search-alias%3Daps&field-keywords=cue+ball&ie=UTF8&tag=sciencebuddie-20). Other heavy, round objects like oranges or grapefruit will also work.
- Lots of duct tape or masking tape, *or* spring clamps (https://www.amazon.com/s/ref=nb_sb_noss_1?url=search-alias%3Daps&field-keywords=spring+clamps&ie=UTF8&tag=sciencebuddie-20) (at least twice as many as you have chairs). Make sure the jaws of the spring clamps open wide enough to clip onto the back of your chairs.
- 8–10 chairs (more if you have a bigger piece of fabric)



## Background Information for Teachers

*This section contains a quick review for teachers of the science and concepts covered in this lesson.*

In everyday language, we describe **gravity** as the thing that pulls us down toward the surface of the Earth. It's the reason behind the old saying "what goes up, must come down." Experiencing it becomes a regular part of our lives from an early age. For example, as a child you quickly learn that if you trip, you will fall down (and it will hurt!). If you drop a ball, it will fall down to the ground—not go sideways or up.

In classical (or "Newtonian") physics, we describe gravity as an attractive **force** that acts between *any* two objects with **mass** (Note: this lesson assumes your students are already familiar with the word mass and understand that it is different from weight. See the Additional Background (#additional-background) section for a reference on this topic.) However, in order for the gravitational force to be *noticeable*, at least one of the masses has to be extremely large. The average human has a mass of somewhere around 60 or 70 kilograms (kg). The Earth has a mass of about $5.97 \times 10^{24}$ kg. If you write out all the zeroes, that's 5,970,000,000,000,000,000,000,000 kg, about as much as 85 *sextillion* people (more than ten trillion times the world's population). This explains why we can only feel the force of gravity pulling us down towards the Earth, and not sideways towards other people; or even larger, heavier objects like cars or buildings. Their masses are much too small for you to notice the gravitational force they exert on you. The strength of the gravitational force between two objects also depends on the distance between them—the force gets stronger as the objects get closer together.

What about the rest of our **solar system**? It contains other planets that, like the Earth, all **orbit** around the Sun in nearly circular (technically elliptical) paths. What makes the planets orbit the Sun instead of either flying off into space, falling into the Sun, or staying motionless? Imaging cutting a rubber band, tying a ball to one end, and twirling it around, as shown in Figure 1. The force in the rubber band (tension) makes the ball move in a circle. If you cut the rubber band, there is no more force to keep the ball moving in a circle, and it will fly off in a straight line. If you stop twirling the ball, the rubber band will pull it back in toward your hand. The Earth's motion around the Sun is similar (Figure 1). If there was no gravitational force between the Earth and Sun, the Earth would just fly off into space. If the Earth had no sideways motion, it would be pulled into the Sun by the gravitational force.

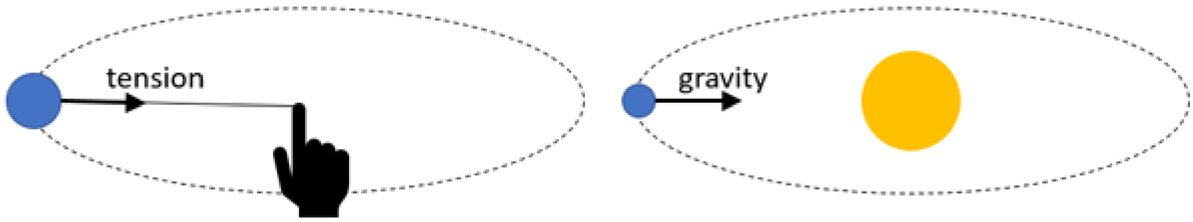



**Figure 1.** The motion of a twirling ball attached to a rubber band (left) is similar to the motion of the planets in our solar system around the Sun (right). (diagram not to scale)

In this lesson plan, your students will create a model for gravity and our solar system using pool balls, marbles, and a sheet of stretchy fabric. The following video provides an excellent demonstration of the activity, and we recommend that you watch it before you start*:

https://www.youtube.com/watch?v=MTY1Kje0yLg (https://www.youtube.com/watch?v=MTY1Kje0yLg)

***Note:** the video starts out by discussing "warped (or curved) spacetime," which is a concept from Einstein's theory of relativity. This is a different explanation for gravity that can be rather difficult to grasp (even for adults with scientific backgrounds!). For purposes of this lesson plan, you can stick with the Newtonian explanation for gravity as a force that acts between two objects with mass. See the Variations (#variations) section for more resources about the relativistic explanation.

