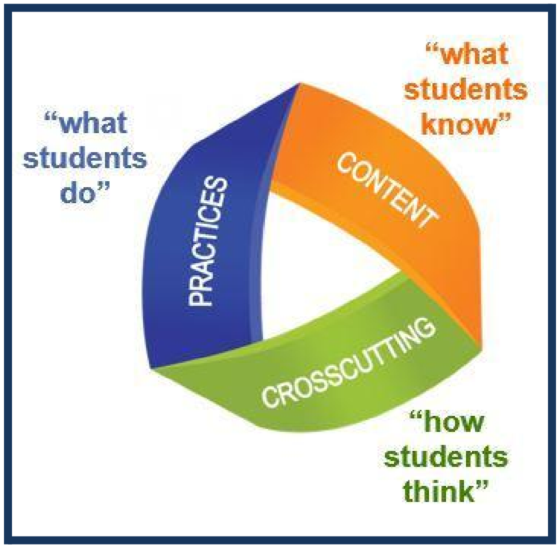
Ledyard Public Schools
Ledyard High School
NGSS Science Curriculum
Physics 1



1.0 credit course
Required for graduation

Table of Contents

Quick Links

A Framework for K-12 Science Education	NGSS Website	K-12 Endpoint Progression

District Philosophy

Ledyard's vision for K-12 inquiry based science is to engage students in scientific and engineering practices as they apply crosscutting concepts to deepen their understanding of the core ideas in these fields.

A New Vision for Science Education

Implications of the Vision of the Framework for K-12 Science Education and the Next Generation Science Standards

SCIENCE EDUCATION WILL INVOLVE LESS:	SCIENCE EDUCATION WILL INVOLVE MORE:
Rote memorization of facts and terminology.	Facts and terminology learned as needed while developing explanations and designing solutions supported by evidence-based arguments and reasoning.
Learning of ideas disconnected from questions about phenomena.	Systems thinking and modeling to explain phenomena and to give a context for the ideas to be learned.
Teachers providing information to the whole class.	Students conducting investigations, solving problems, and engaging in discussions with teachers' guidance.
Teachers posing questions with only one right answer.	Students discussing open-ended questions that focus on the strength of the evidence used to generate claims.
Students reading textbooks and answering questions at the end of the chapter.	Students reading multiple sources, including science-related magazine and journal articles and web-based resources; students developing summaries of information.
Pre-planned outcome for "cookbook" laboratories or hands-on activities.	Multiple investigations driven by students' questions with a range of possible outcomes that collectively lead to a deep understanding of established core scientific ideas.
Worksheets.	Student writing of journals, reports, posters, and media presentations that explain and argue.
Oversimplification of activities for students who are perceived to be less able to do science and engineering	Provision of supports so that all students can engage in sophisticated science and engineering practices

Source: National Research Council. (2015). *Guide to Implementing the Next Generation Science Standards* (pp. 8-9). Washington, DC: National Academies Press. http://www.nap.edu/catalog/18802/guide-to-implementing-the-next-generation-science-standards

Three Dimensions of the *Next Generation Science Standards*: Practices of Science and Engineering:

Scientific and Engineering Practices Matrix - SEP (appendix F)

Asking Questions and Defining Problems

A practice of science is to ask and refine questions that lead to descriptions and explanations of how the natural and designed world works and which can be empirically tested.

Engineering questions clarify problems to determine criteria for successful solutions and identify constraints to solve problems about the designed world. Both scientists and engineers also ask questions to clarify the ideas of others.

Planning and Carrying Out Investigations

Scientists and engineers plan and carry out investigations in the field or laboratory, working collaboratively as well as individually. Their investigations are systematic and require clarifying what counts as data and identifying variables or parameters. Engineering investigations identify the effectiveness, efficiency, and durability of designs under different conditions.

Analyzing and Interpreting Data

Scientific investigations produce data that must be analyzed in order to derive meaning. Because data patterns and trends are not always obvious, scientists use a range of tools—including tabulation, graphical interpretation, visualization, and statistical analysis—to identify the significant features and patterns in the data. Scientists identify sources of error in the investigations and calculate the degree of certainty in the results. Modern technology makes the collection of large data sets much easier, providing secondary sources for analysis.

Engineering investigations include analysis of data collected in the tests of designs. This allows comparison of different solutions and determines how well each meets specific design criteria—that is, which design best solves the problem within given constraints. Like scientists, engineers require a range of tools to identify patterns within data and interpret the results. Advances in science make analysis of proposed solutions more efficient and effective.

Developing and Using Models

A practice of both science and engineering is to use and construct models as helpful tools for representing ideas and explanations. These tools include diagrams, drawings, physical replicas, mathematical representations, analogies, and computer simulations. Modeling tools are used to develop questions, predictions and explanations; analyze and identify flaws in systems; and communicate ideas. Models are used to build and revise scientific explanations and proposed engineered systems. Measurements and observations are used to revise models and designs.

Constructing Explanations and Designing Solutions

The products of science are explanations and the products of engineering are solutions. The goal of science is the construction of theories that provide explanatory accounts of the world. A theory becomes accepted when it has multiple lines of empirical evidence and greater explanatory power of phenomena than previous theories. The goal of engineering design is to find a systematic solution to problems that is based on scientific knowledge and models of the material world. Each proposed solution results from a process of balancing competing criteria of desired functions, technical feasibility, cost, safety, aesthetics, and compliance with legal requirements. The optimal choice depends on how well the proposed solutions meet criteria and constraints.

Engaging in Argument from Evidence

Argumentation is the process by which explanations and solutions are reached. In science and engineering, reasoning and argument based on evidence are essential to identifying the best explanation for a natural phenomenon or the best solution to a design problem. Scientists and engineers use argumentation to listen to, compare, and evaluate competing ideas and methods based on merits. Scientists and engineers engage in argumentation when investigating a phenomenon, testing a design solution, resolving questions about measurements, building data models, and using evidence to identify strengths and weaknesses of claims.

Using Mathematics and Computational Thinking

In both science and engineering, mathematics and computation are fundamental tools for representing physical variables and their relationships. They are used for a range of tasks such as constructing simulations; statistically analyzing data; and recognizing, expressing, and applying quantitative relationships. Mathematical and computational approaches enable scientists and engineers to predict the behavior of systems and test the validity of such predictions. Statistical methods are frequently used to identify significant patterns and establish correlational relationships.

Obtaining, Evaluating, and Communicating Information

Scientists and engineers must be able to communicate clearly and persuasively the ideas and methods they generate. Critiquing and communicating ideas individually and in groups is a critical professional activity. Communicating information and ideas can be done in multiple ways: using tables, diagrams, graphs, models, and equations as well as orally, in writing, and through extended discussions. Scientists and engineers employ multiple sources to acquire information that is used to evaluate the merit and validity of claims, methods, and designs.

NGSS@
NSTA
STEM STARTS HERE
www.nsta.org/ngss

Three Dimensions of the *Next Generation Science Standards*: Disciplinary Core Ideas:

Disciplinary Core Ideas Matrix - DCI (appendix E)

Physical Science	Life Science	Earth and Space Science	Engineering, Technology, and the Application of Science
PS1: Matter and Its Interactions PS1.A: Structure and Properties of Matter PS1.B: Chemical Reactions PS1.C: Nuclear Processes **PS2: Motion and Stability: Forces and Interactions** PS2.A: Forces and Motion PS2.B: Types of Interactions PS2.C: Stability and Instability in Physical Systems **PS3: Energy** PS3.A: Definitions of Energy PS3.B: Conservation of Energy and Energy Transfer PS3.C: Relationship Between Energy and Forces PS3.D: Energy in Chemical Processes and Everyday Life **PS4: Waves and Their Applications in Technologies for Information Transfer** PS4.A: Wave Properties PS4.B: Electromagnetic Radiation PS4.C: Information Technologies and Instrumentation	**LS1: From Molecules to Organisms: Structures and Processes** LS1.A: Structure and Function LS1.B: Growth and Development of Organisms LS1.C: Organization for Matter and Energy Flow in Organisms LS1.D: Information Processing **LS2: Ecosystems: Interactions, Energy, and Dynamics** LS2.A: Interdependent Relationships in Ecosystems LS2.B: Cycles of Matter and Energy Transfer in Ecosystems LS2.C: Ecosystem Dynamics, Functioning, and Resilience LS2.D: Social Interactions and Group Behavior **LS3: Heredity: Inheritance and Variation of Traits** LS3.A: Inheritance of Traits LS3.B: Variation of Traits **LS4: Biological Evolution: Unity and Diversity** LS4.A: Evidence of Common Ancestry and Diversity LS4.B: Natural Selection LS4.C: Adaptation LS4.D: Biodiversity and Humans	**ESS1: Earth's Place in the Universe** ESS1.A: The Universe and Its Stars ESS1.B: Earth and the Solar System ESS1.C: The History of Planet Earth **ESS2: Earth's Systems** ESS2.A: Earth Materials and Systems ESS2.B: Plate Tectonics and Large-Scale System Interactions ESS2.C: The Roles of Water in Earth's Surface Processes ESS2.D: Weather and Climate ESS2.E: Biogeology **ESS3: Earth and Human Activity** ESS3.A: Natural Resources ESS3.B: Natural Hazards ESS3.C: Human Impacts on Earth Systems ESS3.D: Global Climate Change	**ETS1: Engineering Design** ETS1.A: Defining and Delimiting an Engineering Problem ETS1.B: Developing Possible Solutions ETS1.C: Optimizing the Design Solution **ETS2: Links Among Engineering, Technology, Science, and Society** ETS2.A: Interdependence of Science, Engineering, and Technology ETS2.B: Influence of Engineering, Technology, and Science on Society and the Natural World

Developed by NSTA based on content from the *Framework for K-12 Science Education* and supporting documents for the *May 2012 Public Draft of the NGSS*

Three Dimensions of the *Next Generation Science Standards*: Crosscutting Concepts:

Crosscutting Concepts Matrix - CCC (appendix G)		
Patterns **Observed patterns of forms and events guide organization and classification, and they prompt questions about relationships and the factors that influence them.** **Cause and Effect: Mechanism and Explanation** **Events have causes, sometimes simple, sometimes multifaceted. A major activity of science is investigating and explaining causal relationships and the mechanisms by which they are mediated. Such mechanisms can then be tested across given contexts and used to predict and explain events in new contexts.**	**Scale, Proportion, and Quantity** **In considering phenomena, it is critical to recognize what is relevant at different measures of size, time, and energy and to recognize how changes in scale, proportion, or quantity affect a system's structure or performance.** **Systems and System Models** **Defining the system under study—specifying its boundaries and making explicit a model of that system—provides tools for understanding and testing ideas that are applicable throughout science and engineering.**	**Energy and Matter: Flows, Cycles, and Conservation** **Tracking fluxes of energy and matter into, out of, and within systems helps one understand the systems' possibilities and limitations.** **Structure and Function** **The way in which an object or living thing is shaped and its substructure determine many of its properties and functions.** **Stability and Change** **For natural and built systems alike, conditions of stability and determinants of rates of change or evolution of a system are critical elements of study.**

Developed by NSTA based on content from the *Framework for K-12 Science Education* and supporting documents for the *May 2012 Public Draft of the NGSS*

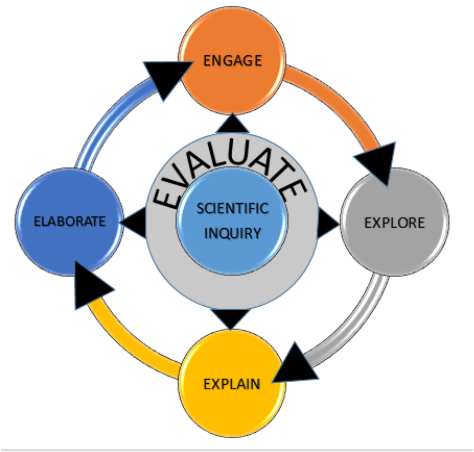
Connections to the Nature of Science

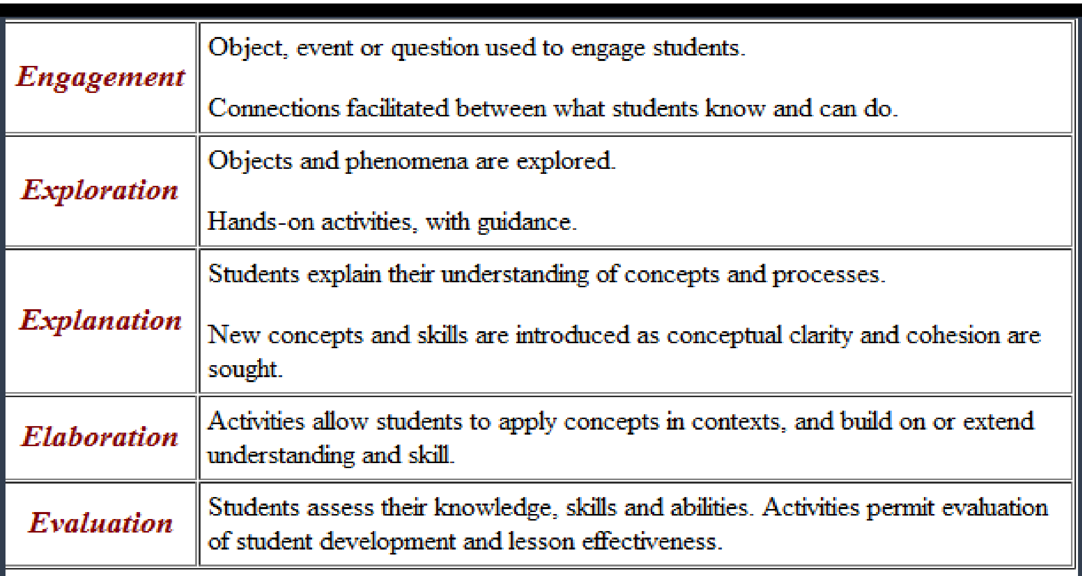
Nature of Science Practices	Nature of Science Crosscutting Concepts
These understandings about the nature of science are closely associated with the science and engineering practices, and are found in that section of the foundation box on a standards page. More information about the Connections to Engineering, Technology and Applications of Science can be found in Appendix H.	These understandings about the nature of science are closely associated with the crosscutting concepts, and are found in that section of the foundation box on a standards page. More information about the Connections to Engineering, Technology and Applications of Science can be found in Appendix H.
Scientific Investigations Use a Variety of Methods	Science is a Way of Knowing
Science Knowledge is Based on Empirical Evidence	Scientific Knowledge Assumes and Order and Consistency in Natural Systems
Scientific Knowledge is Open to Revision in Light of New Evidence	Science is a Human Endeavor
Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena.	Science Addresses Questions About the Natural and Material World

How does Ledyard Define Inquiry?

Inquiry is defined as a way of seeking information, knowledge, or truth through questioning. Inquiry is a way for a learner to acquire new information and data and turn it into useful knowledge. Inquiry involves asking good questions and developing robust investigations from them. Inquiry also involves considering possible solutions and consequences. A third component of inquiry is separating evidence based claims from common opinion, and communicating claims with others, and acting upon these claims when appropriate. Questions lead to gathering information through research, study, experimentation, observation, or interviews. During this time, the original question may be revised, a line of research refined, or an entirely new path may be pursued. As more information is gathered, it becomes possible to make connections and allows individuals to construct their own understanding to form new knowledge. Sharing this knowledge with others develops the relevance of the learning for both the student and a greater community. Sharing is followed by reflection and potentially more questions, bringing the inquiry process full circle.

Inquiry 5 Science Teaching Model





Engagement	Object, event or question used to engage students. Connections facilitated between what students know and can do.
Exploration	Objects and phenomena are explored. Hands-on activities, with guidance.
Explanation	Students explain their understanding of concepts and processes. New concepts and skills are introduced as conceptual clarity and cohesion are sought.
Elaboration	Activities allow students to apply concepts in contexts, and build on or extend understanding and skill.
Evaluation	Students assess their knowledge, skills and abilities. Activities permit evaluation of student development and lesson effectiveness.

Course Overview

This course addresses, in part or in total, three of the four NGSS physical science Core Ideas. The first is **Motion and Stability: Forces and Interactions**, which is introduced in the Chemistry curriculum in the context of chemical bonding, and is expanded to support students' understanding of ideas related to why some objects will keep moving, why objects will fall to the ground and why objects are attracted to each other. The second Core Idea addressed is **Energy**, which focuses on helping students to answer the question, "How is energy transferred and conserved?" The third Core Idea, **Waves and Their Applications in Technologies for Information Transfer** expands on the basics of electromagnetic radiation and waves, introduced in Chemistry, and focuses on helping students understand how waves are used to transfer energy, and send and store information. This course builds on the knowledge and skills from K-8, supporting high school students in meeting NGSS performance expectations.

- This course addresses all of the skills and attributes in Ledyard High Schools Vision of the Graduate with an emphasis on Problem Solving and Critical Thinking.
- LHS Vision of the Graduate skills and attributes:
    1. Collaboration
    2. Communicate information clearly and effectively in a variety of settings.
    3. **Problem Solving**
    4. **Critical thinking**
    5. Perseverance
    6. Creativity

UNIT 1 : Motion and Stability: Forces and Interactions (35 class periods)

Compelling question: How can one explain and predict interactions between objects and within systems?

Core Idea PS2- Interactions between any two objects can cause changes in one or both of them. An understanding of the forces between objects is important for describing how their motions change, as well as for predicting stability or instability in systems at any scale. All forces between objects arise from a few types of interactions: gravity, electromagnetism, and the strong and weak nuclear interactions.

Component Ideas	**NGSS Performance Expectations**
PS2.A: FORCES AND MOTION Supporting question: *How can one predict an object's continued motion, changes in motion, or stability?*	HS-PS2-1, HS-PS2-2, HS-PS2-3
PS2.B: TYPES OF INTERACTIONS Supporting question: *What underlying forces explain the variety of interactions observed?*	HS-PS2-4, HS-PS2-5

NGSS Performance Expectations

Students who demonstrate understanding can:

HS-PS2-1

Analyze data to support the claim that Newton's second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration.

Clarification Statement: Examples of data could include tables or graphs of position or velocity as a function of time for objects subject to a net unbalanced force, such as a falling object, an object rolling down a ramp, or a moving object being pulled or pushed by a constant force.

Assessment Boundary*:* NGSS Assessment is limited to one-dimensional motion and to macroscopic objects moving at non-relativistic speeds. LHS assessment shall include torque and rotational acceleration, and centripetal force and acceleration.

HS-PS2-2

Use mathematical representations to support the claim that the total momentum of a system of objects is conserved when there is no net force on the system.

Clarification Statement: NGSS emphasis is on the quantitative conservation of momentum in interactions and the qualitative meaning of this principle. LHS will include qualitative treatment of rotational inertia and conservation of angular momentum.

Assessment Boundary: NGSS assessment is limited to systems of two macroscopic bodies moving in one dimension. LHS shall include rotating systems.

HS-PS2-3

Apply scientific and engineering ideas to design, evaluate, and refine a device that minimizes the force on a macroscopic object during a collision.

Clarification Statement: Examples of evaluation and refinement could include determining the success of the device at protecting an object from damage and modifying the design to improve it. Examples of a device could include a football helmet or a parachute.

Assessment Boundary: Assessment is limited to qualitative evaluations and/or algebraic manipulations.

HS-PS2-4

Use mathematical representations of Newton's Law of Gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects.

Clarification Statement: Emphasis is on both quantitative and conceptual descriptions of gravitational and electric fields.

Assessment Boundary: Assessment is limited to systems with two objects.

HS-PS2-5

Plan and conduct an investigation to provide evidence that an electric current can produce a magnetic field and that a changing magnetic field can produce an electric current.

Assessment Boundary: Assessment is limited to designing and conducting investigations with provided materials and tools.

