2. Force and Motion

This segment will focus on the relationships between force and motion by connecting gravitational force to free fall acceleration (instructional segment one). It then connects to other forces.

Student Science Performance

Grade or course: 9-12 Physics	**Title:** Force and Motion
Topic: Force and Motion	

Performance Expectation for GSE:

SP2. Obtain, evaluate, and communicate information about how forces affect the motion of objects.

a. Construct an explanation based on evidence using Newton's Laws of how forces affect the acceleration of a body.
   - Explain and predict the motion of a body in absence of a force and when forces are applied using Newton's 1st Law (principle of inertia).
   - Calculate the acceleration for an object using Newton's 2nd Law, including situations where multiple forces act together.
   - Identify the pair of equal and opposite forces between two interacting bodies and relate their magnitudes and directions using Newton's 3rd Law.

b. Develop and use a model of a Free Body Diagram to represent the forces acting on an object (both equilibrium and non-equilibrium).

c. Use mathematical representations to calculate magnitudes and vector components for typical forces including gravitational force, normal force, friction forces, tension forces, and spring forces.

d. Plan and carry out an investigation to gather evidence to identify the force or force component responsible for causing an object to move along a circular path.
   - Calculate the magnitude of centripetal acceleration.

e. Develop and use a model to describe the mathematical relationship between mass, distance, and force as expressed by Newton's Universal Law of Gravitation.

Performance Expectations for Instruction:

1. Explain how mass affects the rate of acceleration of an object with only force acting on it (free fall)
2. Develop Free Body Diagrams for equilibrium and non-equilibrium scenarios.
3. Resolve forces and calculate forces for tension, friction, spring, and circular motion.

Additional notes on student supports

Materials

Bean bags of different masses or balls of different masses, but the same size.
Meter sticks, measuring tapes, rulers
Stopwatches (or student phones to use as stopwatches)

Students will continuously obtain, evaluate, and communicate information. This is not a linear process. Students will communicate through writing and discussions to allow for formative assessment. This benefits the teacher, student, and whole group to guide instruction to clarify misconceptions or extend content.

Engaging Learners	**Phenomenon** Teacher Demo: Crumpled piece of paper and a flat piece of paper fall at different rates; a ball and a crumpled piece of paper appear to fall at the same rate.
	Obtaining 1. Students make and record observations about the factors affecting the falling object.

	2. Think-pair-share within lab groups of the type of factors to investigate. *Some ideas may include:* *How does shape affect the rate of fall?* *How does mass affect how long it takes for the object to fall?* 3. Students will design and implement an investigation to answer the question: **How are mass and acceleration related during free fall motion?**
	Evaluating Before proceeding with the investigation, the teacher will verify that student investigation designs are safe. *Teachers should not evaluate the lab proposal for accuracy of process, but for safety.*
	Communicating Students communicate intended procedures with experiment sheet, including diagrams.
Exploring *Exploring Phenomena*	*Obtaining* Students conduct investigations of the phenomenon. Guide students in gathering and organizing data in way that answers the guiding question. Challenge students to make conclusion based on their findings. This relates back to the kinematics instructional segment and is an excellent bridge between discussing motion in terms of velocity and acceleration and beginning to analyze what causes the acceleration. Students will still need to be able to analyze and explain motion in terms of displacement, velocity, and acceleration. *Teacher Notes: Multiple items could be used during this investigation; the goal is to have different masses of objects that have the same shape. For example, multiple sizes of bouncy balls/golf balls/etc could be used or bean bags. ("Bean bags" could be created ahead of time by filling sandwich baggies with dried beans, rice, gravel, etc. If plastic baggies are used, it may be useful to tape the bag closed in addition to the normal closure.)*
	Communicating 1. After collecting data, students will whiteboard their results using the CER framework. *Students may need help creating their whiteboard and it may be useful to show an image for the structure of the whiteboard sections/template to have consistency in formatting for ease of evaluating ideas and content instead of aesthetics.* 2. Students will engage in a gallery walk of whiteboards. ● *One student per group will remain with the whiteboard as the other group members rotate around the classroom. At each board, the stationary student should present their work and the rotating students will critique methodology, content, conclusions.* ● *Have students switch roles (change students staying at the whiteboard and rotating) to allow all students the opportunity to present information and discuss with other groups.*

