INTRODUCTION TO PERFORMANCE EXPECTATIONS

"The NGSS are standards or goals, that reflect what a student should know and be able to do; they do not dictate the manner or methods by which the standards are taught. . . . Curriculum and assessment must be developed in a way that builds students' knowledge and ability toward the PEs [performance expectations]" (*Next Generation Science Standards*, 2013, page xiv).

This chapter shows how the NGSS Performance Expectations were bundled in the **Gravity and Kinetic Energy Course** to provide a coherent set of instructional materials for teaching and learning.

This chapter also provides details about how this FOSS course fits into the matrix of the FOSS Program (page 43). Each FOSS module K–5 and middle school course 6–8 has a functional role in the FOSS conceptual frameworks that were developed based on a decade of research on science education and the influence of *A Framework for K–12 Science Education* (2012) and *Next Generation Science Standards* (NGSS, 2013).

The FOSS curriculum provides a coherent vision of science teaching and learning in the three ways described by the NRC *Framework*. First, FOSS is designed around learning as a developmental progression, providing experiences that allow students to continually build on their initial notions and develop more complex science and engineering knowledge. Students develop functional understanding over time by building on foundational elements (intermediate knowledge). That progression is detailed in the conceptual frameworks.

Second, FOSS limits the number of core ideas, choosing depth of knowledge over broad shallow coverage. Those core ideas are addressed at multiple grade levels in ever greater complexity. FOSS investigations at each grade level focus on elements of core ideas that are teachable and learnable at that grade level.

Third, FOSS investigations integrate engagement with scientific ideas (content) and the practices of science and engineering by providing firsthand experiences.

Teach the course with the confidence that the developers have carefully considered the latest research and have integrated into each investigation the three dimensions of the NRC *Framework* and NGSS, and have designed powerful connections to the Common Core State Standards for English Language Arts.

Contents

The NGSS Performance Expectations bundled in this course include

Physical Sciences

MS-PS2-1
MS-PS2-2
MS-PS2-4
MS-PS2-5 (foundational)
MS-PS3-1
MS-PS3-2
MS-PS3-5

Earth and Space Sciences

MS-ESS1-2 (foundational)

Engineering, Technology, and the Applications of Science

MS-ETS1-1
MS-ETS1-2
MS-ETS1-3
MS-ETS1-4

Disciplinary Core Ideas Addressed

The **Gravity and Kinetic Energy Course** connects with the NRC *Framework* and the NGSS performance expectations for middle school. The course focuses on core ideas for physical sciences and engineering design.

Physical Sciences

Core idea PS2: Motion and Stability: Forces and Interactions—How can one explain and predict interactions between objects and within systems of objects?

- **PS2.A: Forces and motion**
  How can one predict an object's continued motion, changes in motion, or stability? [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).

  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.]

- **PS2.B: Types of interactions**
  What underlying forces explain the variety of interactions observed? [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. Long-range gravitational interactions govern the evolution and maintenance of large-scale systems in space, such as galaxies or the solar system, and determine the patterns of motion within those structures. Forces that act at a distance (electric and magnetic) 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 magnet, respectively).]

The following NGSS grades 6–8 performance expectations for PS2 are derived from the Framework disciplinary core ideas above.

- **MS-PS2-1.** Apply Newton's third law to design a solution to a problem involving the motion of two colliding objects.
- **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.

DISCIPLINARY CORE IDEAS

A Framework for K–12 Science Education has four core ideas in physical sciences.

- PS1: Matter and its interactions
- PS2: Motion and stability: Forces and interactions
- PS3: Energy
- PS4: Waves and their applications in technologies for information transfer

The questions and descriptions of the core ideas in the text on these pages are taken from the NRC Framework for the middle school grade band to keep the core ideas in a rich and useful context.

The performance expectations related to each core idea are taken from the NGSS for middle school.

- **MS-PS2-4.** Construct and present arguments using evidence to support the claim that gravitational interactions are attractive and depend on the masses of interacting objects.
- **MS-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.

Core idea PS3: Energy— How is energy transferred and conserved?

- **PS3.A: Definitions of energy**
  What is 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. A system of objects may also contain stored (potential) energy, depending on their relative positions. For example, energy is stored—in gravitational interaction with Earth—when an object is raised, and energy is released when the object falls or is lowered.]
- **PS3.B: Conservation of energy and energy transfer**
  What is meant by conservation of energy? How is energy transferred between objects or systems? [When the motion energy of an object changes, there is inevitably some other change in energy at the same time. For example, the friction that causes a moving object to stop also results in an increase in the thermal energy in both surfaces; eventually heat energy is transferred to the surrounding environment as the surfaces cool. Similarly, to make an object start moving or to keep it moving when friction forces transfer energy away from it, energy must be provided from, say, chemical (e.g., burning fuel) or electrical (e.g., an electric motor and a battery) processes.]
- **PS3.C: Relationship between energy and forces**
  How are forces related to energy? [When two objects interact, each one exerts a force on the other that can cause energy to be transferred to or from the object. For example, when energy is transferred to an Earth-object system as an object is raised, the gravitational field energy of the system increases. This energy is released as the object falls; the mechanism of this release is the gravitational force.]

