**Unit Essential Question:** *What forces keep the parts of our solar system together and how can we use this knowledge to plot a telescope route through space?*

**Introduction**

In the last task, students made a model of the solar system so they could begin to visualize a potential telescope route. However, the parts of the solar system are not stationary…they move! In this task, students will examine what factors affect the motions within the solar system—specifically gravity. Because students have already learned about the concept of gravity in Unit 1, they should be able to build off this prior knowledge and apply it to the solar system as a whole. By using simulation models created from actual solar system data, students will gain a clear picture of how gravity helped to create the solar system and continues to maintain its structure and motion. This will continue to help them develop their telescope route as they consider how gravity might affect the telescope’s journey through the solar system.

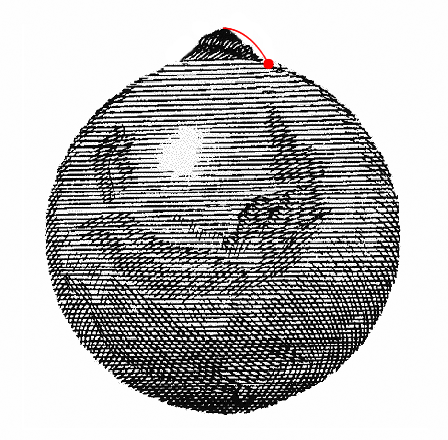
**Alignment Table**

|  |  |  |  |
| --- | --- | --- | --- |
| **Performance Expectations** | **Science and Engineering Practices** | **Disciplinary Core Ideas** | **Crosscutting Concepts** |
| **MS-ESS1-2 Develop and use a model to describe the role of gravity in the motions within galaxies and the solar system.**[Clarification Statement: Emphasis for the model is on gravity as the force that holds together the solar system and Milky Way galaxy and controls orbital motions within them. Examples of models can be physical (such as the analogy of distance along a football field or computer visualizations of elliptical orbits) or conceptual (such as mathematical proportions relative to the size of familiar objects such as students' school or state).] [*Assessment Boundary: Assessment does not include Kepler’s Laws of orbital motion or the apparent retrograde motion of the planets as viewed from Earth.*] | **Developing and Using Models**  * Develop and use a model to describe phenomena. | **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. * The solar system appears to have formed from a disk of dust and gas, drawn together by gravity. * All positions of objects and the directions of forces and motions must be described in an arbitrarily chosen reference frame and arbitrarily chosen units of size. In order to share information with other people, these choices must also be shared. | **Systems and System Models**  * Models can be used to represent systems and their interactions. |
| **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.** [Clarification Statement: Examples of evidence for arguments could include data generated from simulations or digital tools; and charts displaying mass, strength of interaction, distance from the Sun, and orbital periods of objects within the solar system.] [Assessment Boundary: Assessment does not include Newton’s Law of Gravitation or Kepler’s Laws. | **Engaging in Argument from Evidence**   * Construct and present oral and written arguments supported by empirical evidence and scientific reasoning to support or refute an explanation or a model for a phenomenon or a solution to a problem. | **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. | **Systems and System Models**  Models can be used to represent systems and their interactions—such as inputs, processes and outputs—and energy and matter flows within systems. |
| **Supplementary Science and Engineering Practices**   * Using Mathematics and Computational Thinking   + Apply mathematical concepts and/or processes (such as ratio, rate, percent, basic operations, and simple algebra) to scientific and engineering questions and problems. | | | |
| **Equity and Groupwork**   * Groups work together to act out models or manipulate simulation models. * Gather and discuss information collaboratively to use in individual writing. | | | |
| **Language**   * Discuss gravity models. * Synthesize multiple sources of information. * Describe visual representations in writing. * Write an argument for the effect of mass on gravity and the potential impacts of this on a telescope route. | | | |

**Learning Goals:**

This learning task asks students to use models to describe the role of gravity in the solar system and engage in an argument for the effect of mass on gravity. More specifically, students will:

* Engage in a thought experiment that hypothesizes gravity as the key force in planetary motion.
* Use models to explore gravity’s role in the solar system.
* Explain the role of gravity in the motions within the solar system.
* Calculate the rate of falling objects on different planets, dependent on mass.
* Support an argument that the mass of planets affects gravity and thus would impact the telescope route.
* Apply knowledge of gravity and mass to plot a potential route for the new telescope.

**Content Background for Teachers**

In Unit 1, students moved past their understanding of gravity as merely the force that keeps them on the ground and causes objects to fall. They learned that gravity is a force that attracts objects towards any other bodies with mass. This means that gravity does not just pertain to Earth; it also applies to other planets in the solar system.