	• *Remind students that critique in science is about evaluating ideas and not individuals. One way to assist students with this is to have them leave behind at least one positive note for the whole group and one way to improve their research, conclusions, or methodology ("glow and grow" notes).* 3. After the gallery walk, students will meet with their group again and discuss feedback from the gallery walk. *This could be information directly related to their individual group or related information learned from other groups' work. Students may conclude that more data needs to be collected before continuing.*
	Evaluating After students meet with their groups, the students will engage in sustained, silent writing answering questions about: • Background, relevant physics that relates to the guiding question. • Methodology *(What did they do and why?)* • Evidence *(What data did they collect and why? Why is this evidence appropriate?)* • Conclusions/claims *(What is their claim? Does it answer the guiding question? How does their evidence support their claim and how does that help answer the guiding question?)* • *This individual writing should be less than one or two pages and can be used as an individual assessment piece.*
	Formative Assessment of Student Learning
Explaining Finalizing Model	*Obtaining* For various situations explored during the lab and others, students develop Free Body Diagrams. Have students in groups come up with a real-life scenario of multiple forces acting on an object (equilibrium and non-equilibrium). For the scenario, students create a free body diagram. Students swap diagrams with other groups and try and describe what type of scenario exists for the object.
	Evaluating/Communicating On their own, students should be able to produce and interpret Free Body Diagrams. In addition, solving force problems should be included in the evaluation.
Elaborating Applying Model to Solve a Problems	**Phenomenon** Various phenomena exist to elaborate on force and motion; the following investigation scenarios could be set up with different lab stations. Students could use experiment design sheets for each lab station and use the same framework as above to analyze claims from other lab groups.
	Obtaining/Evaluating/Communicating **Phenomenon: Elevators use counterweights to help control the acceleration of the elevator car.** ○ Guiding question: How does the mass in the pulley system affect the acceleration of the system? ▪ Show students images of elevators and counterweights. ▪ Students will investigate the development of elevators and why counterweights are needed.

	▪ To set up this investigation, students would need access to a pulley, string, and various masses to hang at the end of the string. A ring stand or other stable base can be used to support the pulley. **Phenomenon: Lubricants are used to alter the friction force between materials.** o Students will design and carry out an investigation to determine the coefficient of friction between different materials. ▪ Students can model the behavior using a ramp and different blocks on the ramp and looking at the angle when the object starts to slide to determine coefficient of friction. Some different block surfaces to test: sandpaper, felt, wood, aluminum foil, plastic, etc. ▪ If force sensors are available, students can determine the frictional force between metal plates when different oils (cooking oil, motor oil, baby oil, etc.) are spread thinly between the plates. o Facilitate a discussion with students about friction in everyday life. Talking points could include: ▪ High friction surfaces that are beneficial. ▪ High friction surfaces that are not beneficial. ▪ How/when lubricating materials are used to mitigate the effects of negative frictional effects. **Students will design and carry out an investigation to determine the spring constant of various springs.** o Guiding question: How can spring constant be determined for various springs? ▪ Multiple springs should be available for students to test. Some of the springs can have the same spring constants. ▪ Note: The same springs will be used during the instructional segment "Energy & Momentum" to analyze the simple harmonic motion and period of springs. **Students will use a simulation to develop and analyze Free Body Diagrams.** o Guiding question: how can equilibrium and non-equilibrium scenarios be described using Free Body Diagrams? ▪ PhET simulation: Forces and Motion (Attribution: PhET Interactive Simulations, University of Colorado Boulder; https://phet.colorado.edu) ▪ Optional student lab sheet

	Students will design and implement an investigation to analyze the factors affecting the centripetal force on a swinging mass. ○ Guiding Question: What factors affect the centripetal force on a spinning, horizontal mass? ▪ Students will be swinging objects around their heads; after introducing the materials available, the teacher should facilitate a discussion of appropriate safety during the lab (plenty of space around each lab group will help avoid accidents). ▪ To create the apparatus, the following materials are needed: string, hollow, rigid tube (this could be pvc pipe or pen cartridge), small masses, stopwatches. Various experiment designs and alternative equipment can be found online. **Students will design and implement an investigation to analyze the relationship among the factors that influence gravitational force. This investigation can introduce students to the relationship between mass, distance, and gravitational field strength. Students will explore pattern & scale, proportion, and quantity.** ○ Guiding Question: How does the mass of objects and the distance between them affect the gravitational force between two objects? ▪ PhET Simulation: Gravity Force Lab ▪ Students should communicate their data using graphs; an appropriate graph would be gravitational force vs. distance.
Evaluation	***Assessment of Student Learning***
	Students are assessed throughout unit with lab results, whiteboard sharing sessions, calculations, and free body diagrams. The word association game is an option to formatively assess how well students can understand and describe forces and associated variables.
SEP, CCC, DCI	**Science Essentials**
Science and Engineering Practices	• Constructing explanations • Developing and using models • Using mathematics and computational thinking • Planning and carrying out investigations
Crosscutting Concepts	• Cause and effect • Systems and system models • Scale, proportion, and quantity
Disciplinary Core Ideas	From *A Framework for K-12 Science Education*: • PS2A: Forces and Motion • PS2B: Types of Interactions • PS2C: Stability and Instability in Physical Systems • PS3c: Relationship between Energy and Forces.

