Middle School Topics Model Course III – Bundle 1
Forces and Energy

This is the first bundle of the Middle School Topics Model Course III. Each bundle has connections to the other bundles in the course, as shown in the Course Flowchart.

Bundle 1 Question: This bundle is assembled to address the question "How do objects affect other objects?"

Summary

The bundle organizes performance expectations with a focus on helping students build understanding of *how interactions between objects can be explained and predicted*. Instruction developed from this bundle should always maintain the three-dimensional nature of the standards, and is not limited to the practices and concepts directly linked with any of the bundle performance expectations.

Connections between bundle DCIs

This course includes a study of forces and energy, helping to prepare students to explain phenomena in later units on waves, mechanisms of diversity, and Earth's place in the Universe. Motion energy is called kinetic energy and it is proportional to the mass of the moving object and grows with the square of its speed (PS3.A as in MS-PS3-1). A system of objects may also contain stored energy, depending on their relative positions (PS3.A as in MS-PS3-2). When two objects interact, each one exerts a force on the other that can cause energy to be transferred to or from the object (PS3.C as in MS-PS3-2).

The motion of an object is determined by the sum of the forces acting on it; if the total force on the object is not zero, its motion will change (PS2.A as in MS-PS2-2). For any pair of interacting objects, the force exerted by the first object on the second object is equal in strength to the force that the second object exerts on the first but in the opposite direction (PS2.A as in MS-PS2-1) and all the positions of objects and the directions of forces and motions must be described in an arbitrarily chosen reference frame and units of size (PS2.A as in MS-PS2-2).

Forces that act at a distance, such as electric, magnetic, and gravitational forces, can be explained by fields that extend through space (PS2.B as in MS-PS2-5). Electric and magnetic forces can be attractive or repulsive, and their sizes depend on the magnitudes of the charges, currents, or magnetic strengths involved and on the distances between the interacting objects (PS2.B as in MS-PS2-3). 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 (PS2.B as in MS-PS2-4) such as in our solar system. The solar system consists of the sun and a collection of objects that are held in orbit around the sun by its gravitational pull on them (ESS1.B as in MS-ESS1-2). Earth and its solar system formed from a disk of dust and gas, drawn together by gravity, (ESS1.B as in MS-ESS1-2) and is part of the Milky Way galaxy (ESS1.A as in MS-ESS1-2).

The engineering design idea that the more precisely a design task's criteria and constraints can be defined, the more likely it is that the designed solution will be successful (ETS1.A as in MS-ETS1-1) could connect to many different science ideas, such as how kinetic energy is proportional to the mass of the moving object and grows with the square of its speed (PS3.A as in MS-PS3-1) or to the idea that electric and magnetic forces can be attractive or repulsive (PS2.B as in MS-PS2-3). Connections could be made through an engineering design task such as precisely defining the criteria and constraints for the relationship between size of motor vehicles and the distance needed to stop, for the relationship between size of an airplane and its speed, or for the design of an electromagnetic motor in a wind turbine or in a car.

Bundle Science and Engineering Practices

Instruction leading to this bundle of PEs will help students build toward proficiency in elements of the practices of asking questions (MS-PS2-3); defining problems (MS-ETS1-1); developing and using models (MS-PS3-2 and MS-ESS1-2); planning and conducting investigations (MS-PS2-2 and MS-PS2-5); analyzing and interpreting data (MS-PS3-1); constructing explanations and designing solutions (MS-PS2-1); and engaging in argumentation (MS-PS2-4). Many other practice elements can be used in instruction.

Bundle Crosscutting Concepts
Instruction leading to this bundle of PEs will help students build toward proficiency in elements of the crosscutting concepts of Cause and Effect (MS-PS2-3 and MS-PS2-5); Scale, Proportion, and Quantity (MS-PS3-1); Systems and System Models (MS-PS2-1, MS-PS2-4, MS-PS3-2, and MS-ESS1-2); and Stability and Change (MS-PS2-2). Many other crosscutting concept elements can be used in instruction.

All instruction should be three-dimensional.