In this task, students take this understanding from Unit 1 and push it a little bit farther. They have already been introduced through data and simulations that the mass of an object affects the gravitational pull of that object in a proportional relationship. This task asks them to revisit this idea and the associated pieces of evidence, but contextualized within this unit’s culminating project. More specifically, they will end the task by thinking about why understanding the masses and gravitational pulls of different planets is important to charting a safe telescope route through the solar system.

However, just as importantly, students are also now examining the general role of gravity in the motions of bodies in our solar system. This begins with the formation of the solar system. As discussed in the background section of the Lift-Off Task, the solar system was formed when a dense cloud of gas and dust collapsed, forming a swirling disk of material. At the center, it was gravity that pulled more and more material in, causing chemical reactions that released the tons of energy, which birthed the sun. The rest of the matter clumped together, forming larger objects like planets and moons. The rest are part of the asteroid belt.

Because the sun used up 99% of the matter in this event, the sun has the largest mass. This means the sun has the most gravitational pull, explaining why all the planets in the solar system orbit the sun and not the other way around. Each planet orbits the sun because of a balance between the speed in which the planet is moving and gravitational pull of the sun. Each planet is moving at a different speed, but each planet’s distance from the sun also varies, causing a different gravitational pull. This balance is what keeps planets in orbits around the sun. The following is an excellent short video explaining how our solar system structure and motions are possible: https://www.youtube.com/watch?v=uhS8K4gFu4s.

For more background in the form of data and computer simulations, see the resources provided to students in their student guide. Also, if students are struggling with basic physics concepts from last unit, refer back to Unit 1 resources and use them to review content with students as needed throughout this task.

**Academic Vocabulary**

* Speed
* Force
* Gravity
* Orbit
* Mass
* Model
* Rate

**Time Needed (Based on 45-Minute Periods)**

5 Days

* Engage: 1 period
* Explore: 1 period
* Explain: 1 period
* Elaborate: 1 period
* Evaluate and Reflection: 1 period

**Materials**

* Unit 2, Task 3 Student Version

Engage

* Computers or Tablets

Explore

* Computers or Tablets
* Rope or string

Explain

* Projector (per class) OR Tablets (per student)
* Stronger Clearer Handout (Optional)

Elaborate

* Labels (1 per group)
* Marker

Evaluate

* Project Organizer Handout

**Instructions**

**Engage**

1. Introduce Task 3: In the last task, you made a model of the entire solar system, allowing you to begin to see the different routes the new telescope may take when it is launched. Think about what you were still wondering about at the end of the last task (look back if you need to). What questions do you still have?
   * Before you pass out their student guide, give students time to reflect individually or with a partner about the questions they recorded at the end of the last task. Share a few of these out as a class, using facilitating questions to guide students toward questions that relate to this task.
2. Transition to Task 3: However, the parts of the solar system are not stationary…they move! In this task, you will explore what factors affect motion within our solar system.
   * Now pass out their Task 3 student guide.
3. Here, students are presented with Isaac Newton’s thought experiment, which is known as “Newton’s Cannonball.” He used it to hypothesize that the force of gravity was universal and is the key force for planetary motion.
   * The first question for students describes Newton’s thought experiment. In this thought experiment, Newton visualizes a cannon on top of a very high mountain. He explains that without gravity, the cannonball should logically follow a straight line away from Earth, in the direction it was fired. Students are asked to use their own prior knowledge to hypothesize why this doesn’t happen.
4. Students are then given a computer simulation that was made based on “Newton’s Cannonball”.

* This offers preliminary practice of **Developing and Using Models** to describe the phenomenon of gravity—a science and engineering practice that they will use throughout this task. This activity thus also introduces students to the crosscutting concept for this task, **Systems and System Models**, as students experience how a model can be used to represent a system and its interactions (in this case focusing on speed and gravity).
  + Students should experiment with the simulation provided in pairs, using the prompts on their student guide.
    - Through this simulation, students should discover that when an object does not have enough speed, the force of gravity pulls the object back down to Earth. When an object has too much speed, it is able to get out of Earth’s gravitational field and move away from Earth. At a specific speed, the speed the moon orbits the Earth, students will find that gravity keeps the object in an orbit around the Earth. This is what simulates planetary motion around the sun.
  + Recommended: Ask students to share out their predictions and observations of the simulation. When calling on pairs of students to share their description of a scenario, it is recommended that you call on pairs using equity sticks. This encourages more equitable participation in class-wide discussions.