The following NGSS grades 6–8 performance expectations for PS3 are derived from the Framework disciplinary core ideas above.

- **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.

REFERENCES

National Research Council. *A Framework for K–12 Science Education: Practices, Crosscutting Concepts, and Core Ideas.* Washington, DC: The National Academies Press, 2012.

NGSS Lead States. *Next Generation Science Standards: For States, by States.* Washington, DC: National Academies Press, 2013.

National Governors Association Center for Best Practices and Council of Chief States School Officers. *Common Core State Standards for English Language Arts and Literacy in History/Social Studies, Science, and Technical Subjects*. Washington, DC: authors, 2010.

DISCIPLINARY CORE IDEAS

A Framework for K–12 Science Education has three core ideas in earth and space sciences.

ESS1: Earth's place in the universe

ESS2: Earth and the solar system

ESS3: The history of planet Earth

The questions and descriptions of the core ideas in the text on these pages are taken from the NRC Framework for the middle school grade band to keep the core ideas in a rich and useful context.

The performance expectations related to each core idea are taken from the NGSS for middle school.

DISCIPLINARY CORE IDEAS

A Framework for K–12 Science Education has two core ideas in engineering, technology, and applications of science.

ETS1: Engineering design

ETS2: Interdependence of science, engineering, and technology

The questions and descriptions of the core ideas in the text on these pages are taken from the NRC Framework for the middle school grade band to keep the core ideas in a rich and useful context.

The performance expectations related to each core idea are taken from the NGSS for middle school.

- **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.
- **MS-PS3-5.** Construct, use, and present arguments to support the claim that when the motion energy of an object changes, energy is transferred to or from the object.

Earth and Space Sciences

Framework core idea ESS1: Earth's place in the universe— What is the universe, and what is Earth's place in it?

- **ESS1.B: Earth and the solar system**
  What are the predictable patterns caused by Earth's movement in 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. This model of the solar system can explain tides, eclipses of the Sun and the Moon, and the motion of the planets in the sky relative to the stars.]

The following NGSS grades 6–8 performance expectation for ESS1 is derived from the Framework disciplinary core idea above.

- **MS-ESS1-2.** Develop and use a model to describe the role of gravity in the motions within galaxies and the solar system.

Engineering, Technology, and Applications of Science

Framework core idea ETS1: Engineering design—How do engineers solve problems?

- **ETS1.A: Defining and delimiting an engineering problem**
  What is a design for? What are the criteria and constraints of a successful solution? [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 (e.g., familiarity with the local climate may rule out certain plants for the school garden).]
- **ETS1.B: Developing possible solutions**
  What is the process for developing potential design solutions? [A solution needs to be tested, and then modified on the basis of the test results, in order to improve it. There are systematic processes for evaluating solutions with respect to how well they meet the

criteria and constraints of a problem. Sometimes parts of different solutions can be combined to create a solution that is better than any of its predecessors. In any case, it is important to be able to communicate and explain solutions to others. Models of all kinds are important for testing solutions, and computers are a valuable tool for simulating systems.]

- **ETS1.C: Optimizing the design solution**
  How can the various proposed design solutions be compared and improved? [There are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of a problem. Comparing different designs could involve running them through the same kinds of tests and systematically recording the results to determine which design performs best. Although one design may not perform the best across all tests, identifying the characteristics of the design that performed the best in each test can provide useful information for the redesign process—that is, some of those characteristics may be incorporated into the new design. This iterative process of testing the most promising solutions and modifying what is proposed on the basis of the test results leads to greater refinement and ultimately to an optimal solution. Once such a suitable solution is determined, it is important to describe that solution, explain how it was developed, and describe the features that make it successful.]

The following NGSS grades 6–8 performance expectations for ETS1 are derived from the Framework disciplinary core ideas above.

- **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.
- **MS-ETS1-2.** Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.
- **MS-ETS1-3.** Analyze data from tests to determine similarities and differences among several design solutions to identify the solution to better meet the criteria for success.
- **MS-ETS1-4.** Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved.

SCIENCE AND ENGINEERING PRACTICES

A Framework for K–12 Science Education (National Research Council, 2012) describes eight science and engineering practices as essential elements of a K–12 science and engineering curriculum. All of these practices are incorporated into the learning experiences in the **Gravity and Kinetic Energy Course**.

The learning progression for this dimension of the framework is addressed in *Next Generation Science Standards* (National Academies Press, 2013), volume 2, appendix F. Elements of the learning progression for practices recommended for grades 6–8 as described in the performance expectations appear in bullets below each practice.

Science and Engineering Practices Addressed

1. *Asking questions and defining problems*

- Ask questions to clarify and/or refine a model, an explanation, or an engineering problem.
- 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.
- 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.

2. *Developing and using models*

- Develop and/or use a model to predict and/or describe phenomena.
- Develop a model to describe unobservable mechanisms.
- Develop and/or use a model to generate data to test ideas about phenomena in natural or designed systems, including those representing inputs and outputs, and those at unobservable scales.

