INTRODUCTION TO PERFORMANCE EXPECTATIONS

This chapter provides details about how this FOSS middle school course fits into the matrix of the FOSS Program. 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 *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 scientific and engineering knowledge. Students develop understanding over time by building on foundational elements or intermediate knowledge. Those elements are detailed in the conceptual frameworks.

Second, FOSS limits the number of core ideas, choosing depth of knowledge over comprehensive 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) with the practices of science and engineering by providing students with firsthand experiences.

If this is your first time teaching a FOSS middle school course, you should review this conceptual design material but save an in-depth study of it until after you have experienced the course in the classroom with students. 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 *Framework* and *NGSS*, and have designed powerful connections to the Common Core State Standards for English Language Arts.

Contents

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.

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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 primarily taken from the NGSS for middle school.

Disciplinary Core Ideas Addressed

The **Electromagnetic Force 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, with a connection to earth sciences.

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. Forces on an object can also change its shape or orientation. 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.]

- **PS2.B: Types of interactions**
  What underlying forces explain the variety of interactions observed? [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.

  Forces that act at a distance (gravitational, electric, and magnetic) can be explained by force fields that extend through space and can be mapped by their effect on a test object (a ball, 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-PS2-2.** 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.

- **MS-PS2-3.** Ask questions about data to determine the factors that affect the strength of electric and magnetic forces.
- **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. Energy is also stored in the electric fields between charged particles and the magnetic fields between magnets, and it changes when these objects are moved relative to one another. Stored energy is decreased in some chemical reactions and increased in others.]
- **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. Likewise, two magnetic and electrically charged objects interacting at a distance exert forces on each other that can transfer energy between the interacting objects.]

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

- **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 Sciences

Core idea ESS3: Earth and Human Activity—How do Earth's surface processes and human activities affect each other?

- **ESS3.A: Natural resources**
  How do humans depend on Earth's resources? [Humans depend on Earth's land, ocean, atmosphere, and biosphere for many different resources. Minerals, fresh water, and biosphere resources are limited, and many are not renewable or replaceable over human lifetimes. These resources are distributed unevenly around the planet as a result of past geological processes. Renewable energy resources, and the technologies to exploit them, are being rapidly developed.]
- **ESS3.C: Human impacts on earth systems**
  How do humans change the planet? [Human activities have significantly altered the biosphere, sometimes damaging or destroying natural habitats and causing the extinction of many other species. But changes to Earth's environments can have different impacts (negative and positive) for different living things. Typically, as human populations and per-capita consumption of natural resources increase, so do the negative impacts on Earth unless the activities and technologies involved are engineered otherwise.]

The following NGSS grades 6–8 performance expectations for ESS3 are derived from the Framework disciplinary core ideas above.

- **MS-ESS3-4.** Construct an argument supported by evidence for how increases in human population and per-capita consumption of natural resources impact Earth's systems.

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. Simulations are useful for predicting what would happen if various parameters of the model were changed, as well as for making improvements to the model based on peer and leader (e.g., teacher) feedback.]
- **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 Addressed

1. 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.
- Ask questions to identify and/or clarify evidence and/or the premise(s) of an argument.
- 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.

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.
- Analyze and interpret data to provide evidence for phenomena.
- Analyze and interpret data to determine similarities and differences in findings.

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 **Electromagnetic Force 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.

- 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*

- Apply mathematical concepts and/or processes (e.g., ratio, rate, percent, basic operations, simple algebra) to scientific and engineering questions and problems.
- Use digital tools and/or mathematical concepts and arguments to test and compare proposed solutions to an engineering design problem.

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 an explanation using models or representations.
- 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 reasoning to show why the data or evidence is adequate for the explanation or conclusion.
- 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*

- Respectfully provide and receive critiques about one's explanations, procedures, models, and questions by citing relevant evidence and posing and responding to questions that elicit pertinent elaboration and detail.
- Construct, use, and/or present an oral and written argument 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.
- 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.
- Communicate scientific and/or technical information (e.g., about a proposed object, tool, process, system) in writing and/or through oral presentations.

Crosscutting Concepts Addressed

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

- Macroscopic patterns are related to the nature of microscopic and atomic-level structure.
- 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.

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.

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.*

- Systems may interact with other systems; they may have subsystems and be a part of larger complex 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.

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.