<u>**Additional Supports for struggling learners:**</u>

The following supports are suggestions for this lesson and are not the only options to support students in the classroom. These supports target students that struggle with science material, this lesson or a previous lesson. These are generalized supports and do not take the place of IEP accommodations as required by each student's Individualized Education Program.

General supports for the following categories:

Reading:	Writing:	Math:
1. Provide reading support by reading aloud or doing partner reads 2. Have the teacher model what they are thinking when reading the text 3. Annotate the text with students so that they may refer to it as they work through the lab	1. The teacher can provide a sentence starter for the students. 2. The teacher can give students an audience to write to (i.e. Write a letter to your sibling explaining this topic). 3. The teacher can provide constructive feedback during the writing process to help students understand the expectations.	1. Provide calculators as needed. 2. Provide graph paper as needed.

Supports for this specific lesson if needed:

Performance expectations for instruction:

1. The teacher should provide information to students in various formats to reach as many students as possible.
2. The students should be given adequate time to complete each part of the lesson.
3. The students should be allowed to express their knowledge in various formats.
4. The teacher should be sure to provide multiple ways for the students to communicate their knowledge of the material.

Engage:

1. The teacher should consider doing the demo more than once to allow students to make observations.
2. The teacher should consider having students record and discuss the observations.
3. The teacher should use intentional and flexible grouping to group students. Best practice is to use data to drive student groupings.
4. The teacher should consider providing students with an organizer for the designing of the investigation.
5. The teacher may need to use guiding questions to assist students in designing their investigations.
6. The teacher should consider showing students materials that can be used in the investigation prior to students beginning their design.
7. Students may need additional time to complete their investigation design.

Exploring:

1. The teacher should consider providing students with a data sheet to use to collect data.
2. The teacher should consider providing students with a sentence starter to assist students with the writing pieces of the assignment.
3. The teacher should consider providing students with an example of the white board that students can view as they set up their presentation board.
4. The teacher should be sure to provide multiple ways for the students to communicate their knowledge of the material. These formats could include drawing, writing, diagraming or verbally explaining.
5. The teacher should consider providing students with multiple formats to share their work. These formats could include the use of technology, gallery walks or presentations.
6. The teacher should provide a set of clear and consistent guidelines for students to provide peer feedback. These guidelines should ensure that students give respectful, useful and constructive feedback.
7. The teacher should consider having students revise their work.
8. Students may need additional time to complete their assignment.
9. The teacher may need to chunk the silent sustained writing, provide sentence starters and use guiding questions to assist students in the writing process.

Explaining:

1. The teacher should consider showing students free body diagrams and explain the purpose.
2. The teacher should consider explicitly show students how to construct a free body diagram. Then have students practice along with you prior to having students make free body diagrams individually.
3. The teacher should consider providing students with a list of real-world scenarios or brainstorm a list of scenarios where multiple forces act on an object. This will give students a starting point for making their own free body diagrams.
4. The teacher should consider a formative assessment. This will identify students that need re-teaching, reviewing or enriching.

Elaborating:

1. The teacher should use intentional and flexible grouping to group students. Best practice is to use data to drive student groupings.
2. The teacher should be sure that students a provided ample time at each station to make observations and collect data.
3. The teacher should consider providing students with an organizer to record data and observations.
4. The teacher should consider using guiding questions to assist students working at the stations.
5. The teacher should consider a formative assessment to identify students that need reviewing, re-teaching or enriching.

Evaluating:

1. The teacher should consider giving students multiple formats to communicate their knowledge. This could be drawing, writing or designing a presentation.
2. Students may need additional time to complete their assignments.

Experiment Design Sheet

Guiding Question:
Initial Claim:
Procedure and Materials:
Experiment Diagram:
Measurements and Data:

Return to Instructional Segment

Claim—Evidence—Reasoning

Guiding Questions: How are mass and acceleration related during free fall motion?
Claim:
Evidence:
Reasoning:

Return to Instructional Segment

Free Body Diagram Simulation

Directions: Read the background section and then use the Phet simulation here to complete the questions. Answer on your own paper. (Attribution: PhET Interactive Simulations, University of Colorado Boulder; https://phet.colorado.edu)

Background: A free Body diagram, or force diagram, helps us approach and solve physics problems by representing forces. There are a few guidelines about force diagrams:

a. An object is usually simplified by just drawing a box or circle to represent whatever object we are studying. You do not need to spend time accurately drawing the object.
b. Each individual force is represented with an arrow; it starts on the object and points in the direction that it acts. Only forces get arrows—nothing else.
c. Each force arrow (vector) must be labeled.
d. Every force that is acting on the object must be included in the force diagram

Practice: Draw a force diagram for the following situation:

A box is pulled to the right across a flat surface. Construct the diagram and check your result with your partner.