## Prep Work (15 minutes)

- Arrange 8–10 chairs in a circle.
- Stretch the sheet of fabric over the backs of the chairs and secure it using tape or clamps.
- Adjust the tightness of the sheet by moving the chairs farther apart or closer together as needed. Try to avoid wrinkles or dips in the fabric. Make sure that if you put a pool ball in the middle of the sheet, it sags down enough that marbles will roll towards it if you place them at the edge. You may need to re-adjust the sheet throughout the course of the activity.

## Additional Background

- Newton's Law of Universal Gravitation (http://www.physicsclassroom.com/class/circles/Lesson-3/Newton-s-Law-of-Universal-Gravitation), The Physics Classroom
- Why do the planets go around the Sun? (https://spaceplace.nasa.gov/review/dr-marc-solar-system/planet-orbits.html), NASA
- Solar System (https://spaceplace.nasa.gov/menu/solar-system/), NASA
- Our Solar System (https://solarsystem.nasa.gov/planets/solarsystem/), NASA
- Mass of All the People on Earth (https://hypertextbook.com/facts/2006/DanielTouger.shtml), The Physics Factbook
- Confusion of Mass and Weight (http://www.physicsclassroom.com/Class/newtlaws/U2L2b.cfm#mass), The Physics Classroom

## Lesson Flow

Engage (#engage) → Explore (#explore) → Reflect (#reflect) → Make Career Connections (#career) → Variations (#variations)

## Engage (5 minutes)

1. To start the lesson, throw a ball or other object up in the air and then catch it.

   ? *Why does the ball come back down after I throw it up? Why doesn't it keep going up? Why does it fall down and not sideways?*

   The ball comes back down, instead of continuing to go up or in a different direction, because gravity pulls it down towards the middle of the Earth.

2. Explain that in this lesson, the class will use a model to explore how gravity works. A model is something that represents a system that scientists want to study (for example, maybe the students have built model bridges out of toothpicks).

   ? *What is the point of using a model? Why not just study the "real thing" directly?*

   Models can be particularly useful to study systems that are too small to see or hold, too large to see all at once, or too large to fit in a classroom. For example, we can use telescopes to look at the planets in our solar system one at a time. But, you might not have access to a telescope at your school, and even if you did, you couldn't see all the planets at once. A model makes it easier to study the solar system in our classroom. See if your students can think of other examples (e.g. they may have seen models of cells or atoms in science class).

## Explore (30 minutes)

1. Have the class gather around the sheet of stretchy fabric. Explain that it will serve as the basis for your model.
2. Place a single pool ball in the middle of the fabric.
3. Give each student several marbles. Tell them *not* to put the marbles on the sheet until you ask them to. Throughout the activity, you will ask the students to do different things with the marbles, one at a time.
4. Ask the class what will happen if some students, at different places around the perimeter, place their marbles on the edge of the fabric one at a time and release them. Then try it and observe what happens. You should see that the marbles roll towards the pool ball in the middle of the sheet.
5. Ask some other students to place their marbles closer to the middle of the sheet, instead of at the edge, and release them. Observe what happens. You should see that these marbles start rolling faster than the ones that started at the edge of the sheet.
6. Now ask a few students to try reaching out and gently rolling a marble towards themselves (away from the pool ball), then let go. Then stop to discuss what you have observed so far.

   ? *What did we just observe? How does this system act as a model of gravity?*

   We saw that the smaller marbles rolled towards, or were "attracted," to the large pool ball in the middle of the sheet. Even if the marbles were rolled outwards, they turned around and were pulled back towards the pool ball. The closer they got to the pool ball, the faster they rolled. This is similar to how objects on the surface of the Earth, like people, are pulled down by gravity, and objects that are thrown up come back down.