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

- Energy may take different forms (e.g., energy in fields, thermal energy, energy of motion).
- 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.*

- Small changes in one part of a system might cause large changes in another part.
- 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 addresses questions about the natural and material world.** Scientific knowledge is constrained by human capacity, technology, and materials. Science limits its explanations to systems that lend themselves to observation and empirical evidence. Scientific knowledge can describe consequences of actions but is not responsible for society's decisions.
- **Science is a human endeavor.** Men and women from different social, cultural, and ethnic backgrounds work as scientists and engineers. Scientists and engineers rely on human qualities such as persistence, precision, reasoning, logic, imagination, and creativity. Scientists and engineers are guided by habits of mind, such as intellectual honesty, tolerance of ambiguity, skepticism, and openness to new ideas. Advances in technology influence the progress of science, and science has influenced advances in technology.

CONNECTIONS

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

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.
- **Influence of science, engineering, and technology 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.
- **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 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.

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 Electromagnetic Force

Force and Motion

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 (kinetic energy) unless a force is applied. Not just any force will make an object move. 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.

Magnets are fascinating because they apply an invisible force. When a magnet is placed near another magnet, it attracts or repels, and it can do this even when it does not touch the other magnet. This is because a magnet exerts force through a field that extends from its poles. As you extend further from the magnet throughout the field, its force grows weaker.

Electric current running through a circuit also exerts a force. This force can make things happen in various electric components, such as light or heat from a lightbulb, or the rotation of a motor. Light, heat, and motion are evidence of energy. Electrical energy has transferred to another part of the system.

As electricity runs through a wire, it produces a small magnetic field around the wire. This is evidence of the electromagnetic force, one of the four fundamental forces that govern everything we know about the physical world. The relationship between electricity and magnetism can be manipulated by engineers to create electromagnets that are used to start car engines, run washing machines, move high-speed trains, and for medical scanning of internal organs.

As electricity and magnetism interact to move objects or give off light, energy transfers. Energy always comes from somewhere; it cannot be created or destroyed. Potential energy stored in systems, like the chemical potential energy of a battery, provides an energy source, but the energy must originate somewhere. Most human energy use relies on renewable systems like wind (kinetic energy), the Sun (solar energy), and hydroelectricity (kinetic energy), or nonrenewable resources like fossil fuels (chemical potential energy). Because human energy use continues to increase, it is increasingly important to develop new energy-efficient technologies and ways to maximize renewable energy sources.

CONCEPTUAL FRAMEWORK
Physical Sciences, Energy and Change: Electromagnetic Force

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.

- A force is a push or a pull. Net force is the sum of all the forces acting on a mass.
- The magnitude of the magnetic force between two interacting magnetic fields decreases as the distance between them increases.

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

- Magnets are surrounded by an invisible magnetic field. Magnetic materials may become temporary magnets when they interact with magnetic fields.
- The magnetic field produced by a current-carrying wire can induce magnetism in a piece of iron or steel, forming an electromagnet.

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.
- Changing the position of an object in an electric or magnetic field changes the potential energy.
- Energy sources can be categorized as renewable or non-renewable.

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.

- Energy cannot be created or destroyed, only transferred.
- Every energy use can be described as a sequence of energy transfers.

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 their 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.

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 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 can engage in engineering practices without fully engaging in the iterative process of design.

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: Electromagnetic Force

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 **Electromagnetic Force 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)		
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)	• Gravity is an attractive force between two objects; a falling object increases speed with a constant acceleration due to gravity. • 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 object's mass, the greater the force needed to change motion. • For interacting objects, the force exerted by one on the second is equal in strength to the force that the second object exerts on the first, but in the opposite direction.	• Kinetic energy is energy of moving things; potential energy is energy dependent on the position of an object within a system. • Kinetic energy is transferred in a collision. • 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.
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.	

Electromagnetic Force	Motion and Stability: Forces and Interactions	Energy Transfer and Conservation
	• A force is a push or a pull. Net force is the sum of all the forces acting on a mass. • The magnitude of the magnetic force between two interacting magnetic fields decreases as the distance between them increases. • Magnets are surrounded by an invisible magnetic field. Magnetic materials may become temporary magnets when they interact with magnetic fields. • The magnetic field produced by a current-carrying wire can induce magnetism in a piece of iron or steel, forming an electromagnet.	• Kinetic energy is energy of motion; potential energy is dependent on the position of an object within a system. • Changing the position of an object in an electric or magnetic field changes the potential energy. • Energy sources can be categorized as renewable or nonrenewable. • Energy cannot be created or destroyed, only transferred. • Every energy use can be described as a sequence of energy transfers.

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-PS2-2
MS-PS2-3
MS-PS2-5
MS-PS3-2
MS-PS3-5

Earth and Space Sciences
MS-ESS3-4

Engineering Design
MS–ETS1-1
MS–ETS1-2
MS–ETS1-3
MS–ETS1-4

See pages 34–38 in this chapter for more details on the grades 6–8 NGSS Performance Expectations.