3. *Planning and carrying out investigations*

- 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.
- Conduct an investigation and/or evaluate and/or revise the experimental design to produce data to serve as the basis for evidence that meet the goals of the investigation.
- Collect data to serve as the basis for evidence to answer scientific questions or test design solutions under a range of conditions.

4. *Analyzing and interpreting data*

- Construct, analyze, and/or interpret graphical displays of data and/or large data sets to identify linear and nonlinear relationships.
- Use graphical displays (e.g., maps, charts, graphs, and/or tables) of large data sets to identify temporal and spatial relationships.
- Analyze and interpret data to provide evidence for phenomena.
- Analyze and interpret data to determine similarities and differences in findings.

- Analyze data to define an optimal operational range for a proposed object, tool, process or system that best meets criteria for success.

5. Using mathematics and computational thinking

- Use mathematical representations to describe and/or support scientific conclusions and design solutions.
- Create algorithms (a series of ordered steps) to solve a problem.
- Apply mathematical concepts and/or processes (e.g., ratio, rate, percent, basic operations, simple algebra) to scientific and engineering questions and problems.

6. Constructing explanations and designing solutions

- Construct an explanation that includes qualitative or quantitative relationships between variables that predict(s) and/or describe(s) phenomena.
- Construct a scientific explanation based on valid and reliable evidence obtained from sources (including the students' own experiments) 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.
- Apply scientific ideas, principles, and/or evidence to construct, revise and/or use an explanation for real-world phenomena, examples, or events.
- Apply scientific ideas or principles to design, construct, and/or test a design of an object, tool, process or system.
- Undertake a design project, engaging in the design cycle, to construct and/or implement a solution that meets specific design criteria and constraints.

7. Engaging in argument from evidence

- Evaluate competing design solutions based on jointly developed and agreed-upon design criteria.

8. Obtaining, evaluating, and communicating information

- Critically read scientific texts adapted for classroom use to determine the central ideas and/or obtain scientific and/or technical information to describe patterns in and/or evidence about the natural and designed world(s).
- 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.

CROSSCUTTING CONCEPTS

A Framework for K–12 Science Education describes seven crosscutting concepts as essential elements of a K–12 science and engineering curriculum. The learning progression for this dimension of the framework is addressed in volume 2, appendix G, of the NGSS. Elements of the learning progression for crosscutting concepts recommended for grades 6–8, as described in the performance expectations, appear after bullets below each concept.

Crosscutting Concepts Addressed

Patterns: *Observed patterns in nature guide organization and classification and prompt questions about relationships and causes underlying them.*

- Patterns in rates of change and other numerical relationships can provide information about natural and human-designed systems.
- Patterns can be used to identify cause-and-effect relationships.
- Graphs, charts, and images can be used to identify patterns in data.

Cause and effect: *Events have causes, sometimes simple, sometimes multifaceted. Deciphering causal relationships, and the mechanisms by which they are mediated, is a major activity of science and engineering.*

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

Scale, proportion, and quantity: *In considering phenomena, it is critical to recognize what is relevant at different size, time, and energy scales, and to recognize proportional relationships between different quantities as scales change.*

- Time, space, and energy phenomena can be observed at various scales using models to study systems that are too large or too small.
- Proportional relationships among different types of quantities provide information about the magnitude of properties and processes.
- Scientific relationships can be represented through the use of algebraic expressions and equations.

Systems and system models: *A system is an organized group of related objects or components; models can be used for understanding and predicting the behavior of systems.*

- Models can be used to represent systems and their interactions—such as inputs, processes, and outputs—and energy, matter, and information flows within systems.

Energy and matter: *Tracking energy and matter flows into, out of, and within systems helps to understand the system's behavior.*

- Within a natural (or designed) system, the transfer of energy drives the motion and/or cycling of matter.
- The transfer of energy can be tracked as energy flows through a designed or natural system.

Structure and function: *The way an object is shaped or structured determines many of its properties and its functions.*

- Structures can be designed to serve particular functions by taking into account properties of different materials, and how materials can be shaped and used.

Stability and change: *For both designed and natural systems, conditions that affect stability and factors that control rates of change are critical elements to consider and understand.*

- Stability might be disturbed either by sudden events or gradual changes that accumulate over time.

Connections to the Nature of Science

- **Scientific knowledge is based on empirical evidence.** Scientific knowledge is based on logical and conceptual connections between evidence and explanations. Science disciplines share common rules of obtaining and evaluating empirical evidence.
- **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. Science carefully considers and evaluates anomalies in data and evidence.
- **Science models, laws, mechanisms, and theories explain natural phenomena.** Laws are regularities or mathematical descriptions of natural phenomena.
- **Science addresses questions about the natural and material world.** Scientific knowledge can describe the consequences of actions but is not responsible for decisions that society takes.