7. Remove the pool ball from the middle of the sheet, and make sure the sheet is pulled taut. Ask the class to predict what will happen if two students on opposite sides of the sheet each place a single marble near the edge. Then try it and observe what happens. You will most likely see that the marbles stay in place instead of rolling towards each other—they are not attracted to each other at all. (Note: depending on how tightly your sheet is pulled, the marbles might roll towards each other very slowly, this is OK. They should not be attracted to each other as strongly as the marble was to the pool ball).
8. Finally, put the pool ball back in the middle of the sheet. Ask several students at different points around the perimeter to release marbles near the edge of the fabric simultaneously, and observe what happens. Again, pause to discuss your observations as a class.

   ? *What did we observe this time? What happens when we change the mass of objects in our model? behavior of our model?*

   We saw that the smaller, lighter marbles were not attracted towards each other. They were only attracted towards the bigger, heavier pool ball. In order for two things to be pulled towards each other in our model, one of them has to be very heavy.

   ? *What does this have to do with the question we asked at the beginning of class? Particularly, why do we feel gravity pulling us towards the center of the Earth, but not towards other objects?*

   In order for the gravitational attraction between two objects to be noticeable, at least one of them has to have a very large mass. This explains why, when you drop an object, it is pulled down towards the center of the Earth, and not towards other objects—even very heavy ones like cars or buildings. The Earth's mass is *much* larger than the mass of those other objects.

9. Now tell the students that we will "zoom out" when thinking about gravity. Don't just think about how gravity affects everyday objects on the surface of the Earth. Think about how it affects the motion of planets in our solar system. Note that you need to be careful with your use of the words up/down/sideways, since they do not have the same meaning for someone standing on the surface of the Earth as they do when looking at the entire solar system (e.g. "up" to you is "down" to someone on the other side of the planet, and both could be "sideways" to someone who is looking at all the planets in a horizontal plane).

    *How could our model physically represent the solar system?*

    The pool ball in the middle could represent the Sun and the marbles could be the planets.

    *How do planets move in our solar system? How could we use our model to demonstrate this?*

    The planets move around our Sun in nearly circular (elliptical) paths called orbits. We could demonstrate this by trying to get marbles (planets) to "orbit" the pool ball (the Sun).

10. Let each student try this with a couple marbles (one at a time). They will need to figure out how to roll the marbles to get them to orbit (hint: try rolling the marbles instead of just dropping them, but don't roll them directly towards the pool ball!). You will start to accumulate a lot of marbles in the middle of the sheet, so gather them up periodically. Can you get a marble to "orbit" the pool ball, like a planet orbits the Sun? (you may need to demonstrate if your students have trouble).

    *What did we observe this time?*

    You probably observed that if you did not roll a marble fast enough, it would quickly roll towards the pool ball in the middle of the sheet. If you rolled it *too* fast, then it would shoot off the edge of the sheet. However, if you rolled it just right, you could get it to "orbit" the pool ball, spiraling around it a few times before it eventually rolled into the middle.

    *Using these results from our model, can you explain why planets in our solar system orbit around the Sun instead of falling into it or flying off into space?*

    In order to get a marble to orbit the pool ball, two different effects had to balance. The marble's sideways speed had to be just enough to offset the inward pull from the pool ball. Too fast, and it would fly off the sheet; too slow, and it would be pulled into the middle. The orbit of each planet works in a similar manner. They have enough sideways speed to prevent the Sun from pulling them in, but the Sun's pull is also strong enough to prevent them from flying off into space— the two effects are perfectly balanced. If your students are confused about use of the word "sideways" here, see Figure 2 and draw a copy of it on the chalkboard.

11. Allow students to continue experimenting with orbits for the remaining time. See the Variations (#variations) section for many other ideas you can try.