PS2.A: Forces and Motion

(HS-PS2-1, HS-PS2-2, HS-PS2-3)

Supporting question: *How can one predict an object's continued motion, changes in motion, or stability?*

Suggested Content –Vocabulary in **bold**

- Interactions of an object with another object can be explained and predicted using the concept of **forces**, which can cause a change in motion of one or both of the interacting objects. An individual force acts on one particular object and is described by its strength and direction. The strengths of forces can be measured and their values compared.
- What happens when a force is applied to an object depends not only on that force but also on all the other forces acting on that object. A **static object** typically has multiple forces acting on it, but they sum to zero. If the total (**vector sum**) force on an object is not zero, however, its motion will change. 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**).
- At the macroscale, the motion of an object subject to forces is governed by **Newton's second law of motion**. Under everyday circumstances, the mathematical expression of this law in the form **F = ma** (total force = mass times acceleration) accurately predicts changes in the motion of a single macroscopic object of a given mass due to the total force on it. But at speeds close to the speed of light, the second law is not applicable without modification. Nor does it apply to objects at the molecular, atomic, and subatomic scales, or to an object whose mass is changing at the same time as its speed.

  An understanding of the forces between objects is important for describing how their motions change, as well as for predicting stability or instability in systems at any scale.
- For speeds that are small compared with the speed of light, the **momentum** of an object is defined as its mass times its velocity. For any system of interacting objects, the total momentum within the **system** changes only due to transfer of momentum into or out of the system, either because of **external forces** acting on the system or because of matter flows. Within an isolated system of interacting objects, any change in momentum of one object is balanced by an equal and oppositely directed change in the total momentum of the other objects. Thus total momentum is a **conserved quantity**.
- Forces can also cause objects to rotate. **Centripetal forces** are required to keep an object moving in a circular path. The centripetal force causes a mass to have a **centripetal acceleration**, just as a normal push, pull or net force causes a linear acceleration.
- When moving from translational to rotational motion, many of the concepts don't really change at all. You just replace translational quantities with rotational ones. Practically every quantity in translational motion has a rotational equivalent. Instead of linear acceleration, we have rotational (or angular) acceleration. Instead of forces, we have **torques**. Instead of momentum, we have **angular momentum**. Instead of velocity, we have **angular velocity**. And instead of mass, we have the **moment of inertia**.

Disciplinary Core Ideas	**Observable features of student performance** *Unless otherwise specified, "descriptions" referenced in the evidence statements could include but are not limited to written, oral, pictorial, and kinesthetic descriptions
PS2.A: Forces and Motion · Newton's second law accurately predicts changes in the motion	HS-PS2-1 1. Organizing data a. Students organize data that represent the net force on a macroscopic object, its mass (which is held constant), and its acceleration (e.g., via tables, graphs, charts, vector drawings). 2. Identifying relationships a. Students use tools, technologies, and/or models to analyze the data and identify relationships within the datasets, including: i. A more massive object experiencing the same net force as a less massive object has a smaller acceleration, and a larger net force on a given object produces a correspondingly larger acceleration; and ii. The result of gravitation is a constant acceleration on macroscopic objects as evidenced by the fact that the ratio of net force to mass remains constant. 3. Interpreting data a. Students use the analyzed data as evidence to describe* that the relationship between the observed quantities is accurately modeled across the range of data by the formula $a = F_{net}/m$ (e.g., double force yields double acceleration, etc.). b. Students use the data as empirical evidence to distinguish between causal and correlational relationships linking force, mass, and acceleration. c. Students express the relationship $F_{net}=ma$ in terms of causality, namely that a net force on an object causes the object to accelerate.
PS2.A: Forces and Motion · Momentum is defined for a particular frame of reference; it is the mass times the velocity of the object. · If a system interacts with objects outside itself, the total momentum of the system can change; however,	HS-PS2-2 1. Representation a. Students clearly define the system of the two interacting objects that is represented mathematically, including boundaries and initial conditions. b. Students identify and describe* the momentum of each object in the system as the product of its mass and its velocity, $p = mv$ (p and v are restricted to one-dimensional vectors), using the mathematical representations.

any such change is balanced by changes in the momentum of objects outside the system.	c. Students identify the claim, indicating that the total momentum of a system of two interacting objects is constant if there is no net force on the system. 2. Mathematical modeling a. Students use the mathematical representations to model and describe* the physical interaction of the two objects in terms of the change in the momentum of each object as a result of the interaction. b. Students use the mathematical representations to model and describe* the total momentum of the system by calculating the vector sum of momenta of the two objects in the system. 3. Analysis a. Students use the analysis of the motion of the objects before the interaction to identify a system with essentially no net force on it. b. Based on the analysis of the total momentum of the system, students support the claim that the momentum of the system is the same before and after the interaction between the objects in the system, so that momentum of the system is constant. c. Students identify that the analysis of the momentum of each object in the system indicates that any change in momentum of one object is balanced by a change in the momentum of the other object, so that the total momentum is constant. **HS-PS2-3** 1. Using scientific knowledge to generate the design solution a. Students design a device that minimizes the force on a macroscopic object during a collision. In the design, students: i. Incorporate the concept that for a given change in momentum, force in the direction of the change in momentum is decreased by increasing the time interval of the collision ($F\Delta t = m\Delta v$); and ii. Explicitly make use of the principle above so that the device has the desired effect of reducing the net force applied to the object by extending the time the force is applied to the object during the collision. b. In the design plan, students describe* the scientific rationale for their choice of materials and for the structure of the device.

ETS1.A: Defining and Delimiting an Engineering Problem

· Criteria and constraints also include satisfying any requirements set by society, such as taking issues of risk mitigation into account, and they should be quantified to the extent possible and stated in such a way that one can tell if a given design meets them. (secondary)

ETS1.C: Optimizing the Design Solution

· Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (trade offs) may be needed. (secondary)

2. Describing criteria and constraints, including quantification when appropriate
    a. Students describe* and quantify (when appropriate) the criteria and constraints, along with the tradeoffs implicit in these design solutions. Examples of constraints to be considered are cost, mass, the maximum force applied to the object, and requirements set by society for widely used collision-mitigation devices (e.g., seatbelts, football helmets).

3. Evaluating potential solutions
    a. Students systematically evaluate the proposed device design or design solution, including describing* the rationales for the design and comparing the design to the list of criteria and constraints.
    b. Students test and evaluate the device based on its ability to minimize the force on the test object during a collision. Students identify any unanticipated effects or design performance issues that the device exhibits.

4. Refining and/or optimizing the design solution
    a. Students use the test results to improve the device performance by extending the impact time, reducing the device mass, and/or considering cost-benefit analysis.

Cause and Effect

- Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. (HS-PS2-1)

Systems and System Models

· When investigating or describing a system, the boundaries and initial conditions of the system need to be defined. (HS-PS2-2)

Connections to Nature of Science

Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena

· Theories and laws provide explanations in science. (HS-PS2-1)

· Laws are statements or descriptions of the relationships among observable phenomena. (HS-PS2-1)

Science and Engineering Practices

Analyzing and Interpreting Data

- Analyzing data in 9–12 builds on K–8 and progresses to introducing more detailed statistical analysis, the comparison of data sets for consistency, and the use of models to generate and analyze data. Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution. (HS-PS2-1)

Using Mathematics and Computational Thinking

Mathematical and computational thinking at the 9-12 level builds on K-8 and progresses to using algebraic thinking and analysis; a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms; and computational tools for statistical analysis to analyze, represent and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions.

· Use mathematical representations of phenomena or design solutions to describe and/or support claims and/or explanations. (HS-PS2-2)

Constructing Explanations and Designing Solutions

- Refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and trade off considerations. (HS-PS2-3)

Grade Band Endpoint for PS2.A

By the end of grade 12:

Newton's second law accurately predicts changes in the motion of macroscopic objects, but it requires revision for subatomic scales or for speeds close to the speed of light. (Boundary: No details of quantum physics or relativity are included at this grade level.)

Momentum is defined for a particular frame of reference; it is the mass times the velocity of the object. In any system, total momentum is always conserved. If a system interacts with objects outside itself, the total momentum of the system can change; however, any such change is balanced by changes in the momentum of objects outside the system.

K-12 Endpoint Progression

Suggested Activities

Required Activities:

- Impulse/Change in Momentum design activity similar to egg drop. (Run a car holding a “passenger cart” into shock absorbing barriers designed and built by students.)

Suggested Activities:

- Graph Matching Activity (Vernier lab with sonic rangers; linear motion)
- Vector Addition (PHET)
- F=ma activity (LHS lab or Online lesson Univ of Colorado-Boulder-Teach Engineering)
- Conservation of Momentum (Collisions) Lab (Vernier)
- Action Reaction phenomenon
- Newton’s First Law Vignette- interactive video vignettes; demos and data graphing
- Force Interactive-F=ma, The Physics Classroom plus document in LHS shared folder
- Newton’s Second Law Vignette
- Newton’s Third Law Vignette
- A Force Story-create a “story” using at least six different types of force. (See LHS shared folder)

Modifications to Content/Differentiation

Priority	Enrichment
- Newton’s laws of motion, Conservation of Momentum, Impulse, - Torque and rotational acceleration, and centripetal force and acceleration (conceptual)	-More complicated applications -Mathematical treatment of graphs (curve-fitting, linearizing data) -Quantitative treatment of rotational motion concepts.

Suggested Assessments

- Traditional assessment: multiple choice and free response questions, or
- The above project(s) using the eight science and engineering practice standards, or
- A combination of traditional assessment with project, or
- Other format of teacher’s choice

*Required assessments will be determined

PS2.B: TYPES OF INTERACTIONS

HS-PS2-4, HS-PS2-5

Supporting question: *What underlying forces explain the variety of interactions observed?*

Suggested Content– Vocabulary in **bold**

- All forces between objects arise from a few types of interactions: **gravity**, **electromagnetism**, and strong and weak nuclear interactions. Collisions between objects involve forces between them that can change their motion. Any two objects in contact also exert forces on each other that are electromagnetic in origin. These forces result from deformations of the objects' substructures and the **electric charges** of the particles that form those substructures (e.g., a table supporting a book, friction forces).
- **Gravitational, electric,** and **magnetic forces** between a pair of objects do not require that they be in contact. These forces are explained by **force fields** that contain energy and can transfer energy through space. These fields can be mapped by their effect on a test object (**mass**, **charge**, or **magnet**, respectively).
- Objects with mass are sources of **gravitational fields** and are affected by the gravitational fields of all other objects with mass. Gravitational forces are always attractive. For two human-scale objects, these forces are too small to observe without sensitive instrumentation. Gravitational interactions are noteworthy when very massive objects are involved. Thus the gravitational force due to Earth, acting on an object near Earth's surface, pulls that object toward the planet's center. **Newton's law of universal gravitation** provides the mathematical model to describe and predict the effects of gravitational forces between distant objects. These long-range gravitational interactions govern the evolution and maintenance of large-scale structures in the universe (e.g., the solar system, galaxies) and the patterns of motion within them.
- Electric forces and magnetic forces are different aspects of a single electromagnetic interaction. Such forces can be attractive or repulsive, depending on the relative **sign** of the electric charges involved, the direction of **current flow**, and the orientation of magnets. The forces' **magnitudes** depend on the magnitudes of the charges, currents, and **magnetic strengths** as well as on the distances between the interacting objects. All objects with electrical charge or magnetization are sources of electric or magnetic fields and can be affected by the electric or magnetic fields of other such objects. Attraction and repulsion of electric charges at the atomic scale explain the structure, properties, and transformations of matter and the **contact forces** between material objects (link to PS1.A and PS1.B). **Coulomb's law** provides the mathematical model to describe and predict the effects of electrostatic forces (relating to stationary electric charges or fields) between distant objects.