Connections to Engineering, Technology, and Applications of Science

- **Interdependence of science, engineering, and technology.** Engineering advances have led to important discoveries in virtually every field of science, and scientific discoveries have led to the development of entire industries and engineered systems. Science and technology drive each other forward. Technologies extend the measurement, exploration, modeling, and computational capacity of scientific investigations.
- **Influence of engineering, technology, and science on society and the natural world.** The uses of technologies are driven by people's needs, desires, and values; by the findings of scientific research; and by differences in such factors as climate, natural resources, and economic conditions. Technology use varies over time and from region to region.

CONNECTIONS

See volume 2, appendix H and appendix J, in the NGSS for more on these connections.

FOSS CONCEPTUAL FRAMEWORK

FOSS has conceptual structure at the course level. The concepts are carefully selected and organized in a sequence that makes sense to students when presented as intended. In the last half decade, research has focused on learning progressions. The idea behind a learning progression is that **core ideas** in science are complex and wide-reaching—ideas such as the structure of matter or the relationship between the distribution and function of organisms. From the age of awareness throughout life, matter and organisms are important to us. There are things we can and should understand about them in our primary school years, and progressively more complex and sophisticated things we should know about them as we gain experience and develop our cognitive abilities. When we as educators can determine those logical progressions, we can develop meaningful and effective curriculum.

FOSS has elaborated learning progressions for core ideas in science for kindergarten through grade 8. Developing the learning progressions involves identifying successively more sophisticated ways of thinking about core ideas over multiple years. "If mastery of a core idea in a science discipline is the ultimate educational destination, then well-designed learning progressions provide a map of the routes that can be taken to reach that destination" (National Research Council, *A Framework for K–12 Science Education*, 2012, page 26).

The FOSS modules (grades K–5) and courses (grades 6–8) are organized into three domains: physical science, earth science, and life science. Each domain is subdivided into two strands, each representing a core scientific idea, as shown in the columns in the table: matter/energy and change, atmosphere and Earth/rocks and landforms, structure and function/complex systems. The sequence of modules and courses in each strand relates to the core ideas described in the national framework. Modules at the bottom of the table form the foundation in the primary grades. The core ideas develop in complexity as they proceed up the columns.

In addition to the science content framework, every course provides opportunities for students to engage in and understand science practices, and many courses explore issues related to engineering practices and the use of natural resources.

The science content used to develop the FOSS courses describes what we want students to learn; the science and engineering practices describe how we want students to learn; and crosscutting concepts stitch the whole effort into a coherent fabric describing the whole natural world. Practices involve a number of habits of mind and philosophical orientations, and these, too, will develop in richness and complexity as students advance through their science studies. Science and engineering practices involve behaviors, so they can be best assessed while in progress. Thus, assessment of practices is based on teacher observation. The indicators of progress include students involved in the many aspects of active thinking, students motivated to learn, and students taking responsibility for their own learning.

FOSS Next Generation—K–8 Sequence

	PHYSICAL SCIENCE		EARTH SCIENCE		LIFE SCIENCE	
	MATTER	ENERGY AND CHANGE	ATMOSPHERE AND EARTH	ROCKS AND LANDFORMS	STRUCTURE/ FUNCTION	COMPLEX SYSTEMS
6–8	Waves; Gravity and Kinetic Energy Chemical Interactions Electromagnetic Force		Planetary Science Earth History Weather and Water		Heredity and Adaptation Populations and Ecosystems Diversity of Life; Human Systems Interactions	
5	Mixtures and Solutions		Earth and Sun		Living Systems	
4		Energy		Soils, Rocks, and Landforms	Environments	
3	Motion and Matter		Water and Climate		Structures of Life	
2	Solids and Liquids			Pebbles, Sand, and Silt	Insects and Plants	
1		Sound and Light	Air and Weather		Plants and Animals	
K	Materials and Motion		Trees and Weather		Animals Two by Two	

BACKGROUND FOR THE CONCEPTUAL FRAMEWORK *in Gravity and Kinetic Energy*

Force

Sir Isaac Newton (1643-1727) published his three laws of motion in 1687. Over 300 years later, these laws still explain observable behavior, although newer physics models are required to explain phenomena at the level of subatomic particles or at near light speed.

Law 1. An object will stay still or move at a constant speed in a constant direction unless an external force acts on it.

Law 2. The acceleration of an object is directly proportional to the force on the object. It is inversely proportional to its mass ($F = ma$).

Law 3. For every action (force acting on an object), there is an equal and opposite reaction (force acting in the opposite direction).

A force is an interaction, a push or pull, between two objects. These objects can be large, like students playing a game of tug-of-war, or tiny, like subatomic particles. The principle remains the same: nothing changes in motion unless a force is applied. The forces acting on an object are summative, including invisible forces like friction and gravity. If the net force on an object is greater than zero, its motion will change. The greater the object's mass, the more force needed to achieve the same change in motion.

Force of Gravity

When you drop a hammer, it falls toward the ground. Gravity is the force responsible for this predictable and consistent action. Gravity, one of the four fundamental forces of the universe, is a force of attraction between masses. The strength of the force depends on the size of the masses and the distance between them. Small masses exert very little gravitational force, and more massive objects exert greater force.