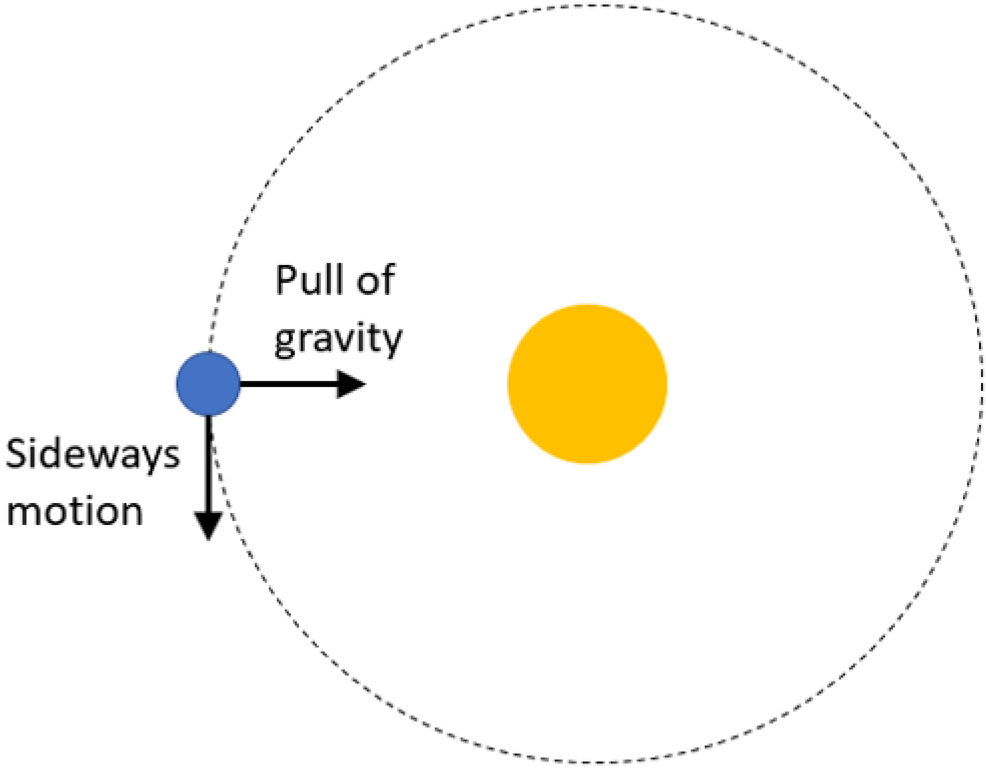



**Figure 2.** A "top" view of a planet orbiting the Sun (as if you were looking down on the sheet from above in this activity). The "sideways" motion of the planet perfectly balances the inward pull of gravity from the Sun, resulting in an elliptical (but nearly circular) orbit. If the planet did not have enough sideways speed, it would be pulled into the Sun by gravity. If there was no gravity pulling it towards the Sun, it would fly off into space in a straight line.

## Reflect (10 minutes)

Briefly review how your model represents gravity and our solar system:

- Smaller masses (marbles) are attracted to a large mass (the pool ball) when placed on the stretchy sheet, but the small masses are not attracted to each other. This represents how relatively small masses (people, cars, buildings, etc.) are pulled toward the center of the Earth by gravity, but not pulled toward each other.
- We can make the marbles orbit the pool ball, representing how the planets in our solar system orbit the Sun. This demonstrates how two effects (sideways motion of the planets and inward pull of gravity from the Sun) need to be balanced, to prevent the planets from flying off into space or falling into the Sun.

However, models are never 100% accurate —they don't completely represent "the real thing." End the lesson with a discussion of some of the limitations of the model and how it could be improved.

? *What are some limitations or inaccuracies of our model? How is it different from the actual solar system? How could we improve it?*

There are several limitations of this model your students might notice:

- The model has a lot of friction between the marbles and the fabric sheet, which causes the marbles to gradually lose energy and slow down. Even if you can get a good "orbit" going, eventually the marble will spiral towards the center and stop moving, probably after a few seconds. Conversely, the planets in our solar system have been orbiting the Sun for *billions* of years.
- The model is not to scale. For example, a pool ball only has a mass about 30 times more than a marble, but the Sun has a mass over *300,000* times bigger than the Earth's. See the Variations (#variations) section for more information about scale.

## Make Career Connections

Discussing or reading about these careers can help students make important connections between the in-class lesson and STEM job opportunities in the real world.