Performance Expectations MS-ESS1-2 is partially assessable.	MS-PS2-1. **Apply Newton's Third Law to design a solution to a problem involving the motion of two colliding objects.*** [Clarification Statement: Examples of practical problems could include the impact of collisions between two cars, between a car and stationary objects, and between a meteor and a space vehicle.] [Assessment Boundary: Assessment is limited to vertical or horizontal interactions in one dimension.] MS-PS2-2. **Plan an investigation to provide evidence that the change in an object's motion depends on the sum of the forces on the object and the mass of the object.** [Clarification Statement: Emphasis is on balanced (Newton's First Law) and unbalanced forces in a system, qualitative comparisons of forces, mass and changes in motion (Newton's Second Law), frame of reference, and specification of units.] [Assessment Boundary: Assessment is limited to forces and changes in motion in one-dimension in an inertial reference frame and to change in one variable at a time. Assessment does not include the use of trigonometry.] MS-PS2-3. **Ask questions about data to determine the factors that affect the strength of electric and magnetic forces.** [Clarification Statement: Examples of devices that use electric and magnetic forces could include electromagnets, electric motors, or generators. Examples of data could include the effect of the number of turns of wire on the strength of an electromagnet, or the effect of increasing the number or strength of magnets on the speed of an electric motor.] [Assessment Boundary: Assessment about questions that require quantitative answers is limited to proportional reasoning and algebraic thinking.] 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.] MS-PS2-5. **Conduct an investigation and evaluate the experimental design to provide evidence that fields exist between objects exerting forces on each other even though the objects are not in contact.** [Clarification Statement: Examples of this phenomenon could include the interactions of magnets, electrically-charged strips of tape, and electrically-charged pith balls. Examples of investigations could include first-hand experiences or simulations.] [Assessment Boundary: Assessment is limited to electric and magnetic fields, and limited to qualitative evidence for the existence of fields.] MS-PS3-1. **Construct and interpret graphical displays of data to describe the relationships of kinetic energy to the mass of an object and to the speed of an object.** [Clarification Statement: Emphasis is on descriptive relationships between kinetic energy and mass separately from kinetic energy and speed. Examples could include riding a bicycle at different speeds, rolling different sizes of rocks downhill, and getting hit by a wiffle ball versus a tennis ball.] MS-PS3-2. **Develop a model to describe that when the arrangement of objects interacting at a distance changes, different amounts of potential energy are stored in the system.** [Clarification Statement: Emphasis is on relative amounts of potential energy, not on calculations of potential energy. Examples of objects within systems interacting at varying distances could include: the Earth and either a roller coaster cart at varying positions on a hill or objects at varying heights on shelves, changing the direction/orientation of a magnet, and a balloon with static electrical charge being brought closer to a classmate's hair. Examples of models could include representations, diagrams, pictures, and written descriptions of systems.] [Assessment Boundary: Assessment is limited to two objects and electric, magnetic, and gravitational interactions.]

Performance Expectations (Continued)	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.] MS-ETS1-1. **Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.**
Example Phenomena	Iron filings make a pattern surrounding magnets. A ball released higher on a hill can push objects farther than can a ball released from lower on the hill.
Additional Practices Building to the PEs	**Asking Questions and Defining Problems** • Ask questions that arise from careful observation of phenomena, models, or unexpected results, to clarify and/or seek additional information. Students could *ask questions to seek additional information* [about how] ***the motion of an object is determined by the sum of the forces acting on it***. MS-PS2-2 **Developing and Using Models** • Develop or modify a model—based on evidence—to match what happens if a variable or component of a system is changed. Students could *modify a model based on* [new] *evidence* [about how] ***the force exerted by*** [one] ***object on a second object is equal in strength to the force that the second object exerts on the first.*** MS-PS2-1 **Planning and Carrying Out Investigations** • Evaluate the accuracy of various methods for collecting data. Students could *evaluate the accuracy of various methods for collecting data* [about how] ***when two objects interact, each one exerts a force on the other that can cause energy to be transferred to or from the object***. MS-PS3-2 **Analyzing and Interpreting Data** • Analyze and interpret data to provide evidence for phenomena. Students could *analyze and interpret data to provide evidence* [that the] ***sizes of electric and magnetic forces depend on the magnitudes of the charges, currents, or magnetic strengths involved and on the distances between the interacting objects***. MS-PS2-3 **Using Mathematical 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. Students could *apply mathematical concepts and/or processes to engineering problems* [related to] ***relative positions*** [of] ***a system of objects with stored (potential) energy***. MS-PS3-2