1. The last question serves to connect their observations from the thought experiment to the solar system as a whole, as well as previous learning about gravity.
   * In Unit 1, they learned about gravity as an attractive force dependent on mass. This question asks students to brainstorm what object in our solar system has the largest gravitational pull and how they think this explains the way objects move in the solar system.
   * Based on the simulation and learning from Unit 1, students should be able to identify the sun as the object with the most mass and gravitational pull. This gravitational pull is the reason why all the planets orbit the sun.
   * Students may discuss and respond to this question in pairs. These questions do not necessarily need to be debriefed class-wide, since they offer a bridge into the next section of the task for continued exploration.

**Explore**

1. Read the first few paragraphs under the *Explore* header on their student guides aloud. This will transition from the *Engage* to the *Explore* and will set the context for this activity. In groups, students will be exploring models to describe the motion of celestial bodies in the solar system.
   * In this section of the task, students are honing their skill of **Using Models**, as they manipulate both physical and computer-based models to describe the phenomenon of how objects move in the solar system. By doing so, they are also emphasizing the crosscutting concept of **Systems and System Models** by considering not just the parts of the solar system that are interacting but also how energy and matter flow within this system to make it function the way it does. Within these models, students will be exploring the interactions between planets and the sun as they relate to speed, mass, and gravitational force.
2. Assign roles to each group. You may use whatever roles you prefer. We recommend the use of the Materials Manager, Facilitator, Harmonizer, and Recorder.
   * Ask the Facilitator to read the directions, make sure everyone understands the task, and facilitate group discussion.
   * Ask the Materials Manager to handle any resources (including computer simulations) needed to complete the task.
   * Ask the Harmonizer to make sure that everyone contributes their ideas and that everyone’s voice is heard.
   * Ask the Recorder to make sure the group is recording their responses to the discussion questions for each model.
3. Students are exploring three models, two of which are computer simulations that require computers or tablets.
   * These would be best completed in sequential order as they ask students to build on understandings from the previous models: first, students examine formation of the solar system, then a model of planetary orbit, then a factor that affects solar system movement.
     + Optional: Conduct the first as a whole-class discussion. This both models the process and saves time during the task.
   * As they explore the models, students should be discussing and recording responses to the discussion questions in their student guide. The purpose of these questions is to guide students towards understanding the role of gravity in the motions of celestial bodies.
4. Sample student responses to the discussion questions are shown below:

* Model 1: Simulating the Formation of Our Solar System
  + What appears to be happening? *Most the matter seems to be getting absorbed into the central body. Other surrounding particles swirl in an orbit, some combining with others to form larger bodies that continue to orbit the central body in one direction.*
  + What does this model imply as the main reason all of the planets orbit the sun? *All of the planets seem to be pulled towards the central body (the sun) by some invisible force (gravity). This causes them to remain in orbit around the sun.*
* Model 2: Simulating an Orbit with Our Bodies
  + When the rope becomes taut, what happens? *The “planet” person starts to move around the “sun” person.*
  + How does the pull of the rope affect the direction and motion (orbit) of the “planet”? *It makes it orbit around the sun instead of in the direction it originally began*.
  + What do you think the force of the rope pulling on the “planet” represents? *The sun.*
* Model 3: Simulating A Factor That Affects Solar System Movement
  + How does the mass of the Sun impact the orbit of the Earth? Use an example from the simulation. *The mass of the sun keeps Earth in orbit. For example, if the mass of the Sun is increased, the pull will be too strong and Earth will be destroyed in collision with the Sun.*
  + How does the mass of the Earth affect the Moon? Use an example from the simulation. *The mass of the Earth keeps the moon in orbit. For example, if the mass of the Earth is decreased, the pull will not be enough to keep the moon in orbit and it will float away.*
  + We learned in the last unit that mass affects gravitational force. But how does this work in the solar system? Use examples from the simulation to explain how mass affects gravitational force in the solar system. *Mass affects how much gravitational pull a body will have…the greater the mass, the greater the gravitational force. This is what keeps planets in orbit around the sun and moons in orbit around planets. If you change the mass, you risk changing the orbits of different bodies in the solar system.*
  + \*Note: This is a revisit of a simulation from Unit 1, so students should be familiar with how to use this simulation.