Lab questions:

Net Force

1. Open the Net Force simulation. Before adding any people to the tug-of-war, draw a force diagram of the stationary cart.
2. Add players to make the red team win. Draw a free body diagram.
3. Describe how to make a tie with a different number of players from the red and blue teams.
4. Start the sim with two small red players only, hit go. After the cart starts to move, add the large blue player. What happens? Draw a force diagram of the situation. Also, construct a position-time graph for this entire trial.
5. Make each side have equal players in order for the forces to be balanced. Hit go. Remove one of the red players, wait for the cart to start moving, and then put the same player back. Describe the motion of the cart. If the forces are balanced, why does the cart continue to move?

Motion

6. Open the Motion tab. Check all boxes in the upper right, so values are displayed.
7. Apply a large force to the girl. Draw two force diagrams for this part: one diagram while the girl is being pushed and another for after the pusher lets go. After the pusher lets go, what happens to the speed? Explain why this happens.
8. Load the skateboard with two crates and the fridge. Apply a constant 50 N force by clicking the right arrow once. The pusher will remain. What is different about the speed now compared to when just the girl was on? Draw a force diagram of this situation.
9. How does this part of the sim illustrate the law of inertia?

Friction

10. Open the friction tab. Check all boxes in the upper right so values are displayed. Apply a constant force of 50 N to the crate without changing the friction. Describe what happens. Draw a force diagram.
11. What is the minimum amount of force needed to move the crate?

12. Apply the maximum amount of force to the crate. Draw a force diagram that represents the crate after the pusher lets go. Use the diagram to explain why the crate stops moving after several seconds.
13. Explain how the force of friction changes as different objects are tested.
14. Explain, using a force diagram, why the fridge cannot be moved with the same amount of friction as before?
15. Reduce the friction to zero and then apply the maximum force to the fridge. Draw a force diagram.

Acceleration

16. Open the acceleration tab. Check all boxes in the upper right so values are displayed. Apply a constant 50 N force to a crate.
17. How does the acceleration value change?
18. Explain how you can get the acceleration to be zero, but have the crate still moving. Draw a force diagram of this.
19. As the crate is moving with friction, describe the relationship between the applied force, friction force, and the sum of forces.
20. Is it possible to have a non-zero value for acceleration and the sum of forces be zero? Explain.

Return to Instructional Segment

Physics Forces Word Association Game:

Directions: Get into groups of 4. You and a partner are playing against the other pair in the group. Sit across from your partner and next to someone from the other team.

You and your partner are playing a physics word association game —a game where you are not allowed to mention certain terms. On the card, there is a term that you are trying to get your partner to say. You are **not** allowed to use the words listed below it. The other team monitors. For each 30 seconds, your goal is to get your partner to guess as many terms as possible. If you mention one of the forbidden words, that card is disqualified.

Force Push Pull Mass Newton Law apply	**Inertia** 1st law Newton Rest Motion Mass	**Mass** Kilogram Accelerate Newton Weight Property	**Newton** Law Force Acceleration Inertia Famous Scientist Unit
Acceleration Force Mass Law Velocity Change	**Newton's 3rd Law** Action Reaction Pairs Force Equal opposite	**Newton's 2nd Law** Acceleration Mass Force Equation	**Newton's 1st Law** Inertia Object Rest Motion force
Friction Force Slows Stop Brake Oppose	**Static Friction** Rest Oppose Push Pull Force	**Kinetic Friction** Force Motion Moving Oppose Push Pull	**Coefficient of Friction** Surface Slide Rough Smooth Unitless
Net Force Total Sum Add Subtract Combination	**Vector** Scalar Direction Velocity Force Quantity	**Normal Force** Perpendicular Surface Away Up Object	**Spring Force** Elastic Stretch Coil Compress

Force of Gravity Attraction Earth Planet G $9.81 m/s^2$ Fall pull	**Equilibrium** Balance Net Force Zero	**Centripetal Force** Circular Around Center Acceleration spin	**Component** Force Resolve Vector Part Angle
$9.81 m/s^2$ Gravity Acceleration G Constant F=ma	**Non-equilibrium** Not balanced Accelerate Force Moving	**Action/Reaction Pair** Force Newton 3^{rd} Law Equal opposite	**Tension** Force Cable String Pull object
Spring Constant K Spring Force Stretch compress	**Law of Gravitation** Newton Gravity Force Distance Mass planet	**Centripetal Acceleration** Force Center Circle Circular	**Tangent** Circle Path Centripetal Direction perpendicular
F = ma Equation 1^{st} law Newton Calculate Force Mass acceleration	**Weight** Pounds Force Gravity Scale Newtons	**Tangential Velocity** Acceleration Centripetal Circle Circular Speed motion	

Return to Instructional Segment