Additional Practices Building to the PEs (Continued)	**Constructing Explanations and Designing Solutions** • Construct a scientific explanation based on valid and reliable evidence obtained from sources and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future. Students could *construct a scientific explanation based on valid and reliable evidence* [that] ***the solar system appears to have formed from a disk of dust and gas, drawn together by gravity***. MS-ESS1-2 **Engaging in Argument from Evidence** • Compare and critique two arguments on the same tropic and analyze whether they emphasize similar or different evidence and/or interpretations of facts. Students could *compare and critique two arguments and analyze whether they emphasize similar or different evidence* [for the claim that] ***a collection of objects*** [is] ***held in orbit around the sun by its gravitational pull on them***. MS-ESS1-2 **Obtaining, Evaluating, and Communicating Information** • Integrate qualitative and/or quantitative scientific and/or technical information in written text with that contained in media and visual displays to clarify claims and findings. Students could *integrate qualitative scientific information in written text with that contained in media and visual displays to clarify claims and findings* [about how] ***forces that act at a distance can be explained by fields that extend through space and can be mapped by their effect on a test object***. MS-PS2-5
Additional Crosscutting Concepts Building to the PEs	**Patterns** • Patterns can be used to identify cause and effect relationships. Students could analyze data for *patterns* [that] *can be used to identify cause and effect relationships* [between] ***any pair of interacting objects,*** [such that] ***the force exerted by the first object on the second object is equal in strength to the force that the second object exerts on the first, but in the opposite direction***. MS-PS2-1 **Cause and Effect** • Phenomena may have more than one cause, and some cause and effect relationships in systems can only be described using probability. Students could develop a model for how ***the motion of an object is determined by*** *more than one cause* [due to] ***the sum of the forces acting on it***. MS-PS2-2 **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. Students could construct an argument that ***the solar system consists of the sun and a collection of objects***, [and] *can be observed at various scales using models to study systems that are too large to observe directly*. MS-ESS1-2

Additional Connections to Nature of Science	**Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena** • Laws are regularities or mathematical descriptions of natural phenomena. Students could describe an example of how Newton's second law uses *mathematical descriptions of natural phenomena* [related to] ***larger forces causing larger changes in motion***. MS-PS2-2 **Science is a Way of Knowing** • Science knowledge is cumulative and many people, from many generations and nations, have contributed to science knowledge. Students could obtain, evaluate, and communicate information for how *people from many generations and nations have contributed to knowledge* [about how] ***a system of objects may contain stored (potential) energy, depending on their relative positions***. MS-PS3-2

MS-PS2-1 Motion and Stability: Forces and Interactions

Students who demonstrate understanding can:

MS-PS2-1. Apply Newton's Third Law to design a solution to a problem involving the motion of two colliding objects.* [Clarification Statement: Examples of practical problems could include the impact of collisions between two cars, between a car and stationary objects, and between a meteor and a space vehicle.] [*Assessment Boundary: Assessment is limited to vertical or horizontal interactions in one dimension.*]

The performance expectation above was developed using the following elements from the NRC document *A Framework for K-12 Science Education*:

Science and Engineering Practices

Constructing Explanations and Designing Solutions

Constructing explanations and designing solutions in 6–8 builds on K–5 experiences and progresses to include constructing explanations and designing solutions supported by multiple sources of evidence consistent with scientific ideas, principles, and theories.

- Apply scientific ideas or principles to design an object, tool, process or system.

Disciplinary Core Ideas

PS2.A: Forces and Motion

- For any pair of interacting objects, the force exerted by the first object on the second object is equal in strength to the force that the second object exerts on the first, but in the opposite direction (Newton's third law).

Crosscutting Concepts

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.

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Connections to Engineering, Technology, and Applications of Science

Influence of Science, Engineering, and Technology on Society and the Natural World

- The uses of technologies and any limitations on their use are driven by individual or societal needs, desires, and values; by the findings of scientific research; and by differences in such factors as climate, natural resources, and economic conditions.

Observable features of the student performance by the end of the course:			
1	Using scientific knowledge to generate design solutions		
	a	Given a problem to solve involving a collision of two objects, students design a solution (e.g., an object, tool, process, or system). In their designs, students identify and describe*:	
		i.	The components within the system that are involved in the collision.
		ii.	The force that will be exerted by the first object on the second object.
		iii.	How Newton's third law will be applied to design the solution to the problem.
		iv.	The technologies (i.e., any human-made material or device) that will be used in the solution.
2	Describing* criteria and constraints, including quantification when appropriate		
	a	Students describe* the given criteria and constraints, including how they will be taken into account when designing the solution.	
		i.	Students describe* how the criteria are appropriate to solve the given problem.
		ii.	Students describe* the constraints, which may include:
			1. Cost.
			2. Mass and speed of objects.
			3. Time.
			4. Materials.
3	Evaluating potential solutions		
	a	Students use their knowledge of Newton's third law to systematically determine how well the design solution meets the criteria and constraints.	
	b	Students identify the value of the device for society.	
	c	Students determine how the choice of technologies that are used in the design is affected by the constraints of the problem and the limits of technological advances.	