**Explain**

1. This section of the task asks students to take what they learned about gravity and motion from all the models and combine it all into one explanation of the solar system as a whole.
2. To lend context and meaning to the task, show the following video that simulates the entire solar system: <https://www.youtube.com/watch?v=9R5P9Y9gRYY>. Emphasize to students that this was created from authentic data on the solar system. Again, students are practicing the science and engineering practice of **Using Models** to describe the phenomenon of the motion of celestial bodies. By describing parts and interactions of the solar system, they are continuing to emphasize the crosscutting concept of **Systems and System Models**. Student explanations should use evidence from the models and discuss the following:

* The orbits of the planets,
  + Including what they are all orbiting around
  + And why they are all in orbit
* Any factors that affect these orbits

1. We recommend students complete this individually as it can serve as a good option for formative assessment. However, students can and should use their group responses to any previous discussion questions to help them formulate an explanation.
   * Once complete, collect student work to identify trends in students’ ability to describe a model using evidence OR accurately explain gravity’s role in the motion of celestial bodies. See “How to Use This Curriculum” for strategies on utilizing formative assessment data to provide feedback to students and inform classroom instruction.
2. Optional: You may want to use the academic language tool introduced in Unit 1—“Stronger Clearer”—to help students strengthen and clarify language and ideas used to describe the solar system model. As they talk to peers, they can build from others’ ideas and borrow language from their partners. This would serve to help solidify basic concepts of gravity and orbits before moving forward.

* This activity can be set up in different ways, but we recommend having students form two concentric circles, so that partners are facing each other.
* A potential guide for students is provided in the box below. As in Unit 1, walk students through the process using the instructions provided on the guide below.

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| **Stronger Clearer:** The following activity is to help you and your peers strengthen and clarify your description of the simulated solar system. Each time you talk to a new partner, you can build from their ideas and borrow the language of previous partners.  Instructions:   1. Record ideas and language you liked from your own description in the chart below to help you think about what you will say to your partner (1 minute). 2. Stand in front of your assigned partner. Turn your papers upside down, so that you are not looking at it while speaking. Take turns sharing your description aloud (1 minute per person).    1. After each partner shares, the listener may ask clarifying questions. Have a discussion about strengths and suggestions (1 minute per person). 3. You will then have time to record any ideas or language that will make your description stronger and clearer (1 minute). 4. When your teacher calls time, each of you in the inner circle will move one space to the right, so you have a new partner. Repeat Steps 2 and 3.  |  |  | | --- | --- | |  | Ideas and Language I like from the model description | | Me |  | | Partner 1 |  | | Partner 2 |  |   Individually, return to your student guide to write a revised description of the simulated solar system, borrowing from the ideas and language of your peers. Remember that while it is encouraged to learn from others, it is **not** okay to copy directly! |

**Elaborate**

1. This section of the task takes student experience with the last model simulation and connects it to actual data—data they have seen before in their exploration of gravity in Unit 1.
   * This data table shows how mass affects gravitational pull, specifically within the context of our solar system.
2. Again, assign roles to each group. We recommend mixing up the group role assignments from the Explore.

1. Ask students to re-examine the data table in their student guides. In this activity, students will be using the science and engineering practice of **Using** **Mathematics and Computational Thinking**; they apply the mathematical concept of rate to answer the scientific question of whether gravitational attraction depends on the masses of the different planets.
   * While the math is very simple, we recommend you ask students to show their process for at least one rate before using mental math for the rest.
   * As students do so, you may want to check that their mathematical process is correct before letting them repeat their process for all the other rates.
2. Students then return to their solar system model from Task 2 and add some more details that they will need in order to plan their telescope route. Here, they continue the process of **Developing Models**, this time to describe how gravity plays a role in our solar system.
   * Provide each group with a label. Each group will label their original assigned planet with its mass and the rate it takes a rock to fall on that planet.
3. Once students have added to their solar system model, students will argue why adding this information to the solar system model makes it more useful for planning the best route for the new telescope. This asks students to use the skill of **Engaging in Arguments From Evidence**, as they use data evidence and scientific reasoning to support an improved model for our solar system.
   * By engaging in this argument, students will have to use data to argue that mass affects gravitational attraction in the solar system and this must be considered as the telescope passes different planets in its journey through space.
   * Students should use data from the data table and likely Model 3 as evidence to justify their argument.
   * Again, you may wish to have students complete this question individually, so it may be used as a formative assessment. Once complete, collect student work to identify trends in students’ ability to support an argument with evidence OR accurately explain how gravitational attraction depends on the mass of objects. See “How to Use This Curriculum” for strategies on utilizing formative assessment data to provide feedback to students and inform classroom instruction.