Disciplinary Core Ideas	**Observable features of student performance** *Unless otherwise specified, "descriptions" referenced in the evidence statements could include but are not limited to written, oral, pictorial, and kinesthetic descriptions.
PS2.B: Types of Interactions · Newton's law of universal gravitation and Coulomb's law provide the mathematical models to describe and predict the effects of gravitational and electrostatic forces between distant objects. · Forces at a distance are explained by fields (gravitational, electric, and magnetic) permeating space that can transfer energy through space. Magnets or electric currents cause magnetic fields; electric charges or changing magnetic fields cause electric fields. (HS-PS2-4) **PS3.A: Definitions of Energy**	**HS-PS2-4** 1. Representation a. Students clearly define the system of the interacting objects that is mathematically represented. b. Using the given mathematical representations, students identify and describe* the gravitational attraction between two objects as the product of their masses divided by the separation distance squared ($F_g = -G\, m_1 m_2 / d^2$), where a negative force is understood to be attractive. c. Using the given mathematical representations, students identify and describe* the electrostatic force between two objects as the product of their individual charges divided by the separation distance squared ($F_e = k\, q_1 q_2 / d^2$), where a negative force is understood to be attractive. 2. Mathematical modeling a. Students correctly use the given mathematical formulas to predict the gravitational force between objects or predict the electrostatic force between charged objects. 3. Analysis a. Students describe* that the mathematical representation of the gravitational field ($F_g = -G\, m_1 m_2 / d^2$) only predicts an attractive force because mass is always positive. b. Students describe* that the mathematical representation of the electric field ($F_e = k\, q_1 q_2 / d^2$) predicts both attraction and repulsion because electric charge can be either positive or negative. c. Students use the given formulas for the forces as evidence to describe* that the change in the energy of objects interacting through electric or gravitational forces depends on the distance between the objects. **HS-PS2-5** 1. Identifying the phenomenon to be investigated a. Students describe* the phenomenon under investigation, which includes the following idea: that an electric current produces a magnetic field and that a changing magnetic field produces an electric current. 2. Identifying the evidence to answer this question

· "Electrical energy" may mean energy stored in a battery or energy transmitted by electric currents. (secondary) (HS-PS2-5)	a. Students develop an investigation plan and describe* the data that will be collected and the evidence to be derived from the data about 1) an observable effect of a magnetic field that is uniquely related to the presence of an electric current in the circuit, and 2) an electric current in the circuit that is uniquely related to the presence of a changing magnetic field near the circuit. Students describe* why these effects seen must be causal and not correlational, citing specific cause-effect relationships. 3. <u>Planning for the investigation</u> a. In the investigation plan, students include: i. The use of an electric circuit through which electric current can flow, a source of electrical energy that can be placed in the circuit, the shape and orientation of the wire, and the types and positions of detectors; ii. A means to indicate or measure when electric current is flowing through the circuit; iii. A means to indicate or measure the presence of a local magnetic field near the circuit; and iv. A design of a system to change the magnetic field in a nearby circuit and a means to indicate or measure when the magnetic field is changing. b. In the plan, students state whether the investigation will be conducted individually or collaboratively. 4. <u>Collecting the data</u> a. Students measure and record electric currents and magnetic fields. 5. <u>Refining the design</u> a. Students evaluate their investigation, including an evaluation of: i. The accuracy and precision of the data collected, as well as limitations of the investigation; and ii. The ability of the data to provide the evidence required. b. If necessary, students refine the investigation plan to produce more accurate, precise, and useful data such that the measurements or indicators of the presence of an electric current in the circuit and a magnetic field near the circuit can provide the required evidence.

Crosscutting Concepts

Patterns

- Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena. (HS-PS2-4)

Cause and Effect (HS-PS2-5)

- Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects.

Science and Engineering Practices

Using Mathematics and Computational Thinking

Mathematical and computational thinking at the 9-12 level builds on K-8 and progresses to using algebraic thinking and analysis; a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms; and computational tools for statistical analysis to analyze, represent and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions.

- Use mathematical representations of phenomena or design solutions to describe and/or support claims and/or explanations. (HS-PS2-4)

Planning and Carrying Out Investigations

Planning and carrying out investigations to answer questions or test solutions to problems in 9–12 builds on K–8 experiences and progresses to include investigations that provide evidence for and test conceptual, mathematical, physical and empirical models.

- Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly. (HS-PS2-5)

Grade Band Endpoints for PS2.B

By the end of grade 12:

Newton’s law of universal gravitation and Coulomb’s law provide the mathematical models to describe and predict the effects of gravitational and electrostatic forces between distant objects.

Forces at a distance are explained by fields permeating space that can transfer energy through space. Magnets or changing electric fields cause magnetic fields; electric charges or changing magnetic fields cause electric fields. Attraction and repulsion between electric charges at the atomic scale explain the structure, properties, and transformations of matter, as well as the contact forces between material objects.

K-12 Endpoint Progression

Activities

Required Activities: - Gravity Force Lab (PHET simulation)

Suggested Activities:

- Determining *g* on an Inclined Plane (LHS)
- Determining *g* with Picket Fence (Vernier)
- Simple Electric Circuits activities (CASTLE kits)
- Electromagnet design lab

Modifications to Content/Differentiation

Priority	Enrichment
- Newton's Law of Universal Gravitation and Coulomb's Law-conceptual and mathematical treatment - Relationships between electrical current and magnetic field	-Mathematical treatment of current-magnetic field relationships

Suggested Assessments

- Traditional assessment: multiple choice and free response questions, or
- The above project(s) using the eight science and engineering practice standards, or
- A combination of traditional assessment with project, or
- Other format of teacher's choice

*Required assessments will be determined.

UNIT 2 : Energy (35 class periods) Compelling question: How is energy transferred and conserved?	
Core Idea PS3 - Interactions of objects can be explained and predicted using the concept of transfer of energy from one object or system of objects to another. The total energy within a defined system changes only by the transfer of energy into or out of the system.	
Component Ideas	**Performance Expectations**
PS3.A: DEFINITIONS OF ENERGY Supporting question: *What is energy?*	**HS-PS3-1, HS-PS3-2, HS-PS3-3**
PS3.B: CONSERVATION OF ENERGY AND ENERGY TRANSFER Supporting questions: *What is meant by conservation of energy?* *How is energy transferred between objects and systems?*	**HS-PS3-1**
PS3.C: RELATIONSHIP BETWEEN ENERGY AND FORCES Supporting question: *How are forces related to energy?*	**HS-PS3-5**

NGSS Performance Expectations
Students who demonstrate understanding can:

HS-PS3-1
Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known.
Clarification Statement: Emphasis is on explaining the meaning of mathematical expressions used in the model.

Assessment Boundary: Assessment is limited to basic algebraic expressions or computations; to systems of two or three components; and to thermal energy, kinetic energy, and/or the energies in gravitational, magnetic, or electric fields.

HS-PS3-2

Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motion of particles (objects) and energy associated with the relative positions of particles (objects).

Clarification Statement: Examples of phenomena at the macroscopic scale could include the conversion of kinetic energy to thermal energy, the energy stored due to position of an object above the earth, and the energy stored between two electrically-charged plates. Examples of models could include diagrams, drawings, descriptions, and computer simulations.

HS-PS3-3

Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.

Clarification Statement: Emphasis is on both qualitative and quantitative evaluations of devices. Examples of devices could include Rube Goldberg devices, wind turbines, solar cells, solar ovens, and generators. Examples of constraints could include use of renewable energy forms and efficiency.

Assessment Boundary: Assessment for quantitative evaluations is limited to total output for a given input. Assessment is limited to devices constructed with materials provided to students.

HS-PS3-5

Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction.

Clarification Statement: Examples of models could include drawings, diagrams, and texts, such as drawings of what happens when two charges of opposite polarity are near each other.

Assessment Boundary: Assessment is limited to systems containing two objects. (Ionic bonding/Coulomb's Law is covered in Chemistry.)

PS3.A: DEFINITIONS OF ENERGY

HS-PS3-1, HS-PS3-2, HS-PS3-3

Supporting question: *What is energy?*

PS3.B: CONSERVATION OF ENERGY AND ENERGY TRANSFER

(HS-PS3-1)

Supporting questions: *What is meant by conservation of energy?*
How is energy transferred between objects and systems?

Suggested Content – Vocabulary in **bold**

- That there is a single quantity called **energy** is due to the remarkable fact that a system's total **energy is conserved**. Regardless of the quantities of energy transferred between subsystems and stored in various ways within the system, the total energy of a system changes only by the amount of energy transferred into and out of the system.
- At the macroscopic scale, energy manifests itself in multiple phenomena, such as **motion, light, sound, electrical** and **magnetic fields**, and **thermal energy**. Historically, different units were introduced for the energy present in these different phenomena, and it took some time

before the relationships among them were recognized. Energy is best understood at the microscopic scale, at which it can be modeled as either motions of particles or as stored in force fields (electric, magnetic, gravitational) that mediate interactions between particles. This last concept includes **electromagnetic radiation**, a phenomenon in which energy stored in fields moves across space (light, radio waves) with no supporting matter or **medium**.