MS-PS2-2 Motion and Stability: Forces and Interactions

Students who demonstrate understanding can:

MS-PS2-2. **Plan an investigation to provide evidence that the change in an object's motion depends on the sum of the forces on the object and the mass of the object.** [Clarification Statement: Emphasis is on balanced (Newton's First Law) and unbalanced forces in a system, qualitative comparisons of forces, mass and changes in motion (Newton's Second Law), frame of reference, and specification of units.] [*Assessment Boundary: Assessment is limited to forces and changes in motion in one-dimension in an inertial reference frame and to change in one variable at a time. Assessment does not include the use of trigonometry.*]

The performance expectation above was developed using the following elements from the NRC document *A Framework for K-12 Science Education*:

Science and Engineering Practices

Planning and Carrying Out Investigations
Planning and carrying out investigations to answer questions or test solutions to problems in 6–8 builds on K–5 experiences and progresses to include investigations that use multiple variables and provide evidence to support explanations or design solutions.

- Plan an investigation individually and collaboratively, and in the design: identify independent and dependent variables and controls, what tools are needed to do the gathering, how measurements will be recorded, and how many data are needed to support a claim.

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Connections to Nature of Science

Scientific Knowledge is Based on Empirical Evidence

- Science knowledge is based upon logical and conceptual connections between evidence and explanations.

Disciplinary Core Ideas

PS2.A: Forces and Motion

- The motion of an object is determined by the sum of the forces acting on it; if the total force on the object is not zero, its motion will change. The greater the mass of the object, the greater the force needed to achieve the same change in motion. For any given object, a larger force causes a larger change in motion.
- 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.

Crosscutting Concepts

Stability and Change

- Explanations of stability and change in natural or designed systems can be constructed by examining the changes over time and forces at different scales.

Observable features of the student performance by the end of the course:			
1	Identifying the phenomenon to be investigated		
	a	Students identify the phenomenon under investigation, which includes the change in motion of an object.	
	b	Students identify the purpose of the investigation, which includes providing evidence that the change in an object's motion is due to the following factors:	
		i.	Balanced or unbalanced forces acting on the object.
		ii.	The mass of the object.
2	Identifying the evidence to address the purpose of the investigation		
	a	Students develop a plan for the investigation individually or collaboratively. In the plan, students describe*:	
		i.	That the following data will be collected:
			1. Data on the motion of the object.
			2. Data on the total forces acting on the object.
			3. Data on the mass of the object.
		ii.	Which data are needed to provide evidence for each of the following:
			1. An object subjected to balanced forces does not change its motion (sum of F=0).
			2. An object subjected to unbalanced forces changes its motion over time (sum of F≠0).

		3. The change in the motion of an object subjected to unbalanced forces depends on the mass of the object.
3	Planning the investigation	
	a	In the investigation plan, students describe*:
		i. How the following factors will be determined and measured:
		1. The motion of the object, including a specified reference frame and appropriate units for distance and time.
		2. The mass of the object, including appropriate units.
		3. The forces acting on the object, including balanced and unbalanced forces.
		ii. Which factors will serve as independent and dependent variables in the investigation (e.g., mass is an independent variable, forces and motion can be independent or dependent).
		iii. The controls for each experimental condition.
		iv. The number of trials for each experimental condition.

MS-PS2-3 Motion and Stability: Forces and Interactions

Students who demonstrate understanding can:

MS-PS2-3. **Ask questions about data to determine the factors that affect the strength of electric and magnetic forces.** [Clarification Statement: Examples of devices that use electric and magnetic forces could include electromagnets, electric motors, or generators. Examples of data could include the effect of the number of turns of wire on the strength of an electromagnet, or the effect of increasing the number or strength of magnets on the speed of an electric motor.] [*Assessment Boundary: Assessment about questions that require quantitative answers is limited to proportional reasoning and algebraic thinking.*]

The performance expectation above was developed using the following elements from the NRC document *A Framework for K-12 Science Education*:

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Asking Questions and Defining Problems Asking questions and defining problems in grades 6–8 builds from grades K–5 experiences and progresses to specifying relationships between variables, and clarifying arguments and models. • Ask questions that can be investigated within the scope of the classroom, outdoor environment, and museums and other public facilities with available resources and, when appropriate, frame a hypothesis based on observations and scientific principles.	**PS2.B: Types of Interactions** • Electric and magnetic (electromagnetic) forces can be attractive or repulsive, and their sizes depend on the magnitudes of the charges, currents, or magnetic strengths involved and on the distances between the interacting objects.	**Cause and Effect** • Cause and effect relationships may be used to predict phenomena in natural or designed systems.