|  |  |
| --- | --- |
| Sample Argument | Optional Sentence Stems |
| Adding the masses of all the planets makes our model more useful because we now know that the mass of an object affects its gravitational attraction. Gravity can pull objects, like the new telescope, towards planets that have a lot of mass, so it is essential we know about the masses of the planets. Model 3 provided evidence of this: when I increased the mass of the Earth, the gravitational pull increased, causing the moon to collide with Earth. We do not want this to happen with the new telescope. The data table also showed us that as planet mass increases, the rate of the falling rock increases, meaning gravity increases. For example, the rate for the Earth is 22.17 m/s, while Mercury, which has smaller mass, is only 13.62 m/s. We would have to stay farther away from Earth than Mercury to avoid the pull of gravity. | * Adding the masses of all the planets makes our model more useful because… * In order to plan the best route for the new telescope, we need to know… * If mass \_\_\_\_, then gravitational pull \_\_\_. * Model 3 provided evidence of this when… * The data table showed us that… * For example… * This means that the route for the new telescope would have to… |

1. Return to the whole-class concept map from the Lift-Off Task.

* In small groups, have students brainstorm new concepts and new connections that they have learned in this task, as well as any new questions that have come up for them. Then have groups share these aloud in a class-wide discussion and add to the class concept map. The use of equity sticks is encouraged for more equitable participation in class-wide discussions (See “How To Use This Curriculum” for more details).
  + Some facilitating questions to ask students are: What new ideas/concepts do you want to add to the map? What connections do you want to add or change? What is your reason for that addition/revision? What connections can we make between the questions/ideas already on the map? What new questions do you have about the phenomenon?
  + Draw circles around each question and boxes around each concept.
  + Write connector words to describe connections between the concept boxes.
  + For this task, students may begin to connect some of their previous question circles to concept boxes about the following: the creation of our solar system, the role of gravity in how objects move in our solar system, and the relationship between mass and gravity.
* Have students analyze the additions to the class concept map for as many examples of this task’s crosscutting concept as they can find. Once a student has identified the crosscutting concept, you can trace the circle in the corresponding color (decided on in the Lift-Off task). We recommend asking students to share key words that helped them identify the crosscutting concept for that concept or question. Some identifying words students might look for are:
  + **Systems and Systems Models**. These could be phrases such as, “is a part of” “connects to,” “interacts with,” “is made up of,” “works together with,” etc.
* Once again, the purpose of this concept map is to facilitate generation of student questions, promote language development, and support understanding of the science content throughout the unit. Allowing students to ask their own questions and use their own words to make meaning of the concepts will not only help them make deep connections about science content, but will also help their oral and written language development.

**Evaluate: Connecting to the Culminating Project**

1. Students independently complete the Task 3 section of the Unit 2 Project Organizer in class. Revisions can be done for homework, depending upon student’s needs and/or class scheduling.
2. Students have developed a model of the solar system and will now begin to brainstorm the best route a new telescope should take through space. The student prompt is as follows: Even though you already have the layout of the solar system, you now know that these objects don’t just remain stationary…they move because of gravity! Based on what you’ve learned about mass, gravity, and motion, draw a potential route for the new telescope on the sketch you made in the Task 2 section. Then in this section:
   * Explain why the solar system is laid out the way it is: what is the role of gravity in the solar system?
   * Use your model and data from the task to explain how gravity might affect the new telescope as it moves through space.
   * Justify your route by explaining why you stay farther away from some planets, but not others.

**Reflection**

1. At the end of the task, ask students to reflect on what they have learned over the course of this task by answering the following three questions in their student guide:

* At the beginning of this task, you used a thought experiment to think about why planets might move the way they do in our solar system. Look back at your responses: after learning everything you have about gravity, how would you add to or revise your responses? Use information from the models to improve your explanation of Newton’s thought experiment.
  + In this task, we focused on the crosscutting concept of **Systems and System Models**: models can be used to represent systems and their interactions. Where did you examples of **Systems and System Models** in this task?
  + Now that you have used and developed models to describe the movement of celestial bodies in our solar system, what questions do you still have?

1. There are no right answers, but encourage students to look back at their student guides and their class concept map. They should not change their initial responses, but rather use this reflection space to add to their ideas and questions based on what they have learned through this task. By generating more of their own questions, students continue to engage in sense-making of the phenomenon and gathering knowledge and skills for their final projects.

**Assessment**

1. You may collect students’ Project Organizer and assess using:

* *Criteria of your choice.* We recommend using the 3-Dimensional Assessment matrix at the beginning of this document to inform your criteria.
* This can be a formative tool to periodically look for trends in student understanding after the completion of a task. You can then use this formative data to inform any re-teaching as necessary.

1. You may also give students time to make revisions with one of the two options:

* Students may make changes to their Project Organizer according to your comments OR
* Ask students to exchange Project Organizers with a partner and give partners 5 minutes to give written feedback. Then allow students time to make changes to their work according to the feedback.