Gravitational force explains why hammers (and all objects) fall toward Earth, as well as why Earth orbits the Sun, the Moon orbits Earth, and the other patterns of motion throughout our solar system, galaxy, and universe. Gravity extends outward as a field surrounding a mass, and its force decreases as you move farther from an object's center of mass.

Referring back to Newton's first law, we can conclude that because the force of gravity acts on a falling object during its fall, it will accelerate the object toward Earth. In fact, this acceleration is constant for all objects on Earth, 9.8 m/s^2, and is known as g. The force of gravity acting on a mass determines its weight. Therefore, on other celestial bodies with greater or smaller gravitational forces and therefore different gravitational acceleration, an object's weight will be different. Another way to think about this is by using Newton's second law, $F = ma$. The object's mass (m) does not change, but if acceleration (a) toward the celestial body is not 9.8 m/s^2, the object will have a different weight (F).

Energy

Energy cannot be created or destroyed, only transferred. Speed is an indication of increased kinetic energy, so if a falling object is accelerating (speeding up), where does this increased energy come from? The act of elevating an object above Earth's surface increases its potential energy. This is the energy stored in an object's position, and when it is released from a height the potential energy transfers to kinetic energy. Following this logic, we can infer that there must have been an energy transfer that increased the object's potential energy. This might be the kinetic energy of an arm moving, which came from the chemical energy released as food was metabolized within the body, which came from solar energy as a plant photosynthesized, and so on.

CONCEPTUAL FRAMEWORK
Physical Sciences, Energy and Change: Gravity and Kinetic Energy

Motion and Stability: Forces and Interactions

Concept A The motion of an object is determined by the sum of the forces (pushes and pulls) acting on it.

- An object in motion will stay in motion (or an object at rest will stay at rest) unless acted on by an external force.
- The greater the mass of the object, the greater the force needed to achieve a change in motion.
- A moving object can have constant speed or acceleration.
- For a pair of interacting objects, the force exerted by one 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.

Concept B All interactions between objects arise from a few types of forces, primarily gravity and electromagnetism.

- A falling object increases speed with a constant acceleration because of gravity. Gravity is an attractive force between two objects.
- Weight is a measurement of the force of gravity on an object.

Energy Transfer and Conservation

Concept A Energy is a quantitative property (condition) of a system that depends on the motion and interactions of matter and radiation within the system.

- Kinetic energy is energy of motion; potential energy is dependent on the position of an object within a system.
- Kinetic energy is proportional to the mass of a moving object. Increasing the speed of an object increases its kinetic energy by the same factor squared.

Concept B The total change of energy in any system is always equal to the total energy transferred into or out of the system. When two objects interact, each one exerts a force on the other, and these forces can transfer energy.

- When objects collide, energy can transfer from one object to another, thereby changing their motion.

Increasing the mass of an object increases its kinetic energy proportionally, and increasing the speed of an object increases its kinetic energy by that factor squared. This has tremendous implications when we consider Newton's third law, which describes what happens when a force acts on an object. An object colliding with another object applies a force that transfers energy between objects. If the kinetic energy of one or more of these objects increases, there is more energy to transfer in a collision. When this collision energy transfer involves a human, the results can cause severe bodily harm, which is why engineering solutions based on these principles are of such concern.

Engineering Design

Science is a discovery activity, a process for producing new knowledge. Scientific knowledge advances when scientists observe objects and events, think about how their observations relate to what is known, test their ideas in logical ways, and generate explanations that integrate the new information into understanding of the natural world. Thus, the scientific enterprise is both what we know (content knowledge) and how we come to know it (practices). Scientists engage in a set of practices as they do their work and these are the same practices students use in their science investigations.

Engineers apply that understanding of the natural world to solve real-world problems. Engineering is the systematic approach to finding solutions to problems identified by people in societies. The fields of science and engineering are mutually supportive, and scientists and engineers collaborate in their work. Often, acquiring scientific data requires designing and producing new technologies—tools, instruments, machines, and processes—to perform specific functions. The practices that engineers use are very similar to science practices but also involve defining problems and designing solutions.

The process of engineering design, while it involves engineering practices, is considered a separate set of disciplinary core ideas in the *Framework* and in the NGSS. There are three basic ideas of engineering design: defining the problem, developing possible solutions, and improving the design.

Defining the problem "with precision" means having a clear understanding of specific criteria and constraints in a complex problem that might have a broader societal or environmental impact. Students develop a helmet in this course, and they consider the grave consequences for humans whose bodies are not protected in a collision.

Developing possible solutions at middle school focuses not only on generating design ideas, but also on a process of evaluating different ideas that have been proposed in a systematic way such as a trade-off matrix to determine the most promising designs. Those most promising designs would be tested and solutions results would be combined into a new solution.