CONNECTIONS TO NGSS BY INVESTIGATION

Inv. 1: What Is Force?

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 Engaging in an 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. 2. Determine the central ideas or conclusions of a text; provide an accurate summary of the text distinct from prior knowledge or opinions. 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. 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). 10. Read and comprehend science/technical texts in the grades 6–8 text complexity band independently and proficiently. **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. **Speaking and Listening** 5. Integrate multimedia and visual displays into presentations to clarify information, strengthen claims and evidence, and add interest. 6. Analyze the author's purpose in providing an explanation, describing a procedure, or discussing an experiment in a text. **Language** 4. Determine or clarify the meaning of unknown words or phrases. 5. Demonstrate understanding of word relationships and nuances in word meaning.

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)** • 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)**		Patterns Cause and effect Systems and system models Energy and matter 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 Engaging in argument from evidence 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. 4. Determine the meaning of symbols, key terms, and domain-specific words and phrases as used in the text. 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. 7. Integrate quantitative or technical information expressed in words in a text with a version of that information expressed visually. 9. Compare and contrast the information gained from experiments, simulations, video, or multimedia sources with that gained from reading a text. 10. Read and comprehend science texts in the grades 6–8 text complexity independently and proficiently. **Writing—Literacy in Science and Technical Subjects** 8. Gather relevant information from multiple print and digital sources, using search terms effectively. **Speaking and Listening** 6. Adapt speech to a variety of contexts and tasks, demonstrating command of formal English. **Language** 5. Demonstrate understanding of word relationships. 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** • 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. **(MS-PS2-3)** • 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 ball, a charged object, or a magnet, respectively). **(MS-PS2-5)**	**PS3.A: Definitions of energy** • A system of objects may also contain stored (potential) energy, depending on their relative positions. **(MS-PS3-2)** **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)**	Patterns Cause and effect Systems and system models Energy and matter

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. 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. 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 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. 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. **Writing—Literacy in Science and Technical Subjects** 8. Gather relevant information from multiple print and digital sources, using search terms effectively. **Speaking and Listening** 1. Engage effectively in a range of collaborative discussions. 4. Present claims and findings, emphasizing salient points in a focused, coherent manner with relevant evidence, valid reasoning, and well-chosen details.

Disciplinary Core Ideas		Crosscutting Concepts
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. **(MS-PS2-3)** • 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 ball, a charged object, or a magnet, respectively). **(MS-PS2-5)** **PS3.A: Definitions of energy** • A system of objects may also contain stored (potential) energy, depending on their relative positions. **(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. Specification of constraints includes consideration of scientific principles and other relevant knowledge that are likely to limit possible solutions. **(secondary to MS-PS3-3)** **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. There are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of a problem. **(secondary to MS-PS3-3)** • Sometimes parts of different solutions can be combined to create a solution that is better than any of its predecessors. **(MS-ETS1-3)** • Models of all kinds are important for testing solutions. **(MS-ETS1-4)** **ETS1.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. **(MS-ETS1-3, MS-ETS1-4)**	Patterns Cause and effect Systems and system models Energy and matter Structure and function

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 Constructing explanations 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. 2. Determine the central ideas or conclusions of a text; provide an accurate summary of the text distinct. 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 as they are used in a specific scientific or technical context relevant to grades 6–8 texts and topics. 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. 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. **Writing—Literacy in Science and Technical Subjects** 9. Draw evidence from informational texts to support analysis, reflection, and research. **Speaking and Listening** 5. Integrate multimedia and visual displays into presentations to clarify information, strengthen claims and evidence, and add interest. **Language** 5. Demonstrate understanding of word relationships and nuances in word meaning. 6. Acquire and use academic and domain-specific words and phrases.

Disciplinary Core Ideas		Crosscutting Concepts
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)**	**ESS3.A: Natural resources** • Humans depend on Earth's land, ocean, atmosphere, and biosphere for many different resources. Minerals, fresh water, and biosphere resources are limited, and many are not renewable or replaceable over human lifetimes. **(MS-ESS3-1)** **ESS3.C: Human impacts on Earth systems** • Typically as human populations and per-capita consumption of natural resources increase, so do the negative impacts on Earth unless the activities and technologies involved are engineered otherwise. **(MS-ESS3-3, MS-ESS3-4)**	Patterns Cause and effect Scale, proportion, and quantity Systems and system models Energy and matter Structure and function Stability and change

RECOMMENDED FOSS NEXT GENERATION K–8 SCOPE AND SEQUENCE

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

*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