- Motion energy is also called **kinetic energy**; defined in a given reference frame, it is proportional to the mass of the moving object and grows with the square of its speed. In contrast, a **sound wave** is a moving pattern of particle vibrations that transmits energy through a medium.
- Electric and magnetic fields also contain energy; any change in the relative positions of charged objects (or in the positions or orientations of magnets) changes the fields between them and thus the amount of energy stored in those fields. When a particle in a molecule of solid matter vibrates, energy is continually being transformed back and forth between the energy of motion and the energy stored in the electric and magnetic fields within the matter. Matter in a stable form minimizes the stored energy in the electric and magnetic fields within it.
- Energy stored in fields within a system can also be described as **potential energy**. For any system where the stored energy depends only on the spatial configuration of the system and not on its history, potential energy is a useful concept (e.g., a massive object above Earth's surface, a **compressed or stretched spring**). It is defined as a difference in energy compared to some arbitrary reference configuration of a system. For example, lifting an object increases the stored energy in the gravitational field between that object and Earth (gravitational potential energy) compared to that for the object at Earth's surface; when the object falls, the stored energy decreases and the object's kinetic energy increases. When a **pendulum** swings, some stored energy is transformed into kinetic energy and back again into stored energy during each swing. (In both examples, energy is transferred out of the system due to collisions with air, and for the pendulum, also by friction in its support.) Any change in potential energy is accompanied by changes in other forms of energy within the system, or by energy transfers into or out of the system.
- Electromagnetic radiation (such as light and X-rays) can be modeled as a wave of changing electric and magnetic fields.
- The idea that there are different forms of energy, such as **thermal energy**, **mechanical energy**, and **chemical energy**, is misleading, as it implies that the nature of the energy in each of these manifestations is distinct when in fact they all are ultimately, at the atomic scale, some mixture of kinetic energy, stored energy, and radiation. It is likewise misleading to call sound or light a form of energy; they are phenomena that, among their other properties, transfer energy from place to place and between objects.

- The total change of energy in any system is always equal to the total energy transferred into or out of the system. This is called **conservation of energy**. Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems. Many different types of phenomena can be explained in terms of **energy transfers**. Mathematical expressions, which quantify changes in the forms of energy within a system and transfers of energy into or out of the system, allow the concept of conservation of energy to be used to predict and describe the behavior of a **system**.

- When objects collide or otherwise come in contact, the motion energy of one object can be transferred to change the motion or stored energy (e.g., change in shape or temperature) of the other objects. For macroscopic objects, any such process (e.g., **collisions**, sliding contact) also transfers some of the energy to the surrounding air by sound or heat.
- Energy can also be transferred from place to place by **electric currents**.
- Uncontrolled systems always evolve toward more stable states—that is, toward more uniform energy distribution within the system or between the **system** and its environment (e.g., water flows downhill, objects that are hotter than their surrounding environment cool down). Any object or system that can degrade with no added energy is unstable. Eventually it will change or fall apart, although in some cases it may remain in the unstable state for a long time before decaying (e.g., long-lived radioactive isotopes).
- Thermal energy transfer is covered in Chemistry.

Disciplinary Core Ideas	Observable features of student performance *Unless otherwise specified, "descriptions" referenced in the evidence statements could include but are not limited to written, oral, pictorial, and kinesthetic descriptions.
PS3.A: Definitions of Energy · Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system. That there is a single quantity called energy is due to the fact that a system's total energy is conserved, even as, within the system, energy is continually transferred from one object to another and between its various possible forms. (HS-PS3-1) · At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy. (HS-PS3-2)	**HS-PS3-1** 1. Representation a. Students identify and describe* the components to be computationally modeled, including: i. The boundaries of the system and that the reference level for potential energy = 0 (the potential energy of the initial or final state does not have to be zero); ii. The initial energies of the system's components (e.g., energy in fields, thermal energy, kinetic energy, energy stored in springs — all expressed as a total amount of Joules in each component), including a quantification in an algebraic description to calculate the total initial energy of the system; iii. The energy flows in or out of the system, including a quantification in an algebraic description with flow into the system defined as positive; and iv. The final energies of the system components, including a quantification in an algebraic description to calculate the total final energy of the system. 2. Computational Modeling a. Students use the algebraic descriptions of the initial and final energy state of the system, along with the energy flows to create a computational model (e.g., simple computer program, spreadsheet, simulation software package application) that is based on the principle of the conservation of energy. b. Students use the computational model to calculate changes in the energy of one component of the system when changes in the energy of the other components and the energy flows are known.

- These relationships are better understood at the microscopic scale, at which all of the different manifestations of energy can be modeled as a combination of energy associated with the motion of particles and energy associated with the configuration (relative position of the particles). In some cases the relative position energy can be thought of as stored in fields (which mediate interactions between particles). This last concept includes radiation, a phenomenon in which energy stored in fields moves across space. (HS-PS3-2)

PS3.B: Conservation of Energy and Energy Transfer

- Conservation of energy means that the total change of energy in any system is always equal to the total energy transferred into or out of the system.
- Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems.
- Mathematical expressions, which quantify how the stored energy in a system depends on its configuration (e.g., relative positions of charged particles, compression of a spring) and how

3. Analysis
   a. Students use the computational model to predict the maximum possible change in the energy of one component of the system for a given set of energy flows.
   b. Students identify and describe* the limitations of the computational model, based on the assumptions that were made in creating the algebraic descriptions of energy changes and flows in the system.

HS-PS3-2

1. Components of the model
   a. Students develop models in which they identify and describe* the relevant components, including:
      i. All the components of the system and the surroundings, as well as energy flows between the system and the surroundings;
      ii. Clearly depicting both a macroscopic and a molecular/atomic-level representation of the system; and
      iii. Depicting the forms in which energy is manifested at two different scales: a) Macroscopic , such as motion, sound, light, thermal energy, potential energy or energy in fields; and b) Molecular/atomic, such as motions (kinetic energy) of particles (e.g., nuclei and electrons), the relative positions of particles in fields (potential energy), and energy in fields.

2. Relationships
   a. Students describe* the relationships between components in their models, including:
      i. Changes in the relative position of objects in gravitational, magnetic or electrostatic fields can affect the energy of the fields (e.g., charged objects moving away from each other change the field energy).
      ii. The total energy of the system and surroundings is conserved at a macroscopic and molecular/atomic level.
      iii. As one form of energy increases, others must decrease by the same amount as energy is transferred among and between objects and fields.

3. Connections
   a. Students use their models to show that in closed systems the energy is conserved on both the macroscopic and molecular/atomic scales so that as one form of energy changes, the total system

kinetic energy depends on mass and speed, allow the concept of conservation of energy to be used to predict and describe system behavior. · The availability of energy limits what can occur in any system.	energy remains constant, as evidenced by the other forms of energy changing by the same amount or changes only by the amount of energy that is transferred into or out of the system. b. Students use their models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles/objects and energy associated with the relative positions of particles/objects on both the macroscopic and microscopic scales. **HS-PS3-3** 1. Using scientific knowledge to generate the design solution. a. Students design a device that converts one form of energy into another form of energy. b. Students develop a plan for the device in which they: i. Identify what scientific principles provide the basis for the energy conversion design; ii. Identify the forms of energy that will be converted from one form to another in the designed system; iii. Identify losses of energy by the design system to the surrounding environment; iv. Describe* the scientific rationale for choices of materials and structure of the device, including how student-generated evidence influenced the design; and v. Describe* that this device is an example of how the application of scientific knowledge and engineering design can increase benefits for modern civilization while decreasing costs and risk. 2. Describing criteria and constraints, including quantification when appropriate a. Students describe* and quantify (when appropriate) prioritized criteria and constraints for the design of the device, along with the trade offs implicit in these design solutions. Examples of constraints to be considered are cost and efficiency of energy conversion. 3. Evaluating potential solutions a. Students build and test the device according to the plan. b. Students systematically and quantitatively evaluate the performance of the device against the criteria and constraints. 4. Refining and/or optimizing the design solution a. Students use the results of the tests to improve the device performance by increasing the efficiency of energy conversion, keeping in mind the criteria and constraints, and noting any modifications in trade offs.

Crosscutting Concepts

Systems and System Models

· Models can be used to predict the behavior of a system, but these predictions have limited precision and reliability due to the assumptions and approximations inherent in models. (HS-PS3-1)

Cause and Effect

· Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. (HS-PS3-1)

Energy and Matter

· Energy cannot be created or destroyed; it only moves between one place and another place, between objects and/or fields, or between systems. (HS-PS3-2)

· Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system. (HS-PS3-3)

Connections to Nature of Science

Scientific Knowledge Assumes an Order and Consistency in Natural Systems

· Science assumes the universe is a vast single system in which basic laws are consistent. (HS-PS3-1)

Connections to Engineering Technology, and Applications of Science

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

· Modern civilization depends on major technological systems. Engineers continuously modify these technological systems by applying scientific knowledge and engineering design practices to increase benefits while decreasing costs and risks. (HS-PS3-3)

Science and Engineering Practices

Using Mathematics and Computational Thinking

- Mathematical and computational thinking at the 9–12 level builds on K–8 and progresses to using algebraic thinking and analysis; a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms; and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions.
    - Create a computational model or simulation of a phenomenon, designed device, process, or system.
    - Use mathematical representations of phenomena or design solutions to describe and/or support claims and/or explanations.

Developing and Using Models

- Modeling in 9–12 builds on K–8 and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed worlds.
    - Develop and use a model based on evidence to illustrate the relationships between systems or between components of a system.

Constructing Explanations and Designing Solutions

- Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories.
    - Design, evaluate, and/or refine a solution to a complex real-world problem based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and trade off considerations.

Grade Band Endpoints for PS3.A and PS3.B

By the end of grade 12:

Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system. That there is a single quantity called energy is due to the fact that a system's *total* energy is conserved, even as, within the system, energy is continually transferred from one object to another and between its various possible forms. At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy. "Mechanical energy" generally refers to some combination of motion and stored energy in an operating machine. "Chemical energy" generally is used to mean the energy that can be released or stored in chemical processes, and "electrical energy" may mean energy stored in a battery or energy transmitted by electric currents. Historically, different units and names were used for the energy present in these different phenomena, and it took some time before the relationships between them were recognized. These relationships are better understood at the microscopic scale, at which all of the different manifestations of energy can be modeled as either motions of particles or energy stored in fields (which mediate interactions between particles). This last concept includes radiation, a phenomenon in which energy stored in fields moves across space.