Optimizing the design involves an iterative process of testing the best design, systematically analyzing the results, modifying the design while controlling variables, retesting, comparing results, and again modifying the design. Students may go through this cycle several times in order to optimize the design. Students need to know that "failure" is not only OK, but expected in engineering design. Having something fail drives you to improve the system and make progress. Collaboration is an important aspect of engineering design; learning from the successes and failures of other design groups can be very productive. Students exchange design feedback with other groups to practice the skill of being receptive to collaborative input.

In this course, there is one investigation in which students explore the disciplinary core ideas of engineering design in the context of force and energy. But students engage in engineering practices in other investigations without engaging in the full engineering design process. FOSS has a continuum of engagements in the engineering practices and process from short experiences to more in-depth experiences where students reflect on the core ideas about the design process.

CONCEPTUAL FRAMEWORK
Engineering Design: Gravity and Kinetic Energy

Concept 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 likely to limit possible solutions.

Concept B **Developing possible solutions**

- A solution needs to be tested and then modified on the basis of the test results in order to improve it.
- There are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of a problem.
- Sometimes parts of different solutions can be combined to create a solution that is better than any of its predecessors.
- Models of all kinds are important for testing solutions.

Concept C **Optimizing the design solution**

- Although one design may not perform the best across all tests, identifying the characteristics of the design that performed the best in each test can provide useful information for the redesign process—that is, some of those characteristics may be incorporated into the new design.
- The iterative process of testing the most promising solutions and modifying what is proposed on the basis of the test results leads to greater refinement and ultimately to an optimal solution.

Physical Science Content Sequence

This table shows all the modules and courses for grades 3–8 in the FOSS content sequence for physical science, with an emphasis on the modules that inform the Energy and Change strand. The supporting elements in these modules (somewhat abbreviated) are listed. The elements for the **Gravity and Kinetic Energy Course** are expanded to show how they fit into the sequence.

	ENERGY AND CHANGE	
Module or course	**Motion and Stability: Forces and Interactions**	**Energy Transfer and Conservation**
Electromagnetic Force (middle school)	• A force is a push or pull. Net force is the sum of all the forces acting on a mass. • Magnets are surrounded by an invisible magnetic field. The magnetic field produced by a current-carrying wire can induce magnetism in iron (electromagnet). • The magnitude of the magnetic force between two interacting magnetic fields decreases as the distance increases.	• Kinetic energy is energy of motion. • Changing the position of an object in an electric or magnetic field changes the potential energy. • Energy cannot be created or destroyed, only transferred. • Every energy use can be described as a sequence of energy transfers. • Energy sources can be categorized.
Waves (middle school)		• A simple wave has a repeating pattern related to the energy of the wave. • Waves interacting with a medium can be absorbed, reflected, or transmitted through the medium. • A wave model can be used to explain the properties of light. • Electromagnetic waves form a spectrum of different wavelengths. • Information technologies are instruments that produce and detect waves to encode and transmit information.
Gravity and Kinetic Energy (middle school)		
Energy (grade 4)	• Magnets interact with each other and with materials that contain iron. • Like poles of magnets repel each other; opposite poles attract. The magnetic force declines as the distance between the magnets increases. • Conductors are materials through which electric current can flow; all metals are conductors. • Any change of motion requires a force. • Gravity is a pulling force that acts between all masses.	• Energy can be generated by burning fossil fuels or harnessing renewable energy. • Electric current transfers energy that can produce heat, light, sound, and motion. • A circuit is a system that includes a pathway through which electric current flows. • Motion of one object can transfer to motion of other objects in a collision. • Waves are a repeating pattern of motion that transfer energy. • An object is seen when light from an object enters and is detected by the eye.
Motion and Matter (grade 3)	• Magnetic forces between a pair of objects do not require that the objects be in contact. The strength of the force depends on the properties of the objects and their distance apart. • Gravity is the force that pulls masses toward the center of Earth. • Any change of motion requires a force. Each force has a strength and direction.	

Gravity and Kinetic Energy

Motion and Stability: Forces and Interactions	Energy Transfer and Conservation
• An object in motion will stay in motion (or an object at rest will stay at rest) unless acted on by an external force. • The greater the mass of the object, the greater the force needed to achieve a change in motion. • A moving object can have constant speed or acceleration. • For a pair of interacting objects, the force exerted by one 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. • A falling object increases speed with a constant acceleration because of gravity. Gravity is an attractive force between two objects. • Weight is a measurement of the force of gravity on an object.	• Kinetic energy is energy of motion; potential energy is dependent on the position of an object within a system. • Kinetic energy is proportional to the mass of a moving object. Increasing the speed of an object increases its kinetic energy by the same factor squared. • When objects collide, energy can transfer from one object to another, thereby changing their motion.

NOTE

See the Assessment chapter in this *Investigations Guide* for more details on how the FOSS embedded and benchmark assessment opportunities align with the conceptual frameworks and the learning progressions. In addition, the Assessment chapter describes specific connections between the FOSS assessments and the NGSS performance expectations.