Observable features of the student performance by the end of the course:			
1	Addressing phenomena of the natural world or scientific theories		
	a	Students formulate questions that arise from examining given data of objects (which can include particles) interacting through electric and magnetic forces, the answers to which would clarify:	
		i.	The cause-and-effect relationships that affect magnetic forces due to:
			1. The magnitude of any electric current present in the interaction, or other factors related to the effect of the electric current (e.g., number of turns of wire in a coil).
			2. The distance between the interacting objects.
			3. The relative orientation of the interacting objects.
			4. The magnitude of the magnetic strength of the interacting objects.
		ii.	The cause-and-effect relationship that affect electric forces due to:
			1. The magnitude and signs of the electric charges on the interacting objects.
			2. The distances between the interacting objects.
			3. Magnetic forces.
	b	Based on scientific principles and given data, students frame hypotheses that:	
		i.	Can be used to predict the strength of electric and magnetic forces due to cause-and-effect relationships.
		ii.	Can be used to distinguish between possible outcomes, based on an understanding of the cause-and-effect relationships driving the system.
2	Identifying the scientific nature of the question		
	a	Students' questions can be investigated scientifically within the scope of a classroom, outdoor environment, museum, or other public facility.	

MS-PS2-4 Motion and Stability: Forces and Interactions

Students who demonstrate understanding can:

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.*]

The performance expectations above were developed using the following elements from the NRC document *A Framework for K-12 Science Education*:

Science and Engineering Practices

Engaging in Argument from Evidence
Engaging in argument from evidence in 6–8 builds from K–5 experiences and progresses to constructing a convincing argument that supports or refutes claims for either explanations or solutions about the natural and designed world.

- 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.

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Connections to Nature of Science

Scientific Knowledge is Based on Empirical Evidence

- Science knowledge is based upon logical and conceptual connections between evidence and explanations.

Disciplinary Core Ideas

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.

Crosscutting Concepts

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.

Observable features of the student performance by the end of the course:		
1	Supported claims	
	a	Students make a claim to be supported about a given phenomenon. In their claim, students include the following idea: Gravitational interactions are attractive and depend on the masses of interacting objects.
2	Identifying scientific evidence	
	a	Students identify and describe* the given evidence that supports the claim, including:
		i. The masses of objects in the relevant system(s).
		ii. The relative magnitude and direction of the forces between objects in the relevant system(s).
3	Evaluating and critiquing the evidence	
	a	Students evaluate the evidence and identify its strengths and weaknesses, including:
		i. Types of sources.
		ii. Sufficiency, including validity and reliability, of the evidence to make and defend the claim.
		iii. Any alternative interpretations of the evidence, and why the evidence supports the given claim as opposed to any other claims.
4	Reasoning and synthesis	
	a	Students use reasoning to connect the appropriate evidence about the forces on objects and construct the argument that gravitational forces are attractive and mass dependent. Students describe* the following chain of reasoning:
		i. Systems of objects can be modeled as a set of masses interacting via gravitational forces.
		ii. In systems of objects, larger masses experience and exert proportionally larger gravitational forces.

		iii. In every case for which evidence exists, gravitational force is attractive.
	b	To support the claim, students present their oral or written argument concerning the direction of gravitational forces and the role of the mass of the interacting objects.

MS-PS2-5 Motion and Stability: Forces and Interactions

Students who demonstrate understanding can:

MS-PS2-5. Conduct an investigation and evaluate the experimental design to provide evidence that fields exist between objects exerting forces on each other even though the objects are not in contact. [Clarification Statement: Examples of this phenomenon could include the interactions of magnets, electrically-charged strips of tape, and electrically-charged pith balls. Examples of investigations could include first-hand experiences or simulations.] [*Assessment Boundary: Assessment is limited to electric and magnetic fields, and limited to qualitative evidence for the existence of fields.*]

The performance expectation above was developed using the following elements from the NRC document *A Framework for K-12 Science Education*:

Science and Engineering Practices

Planning and Carrying Out Investigations
Planning and carrying out investigations to answer questions or test solutions to problems in 6–8 builds on K–5 experiences and progresses to include investigations that use multiple variables and provide evidence to support explanations or design solutions.