### Astronomer (http://www.sciencebuddies.org/science-engineering-careers/earth-physical-sciences/astronomer)

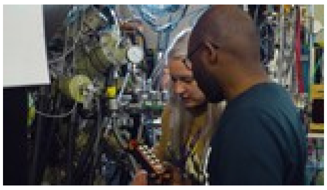
**Career Profile**

(http://www.sciencebuddies.org/science-engineering-careers/earth-physical-sciences/astronomer)

Astronomers study our universe and everything in it—planets, moons, stars, asteroids, comets, galaxies, solar systems—and how gravity affects all of their motion. If you had fun experimenting with orbiting marbles, you should learn more about astronomy. Read more (http://www.sciencebuddies.org/science-engineering-careers/earth-physical-sciences/astronomer)

### Physicist *In Demand!* (http://www.sciencebuddies.org/science-engineering-careers/earth-physical-sciences/physicist)

**Career Profile**



(http://www.sciencebuddies.org/science-engineering-careers/earth-physical-sciences/physicist)

Physicists study the origins of our universe and the physical laws that govern it. Where did the stars and planets come from? What causes gravity? Why does gravity depend on mass? If you want to seek out answers to these questions, you might enjoy being a physicist! Read more (http://www.sciencebuddies.org/science-engineering-careers/earth-physical-sciences/physicist)

## Lesson Plan Variations

- As shown in this video (https://youtu.be/MTY1Kje0yLg), there are many other demonstrations you can do using this setup, including:
  - Try throwing two fistfuls of marbles in opposite directions on the sheet. What happens? Eventually you should see that all the remaining marbles orbit in the same direction.
  - Roll a larger "shooter" marble and a regular marble next to each other on the sheet. It takes some practice, but you should be able to get the smaller marble to orbit the larger marble, while both orbit the pool ball. This models the Earth/Moon/Sun system, where the Moon orbits the Earth while both orbit the Sun.
  - Place two large masses on the sheet, offset from the center (use non-rounded objects so they won't roll towards each other—so we're cheating a little bit). See if you can get a marble to do a "figure 8" orbit around both masses.
  - Place a pole under the sheet to push part of it up, simulating an "antigravity" effect (marbles will roll away from that point instead of towards it).
- Let the students calculate what is needed to make their model to scale with the solar system. For example, given the diameter of the pool ball which represents the Sun, what should the diameter of the marble be to accurately represent the Earth? How far away should the marble be from the pool ball to represent the Earth's orbit? Different groups can do the calculation for different planets. This video (https://youtu.be/Kj4524AAZdE) shows a scale model of the solar system constructed over several *miles* of empty desert.
- This online simulator (https://phet.colorado.edu/en/simulation/gravity-and-orbits) lets you simulate orbits while changing parameters like the mass of the Sun or the Earth's distance from the Sun.
- This lesson provides some useful connections to Newton's laws of motion:
  - Newton's first law (an object in motion remains in motion unless acted upon by an outside force). The force of gravity is required to keep planets moving in elliptical orbits—otherwise, with no external forces acting on

    them, they would fly off into space in a straight line.
    - Newton's second (force equals mass times acceleration, F=ma) and third (for every action there is an equal and opposite reaction) laws. The gravitational force between two objects is felt by *each* object. In other words, while gravity pulls you down towards the Earth, technically you also pull the Earth "up" (Newton's third law). However, the Earth's mass is much larger than yours, so for the same force, the resulting change in motion (acceleration) is much smaller (Newton's second law: if *F* stays the same and *m* gets bigger, than *a* must get smaller). That is why nobody else can notice the Earth moving when you jump.
- As explained in the teacher background (#teacherprep) section, this lesson plan can also be used to introduce Einstein's theory of general relativity. In general relativity, the three-dimensional space we live in is interwoven with a fourth dimension, time, to form a "fabric" called spacetime. Massive objects cause spacetime to curve, and this curvature influences the motion of other nearby objects, just like gravity does in "classical" or "Newtonian" physics. In this version of the lesson, the sheet represents a three-dimensional version of spacetime (two spatial dimensions with time as a third dimension). This simplified model allows us to easily see the curvature of the sheet, since it is impossible for the human brain to visualize the curvature of three-dimensional space. This can be a difficult concept to grasp, but there are some helpful resources and videos available online, like this one (https://youtu.be/R7V3koyL7Mc), as well as books for non-scientists like Astrophysics for People in a Hurry (https://www.amazon.com/Astrophysics-People-Hurry-deGrasse-Tyson/dp/0393609391?ie=UTF8&tag=sciencebuddie-20) by Neil deGrasse Tyson and A Brief History of Time (https://www.amazon.com/Illustrated-Brief-History-Updated-Expanded/dp/0553103741?ie=UTF8&tag=sciencebuddie-20) by Stephen Hawking.

---