Conservation of energy means that the total change of energy in any system is always equal to the total energy transferred into or out of the system. Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems. Mathematical expressions, which quantify how the stored energy in a system depends on its configuration (e.g., relative positions of charged particles, compression of a spring) and how kinetic energy depends on mass and speed, allow the concept of conservation of energy to be used to predict and describe system behavior. The availability of energy limits what can occur in any system.
Uncontrolled systems always evolve toward more stable states—that is, toward more uniform energy distribution (e.g., water flows downhill, objects hotter than their surrounding environment cool down). Any object or system that can degrade with no added energy is unstable. Eventually it will do so, but if the energy releases throughout the transition are small, the process duration can be very long (e.g., long-lived radioactive isotopes).

K-12 Endpoint Progression

Activities

Required Activities:

- Energy Skate Park (PHET simulation and lesson) or LHS lab-Roller Coaster lab

Suggested Activities:

- Energy Forms with Lesson on Temperature and Energy (PHET)
- Simple circuits with batteries.
- Conservation of Energy activities (pendula, carts/masses/ramps, springs, etc.) The Energy Behind Roller Coasters
- Physics Interactives - Chart That Motion
- Activities investigating various forms of energy (gravitational potential, kinetic energy, elastic energy, electrical energy, etc.)
- Rube Goldberg type activity
- Energy from solar, wind, waves etc.

Modifications to Content/Differentiation

Priority	Enrichment
- Types of energy, transference and conservation of energy. Algebraic manipulations of energy equations with multiple variables when addressing conservation of energy. - Thermal energy transfer is covered in Chemistry	- Rotational energy applications

Suggested Assessments

- Traditional assessment: multiple choice and free response questions, or
- The above project(s) using the eight science and engineering practice standards, or
- A combination of traditional assessment with project, or
- Other format of teacher’s choice

*Required assessments will be determined.

PS3.C: RELATIONSHIP BETWEEN ENERGY AND FORCES

HS-PS3-5

Supporting question: *How are forces related to energy?*

Suggested Content– Vocabulary in **bold**

- When two objects interact, each one exerts a **force** on the other. These forces can transfer energy between the objects. Forces between two objects at a distance are explained by **force fields** (gravitational, electric, or magnetic) between them. **Contact forces** between colliding objects can be modeled at the microscopic level as due to electromagnetic force fields between the surface particles. When two objects interacting via a force field change their relative position, the energy in the force field between them changes. For any such pair of objects, the force on each object acts in the direction such that motion of that object, in that direction, would reduce the energy in the force field between the two objects. However, prior motion and other forces also affect the actual direction of motion.
- Patterns of motion, such as a weight bobbing on a spring or a swinging pendulum, can be understood in terms of forces at each instant or in terms of transformation of energy between the motion and one or more forms of stored energy. **Elastic collisions** between two objects can be modeled at the macroscopic scale using conservation of energy without having to examine the detailed microscopic forces.

Disciplinary Core Ideas	Observable features of student performance *Unless otherwise specified, "descriptions" referenced in the evidence statements could include but are not limited to written, oral, pictorial, and kinesthetic descriptions.
PS3.C: Relationship Between Energy and Forces · When two objects interacting through a field change relative position, the energy stored in the field is changed.	HS-PS3-5 1. Components of the model a. Students develop a model in which they identify and describe* the relevant components to illustrate the forces and changes in energy involved when two objects interact, including: i. The two objects in the system, including their initial positions and velocities (limited to one dimension). ii. The nature of the interaction (electric or magnetic) between the two objects. iii. The relative magnitude and the direction of the net force on each of the objects. iv. Representation of a field as a quantity that has a magnitude and direction at all points in space and which contains energy. 2. Relationships a. In the model, students describe* the relationships between components, including the change in the energy of the objects, given the initial and final positions and velocities of the objects.

	3. Connections a. Students use the model to determine whether the energy stored in the field increased, decreased, or remained the same when the objects interacted. b. Students use the model to support the claim that the change in the energy stored in the field (which is qualitatively determined to be either positive, negative, or zero) is consistent with the change in energy of the objects. c. Using the model, students describe* the cause and effect relationships on a qualitative level between forces produced by electric or magnetic fields and the change of energy of the objects in the system.

Crosscutting Concepts

Cause and Effect

· Cause and effect relationships can be suggested and predicted for complex natural and human-designed systems by examining what is known about smaller scale mechanisms within the system.

Science and Engineering Practices

Developing and Using Models

- Modeling in 9–12 builds on K–8 and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed worlds.
    - Develop and use a model based on evidence to illustrate the relationships between systems or between components of a system.

Connections to Nature of Science

Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena

· A scientific theory is a substantiated explanation of some aspect of the natural world, based on a body of facts that have been repeatedly confirmed through observation and experiment. The science community validates each theory before it is accepted. If new evidence is discovered that the theory does not accommodate, the theory is generally modified in light of this new evidence.

Grade Band Endpoints for PS3.C

By the end of grade 12:

Force fields (gravitational, electric, and magnetic) contain energy and can transmit energy across space from one object to another.

When two objects interacting through a force field change relative position, the energy stored in the force field is changed. Each force between the two interacting objects acts in the direction such that motion in that direction would reduce the energy in the force field between the objects. However, prior motion and other forces also affect the actual direction of motion.

K-12 Endpoint Progression

Activities

Required Activities: may not be necessary beyond PS3A, PS3B required activities.

Suggested Activities:

- Electrostatics activities (Better Lesson)
- Gravity Force Lab (PHET simulation)
- Masses and Springs (PHET simulation)

Modifications to Content/Differentiation

Priority	Enrichment
-Focus on changes in energy as an object's position in a field changes. -Basic relationships between forces and distances (ex. larger r=smaller force)	- More rigorous mathematical treatment vs. basic relationships

Suggested Assessments

- Traditional assessment: multiple choice and free response questions, or
- The above project(s) using the eight science and engineering practice standards, or
- A combination of traditional assessment with project, or
- Other format of teacher's choice

*Required assessments will be determined.

UNIT 3 : Waves and Their Applications in Technologies for Information Transfer (20 class periods)

Compelling question: How are waves used to transfer energy and information?

Core Idea PS4 - Waves are a repeating pattern of motion that transfers energy from place to place without overall displacement of matter. Light and sound are wavelike phenomena. By understanding wave properties and the interactions of electromagnetic radiation with matter, scientists and engineers can design systems for transferring information across long distances, storing information, and investigating nature on many scales—some of them far beyond direct human perception.

Component Ideas	**Performance Expectations**
PS4.A: WAVE PROPERTIES Supporting question: *What are the characteristic properties and behaviors of waves?*	**HS-PS4-1**
PS4.B: ELECTROMAGNETIC RADIATION Supporting question: *What is light? How can one explain the varied effects that involve light? What other forms of electromagnetic radiation are there?*	**HS-PS4-3**, **HS-PS4-4**
PS4.C: INFORMATION TECHNOLOGIES AND INSTRUMENTATION Supporting question: *How are instruments that transmit and detect waves used to extend human sense?*	**HS-PS4-2**, **HS-PS4-5**

Student Learning Objectives (NGSS Performance Expectations)

Students who demonstrate understanding can:

HS-PS4-1

Use mathematical representations to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling in various media.

Clarification Statement: Examples of data could include electromagnetic radiation traveling in a vacuum and glass, sound waves traveling through air and water, and seismic waves traveling through the Earth.

Assessment Boundary: Assessment is limited to algebraic relationships and describing those relationships qualitatively.

HS-PS4-2

Evaluate questions about the advantages of using digital transmission and storage of information.

Clarification Statement: Examples of advantages could include that digital information is stable because it can be stored reliably in computer memory, transferred easily, and copied and shared rapidly. Disadvantages could include issues of easy deletion, security, and theft.

HS-PS4-3

Evaluate the claims, evidence, and reasoning behind the idea that electromagnetic radiation can be described either by a wave model or a particle model, and that for some situations one model is more useful than the other.

Clarification Statement: Emphasis is on how the experimental evidence supports the claim and how a theory is generally modified in light of new evidence. Examples of a phenomenon could include resonance, interference, diffraction, and photoelectric effect. Photoelectric effect and wave-particle duality is covered in the Chemistry curriculum but may need some review.

Assessment Boundary: Assessment does not include using quantum theory.

HS-PS4-4

Evaluate the validity and reliability of claims in published materials of the effects that different frequencies of electromagnetic radiation have when absorbed by matter.

Clarification Statement: Emphasis is on the idea that photons associated with different frequencies of light have different energies, and the damage to living tissue from electromagnetic radiation depends on the energy of the radiation. Examples of published materials could include trade books, magazines, web resources, videos, and other passages that may reflect bias.

Assessment Boundary: Assessment is limited to qualitative descriptions.

HS-PS4-5

Communicate technical information about how some technological devices use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy.

Clarification Statement: Examples could include solar cells capturing light and converting it to electricity; medical imaging; and communications technology.

Assessment Boundary: Assessments are limited to qualitative information. Assessments do not include band theory.

PS4.A: WAVE PROPERTIES

HS-PS4-1

Supporting question: *What are the characteristic properties and behaviors of waves?*

Suggested Content– Vocabulary in **bold**

- Whether a wave is in water, a **sound wave**, or a **light wave**, all waves have some features in common. A simple wave has a repeating pattern of specific **wavelength**, **frequency**, and **amplitude**. The wavelength and frequency of a wave are related to one another by the speed of travel of the wave, which, for each type of wave, depends on the **medium** in which the wave is traveling. Waves can be combined with other waves of the same type to produce complex information-containing patterns that can be decoded at the receiving end. Waves, which transfer energy and any encoded information without the bulk motion of matter, can travel unchanged over long distances, pass through other waves undisturbed, and be detected and decoded far from where they were produced. Information can be digitized (converted into a numerical representation), sent over long distances as a series of **wave pulses**, and reliably stored in computer memory.
- Sound is a **pressure wave** in air or any other material medium. The human ear and brain working together are very good at detecting and decoding patterns of information in sound (e.g., speech and music) and distinguishing them from random noise.
- **Resonance** is a phenomenon in which waves add up **in phase** (i.e., matched peaks and valleys), thus growing in amplitude. Structures have particular frequencies at which they **resonate** when some time-varying force acting on them transfers energy to them. This phenomenon (e.g., waves in a stretched string, vibrating air in a pipe) is used in the design of all musical instruments and in the production of sound by the human voice.
- When a wave passes an object that is small compared with its wavelength, the wave is not much affected; for this reason, some things are too small to see with visible light, which is a wave phenomenon with a limited range of wavelengths corresponding to each color. When a wave meets the surface between two different materials or conditions (e.g., air to water), part of the wave is reflected at that surface and another part continues on, but at a different speed. The change of speed of the wave when passing from one medium to another can cause the wave to change direction or **refract.** These wave properties are used in many applications (e.g., lenses, seismic probing of Earth).