- Conduct an investigation and evaluate the experimental design to produce data to serve as the basis for evidence that can meet the goals of the investigation.

Disciplinary Core Ideas

PS2.B: Types of Interactions

- Forces that act at a distance (electric, magnetic, and gravitational) can be explained by fields that extend through space and can be mapped by their effect on a test object (a charged object, or a ball, respectively).

Crosscutting Concepts

Cause and Effect

- Cause and effect relationships may be used to predict phenomena in natural or designed systems.

Observable features of the student performance by the end of the course:			
1	Identifying the phenomenon to be investigated		
	a	From the given investigation plan, students identify the phenomenon under investigation, which includes the idea that objects can interact at a distance.	
	b	Students identify the purpose of the investigation, which includes providing evidence that fields exist between objects exerting forces on each other even though the objects are not in contact.	
2	Identifying evidence to address the purpose of the investigation		
	a	From the given plan, students identify and describe* the data that will be collected to provide evidence for each of the following:	
		i.	Evidence that two interacting objects can exert forces on each other even though the two interacting objects are not in contact with each other.
		ii.	Evidence that distinguishes between electric and magnetic forces.
		iii.	Evidence that the cause of a force on one object is the interaction with the second object (e.g., evidence for the presence of force disappears when the second object is removed from the vicinity of the first).
3	Planning the investigation		
	a	Students describe* the rationale for why the given investigation plan includes:	
		i.	Changing the distance between objects.
		ii.	Changing the charge or magnetic orientation of objects.
		iii.	Changing the magnitude of the charge on an object or the strength of the magnetic field.
		iv.	A means to indicate or measure the presence of electric or magnetic forces.
4	Collecting the data		
	a	Students make and record observations according to the given plan. The data recorded may include observations of:	
		i.	Motion of objects.
		ii.	Suspension of objects.
		iii.	Simulations of objects that produce either electric or magnetic fields through space and the effects of moving those objects closer to or farther away from each other.
		iv.	A push or pull exerted on the hand of an observer holding an object.

5	Evaluation of the design	
	a	Students evaluate the experimental design by assessing whether or not the data produced by the investigation can provide evidence that fields exist between objects that act on each other even though the objects are not in contact.

MS-PS3-1 Energy

Students who demonstrate understanding can:

MS-PS3-1. **Construct and interpret graphical displays of data to describe the relationships of kinetic energy to the mass of an object and to the speed of an object.** [Clarification Statement: Emphasis is on descriptive relationships between kinetic energy and mass separately from kinetic energy and speed. Examples could include riding a bicycle at different speeds, rolling different sizes of rocks downhill, and getting hit by a wiffle ball versus a tennis ball.]

The performance expectation above was developed using the following elements from the NRC document *A Framework for K-12 Science Education*:

Science and Engineering Practices

Analyzing and Interpreting Data
Analyzing data in 6–8 builds on K–5 and progresses to extending quantitative analysis to investigations, distinguishing between correlation and causation, and basic statistical techniques of data and error analysis.

- Construct and interpret graphical displays of data to identify linear and nonlinear relationships.

Disciplinary Core Ideas

PS3.A: Definitions of Energy

- Motion energy is properly called kinetic energy; it is proportional to the mass of the moving object and grows with the square of its speed.

Crosscutting Concepts

Scale, Proportion, and Quantity

- Proportional relationships (e.g. speed as the ratio of distance traveled to time taken) among different types of quantities provide information about the magnitude of properties and processes.

Observable features of the student performance by the end of the course:			
1	Organizing data		
	a	Students use graphical displays to organize the following given data:	
		i.	Mass of the object.
		ii.	Speed of the object.
		iii.	Kinetic energy of the object.
	b	Students organize the data in a way that facilitates analysis and interpretation.	
2	Identifying relationships		
	a	Using the graphical display, students identify that kinetic energy:	
		i.	Increases if either the mass or the speed of the object increases or if both increase.
		ii.	Decreases if either the mass or the speed of the object decreases or if both decrease.
3	Interpreting data		
	a	Using the analyzed data, students describe*:	
		i.	The relationship between kinetic energy and mass as a linear proportional relationship (KE ∝ m) in which:
			1. The kinetic energy doubles as the mass of the object doubles.
			2. The kinetic energy halves as the mass of the object halves.
		ii.	The relationship between kinetic energy and speed as a nonlinear (square) proportional relationship (KE ∝ v2) in which:
			1. The kinetic energy quadruples as the speed of the object doubles.
			2. The kinetic energy decreases by a factor of four as the speed of the object is cut in half.