The NGSS Performance Expectations addressed in this course include

Physical Sciences
MS-PS2-1
MS-PS2-2
MS-PS2-4
MS-PS2-5 (foundational)
MS-PS3-1
MS-PS3-2
MS-PS3-5

Earth and Space Sciences
MS-ESS1-2 (foundational)

Engineering, Technology, and the Applications of Science
MS-ETS1-1
MS-ETS1-2
MS-ETS1-3
MS-ETS1-4

See pages 34–37 in this chapter for more details on the Grades 6–8 NGSS Performance Expectations.

CONNECTIONS TO NGSS BY INVESTIGATION

Inv. 1: Acceleration

Science and Engineering Practices	Connections to Common Core State Standards—ELA
Asking questions Developing and using models Planning and carrying out investigations Analyzing and interpreting data Using mathematics and computational thinking Constructing explanations Obtaining, evaluating, and communicating information	**Reading—Literacy in Science and Technical Subjects** 1. Cite specific textual evidence to support analysis of science and technical texts. 2. Determine the central ideas or conclusions of a text; provide an accurate summary of the text distinct from prior knowledge or opinions. 3. Follow precisely a multistep procedure when carrying out experiments, taking measurements, or performing technical tasks. 4. Determine the meaning of symbols, key terms, and other domain-specific words and phrases. 5. Analyze the structure an author uses to organize a text, including how the major sections contribute to the whole and to an understanding of the topic. 6. Analyze the author's purpose in providing an explanation, describing a procedure, or discussing an experiment in a text. 8. Distinguish among facts, reasoned judgment based on research findings, and speculation in a text. 9. Compare and contrast the information gained from experiments, video, or multimedia sources with that gained from reading a text on the same topic. 10. Read and comprehend science/technical texts in grades 6–8 text independently and proficiently. **Speaking and Listening** 1. Engage effectively in a range of collaborative discussions with diverse partners, building on others' ideas and expressing their own clearly. 5. Integrate multimedia and visual displays into presentations to clarify information, strengthen claims and evidence, and add interest. **Writing—Literacy in Science and Technical Subjects** 5. With some guidance and support from peers and adults, develop and strengthen writing as needed by planning, revising, editing, rewriting, or trying a new approach, focusing on how well purpose and audience have been addressed. 8. Gather relevant information from multiple print and digital sources, using search terms effectively. 9. Draw evidence from informational texts to support analysis, reflection, and research. **Language** 5. Demonstrate understanding of word relationships and nuances in word meaning.

Disciplinary Core Ideas		Crosscutting Concepts
PS2.A: Forces and 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. **(MS-PS2-2)** **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. **(MS-PS2-4)**		Patterns Scale, proportion, and quantity Systems and system models Structure and function Stability and Change

Science and Engineering Practices	Connections to Common Core State Standards—ELA
Asking questions Developing and using models Planning and carrying out investigations Analyzing and interpreting data Using mathematics and computational thinking Constructing explanations Obtaining, evaluating, and communicating information	**Reading—Literacy in Science and Technical Subjects** 1. Cite specific textual evidence to support analysis of science and technical texts. 2. Determine the central ideas or conclusions of a text; provide an accurate summary of the text distinct from prior knowledge or opinions. 7. Integrate quantitative or technical information expressed in words in a text with a version of that information expressed visually (e.g., in a flowchart, diagram, model, graph, or table). 8. Distinguish among facts, reasoned judgment based on research findings, and speculation in a text. 9. Compare and contrast the information gained from experiments, simulations, video, or multimedia sources with that gained from reading a text on the same topic. 10. Read and comprehend science/technical texts in the grades 6–8 text complexity band independently and proficiently. **Speaking and Listening** 1. Engage effectively in a range of collaborative discussions (one-on-one, in groups, and teacher led) with diverse partners on middle school topics, texts, and issues, building on others' ideas and expressing their own clearly. 4. Present claims and findings, emphasizing salient points in a focused, coherent manner with relevant evidence, sound valid reasoning, and well-chosen details; use appropriate eye contact, adequate volume, and clear pronunciation. **Writing—Literacy in Science and Technical Subjects** 2. Write informative/explanatory texts, including the narration of historical events, scientific procedures/experiments, or technical processes. 5. With some guidance and support from peers and adults, develop and strengthen writing as needed by planning, revising, editing, rewriting, or trying a new approach, focusing on how well purpose and audience have been addressed. 9. Draw evidence from informational texts to support analysis, reflection, and research. **Language** 6. Acquire and use academic and domain-specific words and phrases.