Disciplinary Core Ideas	**Observable features of student performance** *Unless otherwise specified, "descriptions" referenced in the evidence statements could include but are not limited to written, oral, pictorial, and kinesthetic descriptions.

PS4.A: Wave Properties

- The wavelength and frequency of a wave are related to one another by the speed of travel of the wave, which depends on the type of wave and the medium through which it is passing. (HS-PS4-1)

HS-PS4-1

1. Representation
   a. Students identify and describe* the relevant components in the mathematical representations:
      i. Mathematical values for frequency, wavelength, and speed of waves traveling in various specified media; and
      ii. The relationships between frequency, wavelength, and speed of waves traveling in various specified media.
2. Mathematical modeling
   a. Students show that the product of the frequency and the wavelength of a particular type of wave in a given medium is constant, and identify this relationship as the wave speed according to the mathematical relationship $v = f\lambda$.
   b. Students use the data to show that the wave speed for a particular type of wave changes as the medium through which the wave travels changes.
   c. Students predict the relative change in the wavelength of a wave when it moves from one medium to another (thus different wave speeds using the mathematical relationship $v = f\lambda$). Students express the relative change in terms of cause (different media) and effect (different wavelengths but same frequency).
3. Analysis
   a. Using the mathematical relationship $v = f\lambda$, students assess claims about any of the three quantities when the other two quantities are known for waves travelling in various specified media.
   b. Students use the mathematical relationships to distinguish between cause and correlation with respect to the supported claims.

Crosscutting Concepts

Cause and Effect

- Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects.

Science and Engineering Practices

Using Mathematics and Computational Thinking

Mathematical and computational thinking at the 9-12 level builds on K-8 and progresses to using algebraic thinking and analysis; a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms; and computational tools for statistical analysis to analyze, represent and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions.

- Use mathematical representations of phenomena or design solutions to describe and/or support claims and/or explanations.(HS-PS4-1)

Asking Questions and Defining Problems

Asking questions and defining problems in grades 9–12 builds from grades K–8 experiences and progresses to formulating, refining, and evaluating empirically testable questions and design problems using models and simulations.

- Evaluate questions that challenge the premise(s) of an argument, the interpretation of a data set or the suitability of a design.(HS-PS4-2)

Engaging in Argument from Evidence

Engaging in argument from evidence in 9– 12 builds on K–8 experiences and progresses to using appropriate and sufficient evidence and scientific reasoning to defend and critique claims and explanations about the natural and designed world(s). Arguments may also come from current scientific or historical episodes in science.

- Evaluate the claims, evidence, and reasoning behind currently accepted explanations or solutions to determine the merits of arguments. (HS-PS4-3)

Obtaining, Evaluating, and Communicating Information

Obtaining, evaluating, and communicating information in 9–12 builds on K–8 and progresses to evaluating the validity and reliability of the claims, methods, and designs.

- Communicate technical information or ideas (e.g., about phenomena and/or the process of development and the design and performance of a proposed process or system) in multiple formats (including orally, graphically, textually, and mathematically). (HS-PS4-5)

Connections to Nature of Science

Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena

- A scientific theory is a substantiated explanation of some aspect of the natural world, based on a body of facts that have been repeatedly confirmed through observation and experiment. The science community validates each theory before it is accepted. If new evidence is discovered that the theory does not accommodate, the theory is generally modified in light of this new evidence.

Grade Band Endpoints for PS4.A

By the end of grade 12:

The wavelength and frequency of a wave are related to one another by the speed of travel of the wave, which depends on the type of wave and the medium through which it is passing. The reflection, refraction, and transmission of waves at an interface between two media can be modeled on the basis of these properties.

Combining waves of different frequencies can make a wide variety of patterns and thereby encode and transmit information. Information can be digitized (e.g., a picture stored as the values of an array of pixels); in this form, it can be stored reliably in computer memory and sent over long distances as a series of wave pulses.

Resonance is a phenomenon in which waves add up in phase in a structure, growing in amplitude due to energy input near the natural vibration frequency. Structures have particular frequencies at which they resonate. This phenomenon (e.g., waves in a stretched string, vibrating air in a pipe) is used in speech and in the design of all musical instruments.

K-12 Endpoint Progression

Activities

Required Activities: Basic wave activity with Slinkys or Simulation (PHET or The Physics Classroom)

Suggested Activities:

- Standing Wave Maker Interactive (The Physics Classroom)
- Resonance of Sound Waves Investigation with tuning forks and resonance tubes (LHS)

Modifications to Content/Differentiation

Priority	Enrichment
-Waves and energy; Resonance -Reflection, Refraction and Interference of waves	- Connection to music- harmonics

Suggested Assessments

- Traditional assessment: multiple choice and free response questions, or
- The above project(s) using the eight science and engineering practice standards, or
- A combination of traditional assessment with project, or
- Other format of teacher’s choice

*Required assessments will be determined.

PS4.B: ELECTROMAGETIC RADIATION

HS-PS4-3, HS-PS4-4

Supporting questions: ***What is light? How can one explain the varied effects that involve light?***

What other forms of electromagnetic radiation are there?

Suggested Content– Vocabulary in **bold**

- **Electromagnetic radiation** (e.g., radio, microwaves, light) can be modeled as a wave pattern of changing **electric and magnetic fields** or, alternatively, as particles. Each model is useful for understanding aspects of the phenomenon and its interactions with matter, and **quantum theory** relates the two models. Electromagnetic waves can be detected over a wide range of frequencies, of which the **visible spectrum** of colors detectable by human eyes is just a small part. Many modern technologies are based on the manipulation of electromagnetic waves.
- By understanding wave properties and the interactions of electromagnetic radiation with **matter**, scientists and engineers can design systems for transferring information across long distances, storing information, and investigating nature on many scales—some of them far beyond direct human perception.
- All electromagnetic radiation travels through a vacuum at the same speed, called the **speed of light**. Its speed in any given medium depends on its wavelength and the properties of that medium. At the surface between two media, like any wave, light can be **reflected, refracted** (its path bent), **or absorbed**. What occurs depends on properties of the surface and the wavelength of the light. When shorter wavelength electromagnetic radiation (ultraviolet, X-rays, gamma rays) is absorbed in matter, it can **ionize atoms** and cause damage to living cells. However, because X-rays can travel through soft body matter for some distance but are more rapidly absorbed by denser matter, particularly bone, they are useful for medical imaging. **Photovoltaic materials** emit electrons when they absorb light of a high-enough frequency. This phenomenon is used in barcode scanners and "electric eye" systems, as well as in **solar cells**. It is best explained using a particle model of light.

Disciplinary Core Ideas	**Observable features of student performance** *Unless otherwise specified, "descriptions" referenced in the evidence statements could include but are not limited to written, oral, pictorial, and kinesthetic descriptions.
PS4.A: Wave Properties	HS-PS4-3 1. Identifying the given explanation and associated claims, evidence, and reasoning

· [From the 3–5 grade band endpoints] Waves can add or cancel one another as they cross, depending on their relative phase (i.e., relative position of peaks and troughs of the waves), but they emerge unaffected by each other. (Boundary: The discussion at this grade level is qualitative only; it can be based on the fact that two different sounds can pass a location in different directions without getting mixed up.) (HS-PS4-3) **PS4.B: Electromagnetic Radiation** · When light or longer wavelength electromagnetic radiation is absorbed in matter, it is generally converted into thermal energy (heat). Shorter wavelength electromagnetic radiation (ultraviolet, X-rays, gamma rays) can ionize atoms and cause damage to living cells. (HS-PS4-4)	a. Students identify the given explanation that is to be supported by the claims, evidence, and reasoning to be evaluated, and that includes the following idea: Electromagnetic radiation can be described either by a wave model or a particle model, and for some situations one model is more useful than the other. b. Students identify the given claims to be evaluated. c. Students identify the given evidence to be evaluated, including the following phenomena: i. Interference behavior by electromagnetic radiation; and ii. The photoelectric effect. d. Students identify the given reasoning to be evaluated. 2. Evaluating given evidence and reasoning a. Students evaluate the given evidence for interference behavior of electromagnetic radiation to determine how it supports the argument that electromagnetic radiation can be described by a wave model. b. Students evaluate the phenomenon of the photoelectric effect to determine how it supports the argument that electromagnetic radiation can be described by a particle model. c. Students evaluate the given claims and reasoning for modeling electromagnetic radiation as both a wave and particle, considering the transfer of energy and information within and between systems, and why for some aspects the wave model is more useful and for other aspects the particle model is more useful to describe the transfer of energy and information **HS-PS4-4** 1. Obtaining information a. Students obtain at least two claims proposed in published material (using at least two sources per claim) regarding the effect of electromagnetic radiation that is absorbed by matter. One of these claims deals with the effect of electromagnetic radiation on living tissue. 2. Evaluating information a. Students use reasoning about the data presented, including the energies of the photons involved (i.e., relative wavelengths) and the probability of ionization, to analyze the validity and reliability of each claim. b. Students determine the validity and reliability of the sources of the claims. c. Students describe* the cause and effect reasoning in each claim, including the extrapolations to larger scales from cause and effect relationships of mechanisms at small scales (e.g., extrapolating from the effect of a particular wavelength of radiation on a single cell to the effect of that wavelength on the entire organism).

Crosscutting Concepts

Systems and System Models

- Models (e.g., physical, mathematical, and computer models) can be used to simulate systems and interactions — including energy, matter and information flows — within and between systems at different scales.

Cause and Effect

- Cause and effect relationships can be suggested and predicted for complex natural and human-designed systems by examining what is known about smaller scale mechanisms within the system.