MS-PS3-2 Energy

Students who demonstrate understanding can:

MS-PS3-2. Develop a model to describe that when the arrangement of objects interacting at a distance changes, different amounts of potential energy are stored in the system. [Clarification Statement: Emphasis is on relative amounts of potential energy, not on calculations of potential energy. Examples of objects within systems interacting at varying distances could include: the Earth and either a roller coaster cart at varying positions on a hill or objects at varying heights on shelves, changing the direction/orientation of a magnet, and a balloon with static electrical charge being brought closer to a classmate's hair. Examples of models could include representations, diagrams, pictures, and written descriptions of systems.] [*Assessment Boundary: Assessment is limited to two objects and electric, magnetic, and gravitational interactions.*]

The performance expectation above was developed using the following elements from the NRC document *A Framework for K-12 Science Education*:

Science and Engineering Practices

Developing and Using Models
Modeling in 6–8 builds on K–5 and progresses to developing, using and revising models to describe, test, and predict more abstract phenomena and design systems.

- Develop a model to describe unobservable mechanisms.

Disciplinary Core Ideas

PS3.A: Definitions of Energy

- A system of objects may also contain stored (potential) energy, depending on their relative positions.

PS3.C: Relationship Between Energy and Forces

- When two objects interact, each one exerts a force on the other that can cause energy to be transferred to or from the object.

Crosscutting Concepts

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.

Observable features of the student performance by the end of the course:			
1	Components of the model		
	a	To make sense of a given phenomenon involving two objects interacting at a distance, students develop a model in which they identify the relevant components, including:	
		i.	A system of two stationary objects that interact.
		ii.	Forces (electric, magnetic, or gravitational) through which the two objects interact.
		iii.	Distance between the two objects.
		iv.	Potential energy.
2	Relationships		
	a	In the model, students identify and describe* relationships between components, including:	
		i.	When two objects interact at a distance, each one exerts a force on the other that can cause energy to be transferred to or from an object.
		ii.	As the relative position of two objects (neutral, charged, magnetic) changes, the potential energy of the system (associated with interactions via electric, magnetic, and gravitational forces) changes (e.g., when a ball is raised, energy is stored in the gravitational interaction between the Earth and the ball).
3	Connections		
	a	Students use the model to provide a causal account for the idea that the amount of potential energy in a system of objects changes when the distance between stationary objects interacting in the system changes because:	
		i.	A force has to be applied to move two attracting objects farther apart, transferring energy to the system.
		ii.	A force has to be applied to move two repelling objects closer together, transferring energy to the system.

MS-ESS1-2 Earth's Place in the Universe

Students who demonstrate understanding can:

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.*]

The performance expectation above was developed using the following elements from the NRC document *A Framework for K-12 Science Education*:

Science and Engineering Practices

Developing and Using Models
Modeling in 6–8 builds on K–5 experiences and progresses to developing, using, and revising models to describe, test, and predict more abstract phenomena and design systems.

- Develop and use a model to describe phenomena.

Disciplinary Core Ideas

ESS1.A: The Universe and Its Stars

- Earth and its solar system are part of the Milky Way galaxy, which is one of many galaxies in the universe.

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.

Crosscutting Concepts

Systems and System Models

- Models can be used to represent systems and their interactions.

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Connections to Nature of Science

Scientific Knowledge Assumes an Order and Consistency in Natural Systems

- Science assumes that objects and events in natural systems occur in consistent patterns that are understandable through measurement and observation.