Disciplinary Core Ideas		Crosscutting Concepts
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. **(MS-PS2-2)** **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. **(MS-PS2-4)** • Forces that act at a distance (electric and magnetic) 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 magnet, respectively). **(MS-PS2-5)**	**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. **(MS-ESS1-2)**	Patterns Cause and effect Scale, proportion, and quantity Systems and system models Stability and change

Science and Engineering Practices	Connections to Common Core State Standards—ELA
Developing and using models Planning and carrying out investigations Analyzing and interpreting data Using mathematics and computational thinking Constructing explanations Obtaining, evaluating, and communicating information	**Reading—Literacy in Science and Technical Subjects** 2. Determine the central ideas or conclusions of a text; provide an accurate summary of the text distinct from prior knowledge or opinions. 4. Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to grades 6–8 texts and topics. 5. Analyze the structure an author uses to organize a text, including how the major sections contribute to the whole and to an understanding of the topic. 6. Analyze the author's purpose in providing an explanation, describing a procedure, or discussing an experiment in a text. 7. Integrate quantitative or technical information expressed in words in a text with a version of that information expressed visually (e.g., in a flowchart, diagram, model, graph, or table). 8. Distinguish among facts, reasoned judgment based on research findings, and speculation in a text. 9. Compare and contrast the information gained from experiments, simulations, video, or multimedia sources with that gained from reading a text on the same topic. 10. Read and comprehend science/technical texts in the grades 6–8 text complexity band independently and proficiently. **Speaking and Listening** 1. Engage effectively in a range of collaborative discussions (one-on-one, in groups, and teacher led) with diverse partners on middle school topics, texts, and issues, building on others' ideas and expressing their own clearly. **Writing—Literacy in Science and Technical Subjects** 7. Conduct short research projects to answer a question, drawing on several sources and generating additional related, focused questions that allow for multiple avenues of exploration. 8. Gather relevant information from multiple print and digital sources, using search terms effectively. 9. Draw evidence from informational texts to support analysis, reflection, and research.

Disciplinary Core Ideas		Crosscutting Concepts
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). **(MS-PS2-1)** • 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. **(MS-PS2-2)**	**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. **(MS-PS3-1)** • A system of objects may also contain stored (potential) energy, depending on their relative positions. **(MS-PS3-2)** **PS3.B: Conservation of energy and energy transfer** • When the motion energy of an object changes, there is inevitably some other change in energy at the same time. **(MS-PS3-5)** **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. **(MS-PS3-2)**	Patterns Cause and effect Scale, proportion, and quantity Systems and system models Energy and matter Stability and change

Science and Engineering Practices	Connections to Common Core State Standards—ELA
Asking questions and defining problems Developing and using models Planning and carrying out investigations Analyzing and interpreting data Using mathematics and computational thinking Constructing explanations and designing solutions Engaging in argument from evidence Obtaining, evaluating, and communicating information	**Reading—Literacy in Science and Technical Subjects** 1. Cite specific textual evidence to support analysis of science and technical texts. 6. Analyze the author's purpose in providing an explanation, describing a procedure, or discussing an experiment in a text. 7. Integrate quantitative or technical information expressed in words in a text with a version of that information expressed visually (e.g., in a flowchart, diagram, model, graph, or table). **Speaking and Listening** 2. Interpret and analyze information presented in diverse media and formats and evaluate the motives behind its presentation. 3. Delineate a speaker's argument and specific claims, evaluating the soundness of the reasoning and relevance and sufficiency of the evidence and identifying when irrelevant evidence is introduced. 4. Present claims and findings, emphasizing salient points in a focused, coherent manner with relevant evidence, sound valid reasoning, and well-chosen details; use appropriate eye contact, adequate volume, and clear pronunciation. **Writing—Literacy in Science and Technical Subjects** 8. Gather relevant information from multiple print and digital sources, using search terms effectively. 9. Draw evidence from informational texts to support analysis, reflection, and research.

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). **(MS-PS2-1)**

PS3.B: Conservation of energy and energy transfer

- When the motion energy of an object changes, there is inevitably some other change in energy at the same time. **(MS-PS2-2)**

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. **(MS-PS3-2)**

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. **(MS-ETS1-1)**

ETS1.B: Developing possible solutions

- A solution needs to be tested, and then modified on the basis of the test results in order to improve it. Specification of constraints includes considerations of scientific principles and other relevant knowledge that is likely to limit possible solutions. **(MS-ETS1-2)**

ETS1.C: Optimizing the design solution

- The iterative process of testing the most promising solutions and modifying what is proposed on the basis of the test results leads to greater refinement and ultimately to an optimal solution. **(MS-ETS1-3, MS-ETS1-4)**

Crosscutting Concepts

Patterns
Cause and effect
Systems and system models
Energy and matter
Structure and function

RECOMMENDED FOSS NEXT GENERATION K–8 SCOPE AND SEQUENCE

Grade	Integrated Middle Grades				
6–8	Heredity and Adaptation*	Electromagnetic Force*	Gravity and Kinetic Energy*	Waves*	Planetary Science
	Chemical Interactions		Earth History		Populations and Ecosystems
	Weather and Water		Diversity of Life		Human Systems Interactions*

*Half-length courses — Physical Science content — Earth Science content — Life Science content — Engineering content

Grade	Physical Science	Earth Science	Life Science
5	Mixtures and Solutions	Earth and Sun	Living Systems
4	Energy	Soils, Rocks, and Landforms	Environments
3	Motion and Matter	Water and Climate	Structures of Life
2	Solids and Liquids	Pebbles, Sand, and Silt	Insects and Plants
1	Sound and Light	Air and Weather	Plants and Animals
K	Materials and Motion	Trees and Weather	Animals Two by Two