Connections to Nature of Science

Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena

- A scientific theory is a substantiated explanation of some aspect of the natural world, based on a body of facts that have been repeatedly confirmed through observation and experiment. The science community validates each theory before it is accepted. If new evidence is discovered that the theory does not accommodate, the theory is generally modified in light of this new evidence.

Science and Engineering Practices

Engaging in Argument from Evidence

Engaging in argument from evidence in 9– 12 builds on K–8 experiences and progresses to using appropriate and sufficient evidence and scientific reasoning to defend and critique claims and explanations about the natural and designed world(s). Arguments may also come from current scientific or historical episodes in science.

- Evaluate the claims, evidence, and reasoning behind currently accepted explanations or solutions to determine the merits of arguments. (HS-PS4-3)

Obtaining, Evaluating, and Communicating Information

Obtaining, evaluating, and communicating information in 9–12 builds on K–8 and progresses to evaluating the validity and reliability of the claims, methods, and designs.

- Evaluate the validity and reliability of multiple claims that appear in scientific and technical texts or media reports, verifying the data when possible. (HS-PS4-4)
- Communicate technical information or ideas (e.g., about phenomena and/or the process of development and the design and performance of a proposed process or system) in multiple formats (including orally, graphically, textually, and mathematically). (HS-PS4-5)

Using Mathematics and Computational Thinking:

Mathematical and computational thinking in 9–12 builds on K–8 experiences and progresses to using algebraic thinking and analysis; a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms; and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions.

- ○ Use mathematical representations of phenomena to describe explanations. (HS-PS2-4)

Grade Band Endpoint for PS4.B

By the end of grade 12

Electromagnetic radiation (e.g., radio, microwaves, light) can be modeled as a wave of changing electric and magnetic fields or as particles called photons. The wave model is useful for explaining many features of electromagnetic radiation, and the particle model explains other features. Quantum theory relates the two models. (Boundary: Quantum theory is not explained further at this grade level.)

Because a wave is not much disturbed by objects that are small compared with its wavelength, visible light cannot be used to see such objects as individual atoms. All electromagnetic radiation travels through a vacuum at the same speed, called the speed of light. Its speed in any other given medium depends on its wavelength and the properties of that medium.

When light or longer wavelength electromagnetic radiation is absorbed in matter, it is generally converted into thermal energy (heat). Shorter wavelength electromagnetic radiation (ultraviolet, X-rays, gamma rays) can ionize atoms and cause damage to living cells. Photovoltaic materials emit electrons when they absorb light of a high-enough frequency.

Atoms of each element emit and absorb characteristic frequencies of light, and nuclear transitions have distinctive gamma ray wavelengths. These characteristics allow identification of the presence of an element, even in microscopic quantities.

K-12 Endpoint Progression

Activities

Required Activities:

- Activity involving wave vs. particle nature of light: diffraction patterns with lasers-(LHS) or simulation

Suggested Activities:

- Index of Refraction Investigation (LHS)
- Diffraction of light activity (Better Lessons)
- A Closer Look at Photoelectricity (Better Lessons)
- PHET-Wave-particle duality simulation and resources

Modifications to Content/Differentiation

Priority	Enrichment
-wave-particle duality evidence -reflection, refraction, and absorption of light.	-mathematical treatment of diffraction patterns -photovoltaic cells -ionizing radiation health effects

Suggested Assessments

- Traditional assessment: multiple choice and free response questions, or
- The above project(s) using the eight science and engineering practice standards, or
- A combination of traditional assessment with project, or
- Other format of teacher's choice

*Required assessments will be determined.

PS4.C: INFORMATION TECHNOLOGIES AND INSTRUMENTATION

HS-PS4-2, HS-PS4-5

Supporting question: *How are instruments that transmit and detect waves used to extend human sense?*

Suggested Content– Vocabulary in **bold**

Understanding of waves and their interactions with matter has been used to design technologies and instruments that greatly extend the range of phenomena that can be investigated by science (e.g., telescopes, microscopes) and have many useful applications in the modern world.

Light waves, radio waves, microwaves, and infrared waves are applied to **communications systems**, many of which use **digitized signals** (i.e., sent as wave pulses) as a more reliable way to convey information. Signals that humans cannot sense directly can be detected by appropriately designed devices (e.g., telescopes, cell phones, wired or wireless computer networks). When in digitized form, information can be recorded, stored for future recovery, and transmitted over long distances without significant degradation.

Medical imaging devices collect and interpret signals from waves that can travel through the body and are affected by, and thus gather information about, structures and motion within it (e.g., ultrasound, X-rays). **Sonar** (based on sound pulses) can be used to measure the depth of the sea, and a system based on **laser pulses** can measure the distance to objects in space, because it is known how fast sound travels in water and light travels in a vacuum. The better the interaction of the wave with the medium is understood, the more detailed the information that can be extracted (e.g., medical imaging or astronomical observations at multiple frequencies).

<u>**Disciplinary Core Ideas**</u>	<u>**Observable features of student performance**</u> *Unless otherwise specified, "descriptions" referenced in the evidence statements could include but are not limited to written, oral, pictorial, and kinesthetic descriptions.
PS4.A: Wave Properties · Information can be digitized (e.g., a picture stored as the values of an array of pixels); in this form, it can be stored reliably in computer memory and sent over long distances as a series of wave pulses. (HS-PS4-2)	**HS-PS4-2** 1. <u>Addressing phenomena or scientific</u> theories a. Students evaluate the given questions in terms of whether or not answers to the questions would: i. Provide examples of features associated with digital transmission and storage of information (e.g., can be stored reliably without degradation over time, transferred easily, and copied and shared rapidly; can be easily deleted; can be stolen easily by making a copy; can be broadly accessed); and b. In their evaluation of the given questions, students: i. Describe* the stability and importance of the systems that employ digital information as they relate to the advantages and disadvantages of digital transmission and storage of information; and ii. Discuss the relevance of the answers to the question to real-life examples (e.g., emailing your homework to a teacher, copying music, using the internet for research, social media). 2. <u>Evaluating empirical testability</u> Students evaluate the given questions in terms of whether or not answers to the questions would provide means to empirically determine whether given features are advantages or disadvantages.
PS4.A: Wave Properties · Information can be digitized (e.g., a picture stored as the values of an array of pixels); in this form, it can be stored reliably in computer memory and sent over long distances as a series of wave pulses. (HS-PS4-5)	**HS-PS4-5** 1. <u>Communication style and format</u> a. Students use at least two different formats (e.g., oral, graphical, textual, and mathematical) to communicate technical information and ideas, including fully describing* at least two devices and the physical principles upon which the devices depend. One of the devices must depend on the photoelectric effect for its operation. Students cite the origin of the information as appropriate. 2. <u>Connecting the DCIs and the CCCs</u> a. When describing* how each device operates, students identify the wave behavior utilized by the device or the absorption of photons and production of electrons for devices that rely on the photoelectric effect, and qualitatively describe* how the basic physics principles were utilized in the

PS4.C: Information Technologies and Instrumentation · Multiple technologies based on the understanding of waves and their interactions with matter are part of everyday experiences in the modern world (e.g., medical imaging, communications, scanners) and in scientific research. They are essential tools for producing, transmitting, and capturing signals and for storing and interpreting the information contained in them. (HS-PS4-5)	design through research and development to produce this functionality (e.g., absorbing electromagnetic energy and converting it to thermal energy to heat an object; using the photoelectric effect to produce an electric current). b. For each device, students discuss the need for the device, the real-world problem it solves, and how civilization now depends on the device. c. Students identify and communicate the cause and effect relationships that are used to produce the functionality of the device.

Crosscutting Concepts

Stability and Change

- Systems can be designed for greater or lesser stability.

Cause and Effect

- Systems can be designed to cause a desired effect.

Connections to Engineering, Technology, and Applications of Science

Interdependence of Science, Engineering, and Technology

- Science and engineering complement each other in the cycle known as research and development (R&D).

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

- Modern civilization depends on major technological systems.

Science and Engineering Practices

Obtaining, Evaluating, and Communicating Information

Obtaining, evaluating, and communicating information in 9–12 builds on K–8 and progresses to evaluating the validity and reliability of the claims, methods, and designs.

- Communicate technical information or ideas (e.g., about phenomena and/or the process of development and the design and performance of a proposed process or system) in multiple formats (including orally, graphically, textually, and mathematically). (HS-PS4-5)

Grade Band Endpoint for PS4.C

By the end of grade 12:

Multiple technologies based on the understanding of waves and their interactions with matter are part of everyday experiences in the modern world (e.g., medical imaging, communications, scanners) and in scientific research. They are essential tools for producing, transmitting, and capturing signals and for storing and interpreting the information contained in them.

Knowledge of quantum physics enabled the development of semiconductors, computer chips, and lasers, all of which are now essential components of modern imaging, communications, and information technologies. (Boundary: Details of quantum physics are not formally taught at this grade level.)

K-12 Endpoint Progression

Activities

Required Activities:

- Technological Device project (TBD)

Suggested Activities:

- Evaluate advantages of using digital transmission and storage of information
- Lesson and Lab Activity with Photovoltaic Cells
- NGSS Cell Phone Unit (in LHS shared folder)
- Mixing Colors with Light (Better Lessons)

Modifications to Content/Differentiation

Priority	Enrichment
-Investigate how energy is captured by solar cells. -digitization of information transmitted by waves	-Revisit after piloting project. Determine whether parts of the project can be enhanced.

Suggested Assessments

- Traditional assessment: multiple choice and free response questions, or
- The above project(s) using the eight science and engineering practice standards, or
- A combination of traditional assessment with project, or
- Other format of teacher's choice

*Required assessments will be determined.

Pacing Guide

- Suggested/tentative timeline
- Class periods: 84 min/block instructional time
- Total class periods: 90 over one semester

Suggested instructional time	Content
36 class periods	**Unit 1 : Motion and Stability: Forces and Interactions** ● PS2.A: Forces and Motion ● PS2.B: Types of Interactions
34 class periods	**Unit 2 : Energy** ● PS3.A: Definitions of Energy ● PS3.B: Conservation of Energy and Energy Transfer ● PS3.C: Relationship Between Energy and Forces
20 class periods	**Unit 3 : Waves and Their Applications in Technologies for Information Transfer** ● PS4.A: Waves Properties ● PS4.B: Electromagnetic Radiation ● PS4.C: Information Technologies and Instrumentation