Observable features of the student performance by the end of the course:			
1	Components of the model		
	a	To make sense of a given phenomenon, students develop a model in which they identify the relevant components of the system, including:	
		i.	Gravity.
		ii.	The solar system as a collection of bodies, including the sun, planets, moons, and asteroids.
		iii.	The Milky Way galaxy as a collection of stars (e.g., the sun) and their associated systems of objects.
		iv.	Other galaxies in the universe
	b	Students indicate the relative spatial scales of solar systems and galaxies in the model.	
2	Relationships		
	a	Students describe* the relationships and interactions between components of the solar and galaxy systems, including:	
		i.	Gravity as an attractive force between solar system and galaxy objects that:
			1. Increases with the mass of the interacting objects increases.
			2. Decreases as the distances between objects increases.
		ii.	The orbital motion of objects in our solar system (e.g., moons orbit around planets, all objects within the solar system orbit the sun).
		iii.	The orbital motion, in the form of a disk, of vast numbers of stars around the center of the Milky Way.
		iv.	That our solar system is one of many systems orbiting the center of the larger system of the Milky Way galaxy.

		v. The Milky Way is one of many galaxy systems in the universe.
3	Connections	
	a	Students use the model to describe* that gravity is a predominantly inward-pulling force that can keep smaller/less massive objects in orbit around larger/more massive objects.
	b	Students use the model to describe* that gravity causes a pattern of smaller/less massive objects orbiting around larger/more massive objects at all system scales in the universe, including that:
		i. Gravitational forces from planets cause smaller objects (e.g., moons) to orbit around planets.
		ii. The gravitational force of the sun causes the planets and other bodies to orbit around it, holding the solar system together.
		iii. The gravitational forces from the center of the Milky Way cause stars and stellar systems to orbit around the center of the galaxy.
		iv. The hierarchy pattern of orbiting systems in the solar system was established early in its history as the disk of dust and gas was driven by gravitational forces to form moon-planet and planet-sun orbiting systems.
	c	Students use the model to describe* that objects too far away from the sun do not orbit it because the sun’s gravitational force on those objects is too weak to pull them into orbit.
	d	Students use the model to describe* what a given phenomenon might look like without gravity (e.g., smaller planets would move in straight paths through space, rather than orbiting a more massive body).

MS-ETS1-1 Engineering Design

Students who demonstrate understanding can:

MS-ETS1-1. Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.

The performance expectation above was developed using the following elements from the NRC document *A Framework for K-12 Science Education*:

Science and Engineering Practices

Asking Questions and Defining Problems

Asking questions and defining problems in grades 6–8 builds on grades K–5 experiences and progresses to specifying relationships between variables, and clarifying arguments and models.

- Define a design problem that can be solved through the development of an object, tool, process or system and includes multiple criteria and constraints, including scientific knowledge that may limit possible solutions.

Disciplinary Core Ideas

ETS1.A: Defining and Delimiting Engineering Problems

- The more precisely a design task's criteria and constraints can be defined, the more likely it is that the designed solution will be successful. Specification of constraints includes consideration of scientific principles and other relevant knowledge that are likely to limit possible solutions.

Crosscutting Concepts

Influence of Science, Engineering, and Technology on Society and the Natural World

- All human activity draws on natural resources and has both short and long-term consequences, positive as well as negative, for the health of people and the natural environment.
- The uses of technologies and limitations on their use are driven by individual or societal needs, desires, and values; by the findings of scientific research; and by differences in such factors as climate, natural resources, and economic conditions.

Observable features of the student performance by the end of the course:			
1	Identifying the problem to be solved		
	a	Students describe* a problem that can be solved through the development of an object, tool, process, or system.	
2	Defining the process or system boundaries and the components of the process or system		
	a	Students identify the system in which the problem is embedded, including the major components and relationships in the system and its boundaries, to clarify what is and is not part of the problem. In their definition of the system, students include:	
		i.	Which individuals or groups need this problem to be solved.
		ii.	The needs that must be met by solving the problem.
		iii.	Scientific issues that are relevant to the problem.
		iv.	Potential societal and environmental impacts of solutions.
		v.	The relative importance of the various issues and components of the process or system.
3	Defining criteria and constraints		
	a	Students define criteria that must be taken into account in the solution that:	
		i.	Meet the needs of the individuals or groups who may be affected by the problem (including defining who will be the target of the solution).
		ii.	Enable comparisons among different solutions, including quantitative considerations when appropriate.
	b	Students define constraints that must be taken into account in the solution, including:	
		i.	Time, materials, and costs.
		ii.	Scientific or other issues that are relevant to the problem.
		iii.	Needs and desires of the individuals or groups involved that may limit acceptable solutions.
		iv.	Safety considerations.
		v.	Potential effect(s) on other individuals or groups.
		vi.	Potential negative environmental effects of possible solutions or failure to solve the problem.