High School Conceptual Progressions Course 1 - Bundle 6
Electric and Electromagnetic Energy

This is the sixth bundle of the High School Conceptual Progressions Model Course 1. Each bundle has connections to the other bundles in the course, as shown in the [Course Flowchart](#).

Bundle 6 Question: This bundle is assembled to address the question of "How are waves used to transfer energy and information?"

Summary

The bundle organizes performance expectations with a focus on helping students understand *how waves are used to transfer energy and information*. Instruction developed from this bundle should always maintain the three-dimensional nature of the standards, but recognize that instruction is not limited to the practices and concepts directly linked with any of the bundle performance expectations.

Connections between bundle DCIs

The concept that forces at a distance are explained by fields (gravitational, electric, and magnetic) permeating space that can transfer energy through space (PS2.B as in HS-PS2-5) connects to the ideas that attraction and repulsion between electric charges at the atomic scale explain the structure, properties, and transformations of matter, (PS2.B as in HS-PS2-6). Also, the idea of electric and magnetic fields (PS2.B as in HS-PS2-5) connect to the concepts of electromagnetic radiation (PS4.B as in HS-PS4-3).

Electromagnetic radiation can be modeled as a wave of changing electric and magnetic fields or as particles called photons (PS4.B as in HS-PS4-3), so this concept connects to the idea that the wave model is useful for explaining many features of electromagnetic radiation, and the particle model explains other features (PS4.B as in HS-PS4-3). This concept of the particle model of electromagnetic radiation also connects to understandings of photoelectric materials (PS4.B as in HS-PS4-5).

The wave model of electromagnetic radiation (PS4.B as in HS-PS4-3) connects to the concepts of wavelength and frequency (PS4.A as in HS-PS4-1). Wavelength and frequency connect to the idea of wave pulses, and the idea that information can be digitized and sent over long distances (PS4.A as in HS-PS4-2, HS-PS4-5). The ideas of digitizing and sending information connect to understandings that multiple technologies are based on the understanding of waves (PS4.C as in HS-PS4-5).

Bundle Science and Engineering Practices

Instruction leading to this bundle of PEs will help students build toward proficiency in elements of the practices of evaluating questions (HS-PS4-2), planning and conducting an investigation (HS-PS2-5), using mathematical representations (HS-PS4-1), engaging in argumentation (HS-PS4-3), and communicating scientific and technical information (HS-PS2-6 and HS-PS4-5). Many other practice elements can be used in instruction.

Bundle Crosscutting Concepts

Instruction leading to this bundle of PEs will help students build toward proficiency in elements of the crosscutting concepts of Cause and Effect (HS-PS2-5, HS-PS4-1, and HS-PS4-5), Systems and System Models (HS-PS4-3), Structure and Function (HS-PS2-6), and Stability and Change (HS-PS4-2). Many other CCC elements can be used in instruction.

All instruction should be three-dimensional.

Performance Expectations HS-PS2-6 is partially assessable	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.] HS-PS2-6. **Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.*** [Clarification Statement: Emphasis is on the attractive and repulsive forces that determine the functioning of the material. Examples could include why electrically conductive materials are often made of metal, flexible but durable materials are made up of long chained molecules, and pharmaceuticals are designed to interact with specific receptors.] [Assessment Boundary: Assessment is limited to provided molecular structures of specific designed materials.] 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 a 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.] [Assessment Boundary: Assessment does not include using quantum theory.] 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.]
Example Phenomena	Some flashlights have to be shaken to work and other flashlights need batteries to work. When I use wireless headphones, I can listen to music from my computer without a cord.
Additional Practices Building to the PEs	**Asking Questions and Defining Problems** • Ask questions to determine relationships, including quantitative relationships, between independent and dependent variables. Students could *ask questions to determine relationships between* ***the wavelength and frequency of a wave.*** HS-PS4-1 **Developing and Using Models** • Develop and/or use multiple types of models to provide mechanistic accounts and/or predict phenomena, and move flexibly between model types based on merits and limitations. Students could *use multiple types of models based on merits and limitations* [for how] ***electromagnetic radiation can be modeled as a wave of changing electric and magnetic fields or as particles called photons***. HS-PS4-3

Additional Practices Building to the PEs (Continued)	**Planning and Carrying Out Investigations** • Make directional hypotheses that specify what happens to a dependent variable when an independent variable is manipulated. Students could *make directional hypotheses* [about how] ***the wavelength and frequency of a wave are related to one another.*** HS-PS4-1 **Analyzing and Interpreting Data** • Analyze data to identify design features or characteristics of a proposed process or system to optimize it relative to criteria for success. Students could *analyze data to identify design features of a proposed system* [that uses] ***magnets or electric currents*** [to generate] ***magnetic fields***. HS-PS2-5 **Using Mathematical and Computational Thinking** • Create and/or revise a computational model or simulation of a phenomenon, designed device, process, or system. Students could *create a computational model* [of how] ***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 **Constructing Explanations and Designing Solutions** • 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 tradeoff considerations. Students could *refine a solution to a real-world problem based on scientific knowledge* [about how] ***the 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.*** HS-PS2-6 **Engaging in Argument from Evidence** • Respectfully provide and/or receive critiques on scientific arguments by probing reasoning and evidence and challenging ideas and conclusions, responding thoughtfully to diverse perspectives, and determining what additional information is required to resolve contradictions. Students could *respectfully provide critiques on scientific arguments by probing reasoning and evidence* [for how] ***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

Additional Practices Building to the PEs (Continued)	**Obtaining, Evaluating, and Communicating Information** • Compare, integrate and evaluate sources of information presented in different media or formats (e.g., visually, quantitatively) as well as in words in order to address a scientific question or solve a problem. Students could *compare and evaluate sources of information presented in different media or formats* [about how] ***electromagnetic radiation can be modeled as a wave of changing electric and magnetic fields or as particles called photons***. HS-PS4-3
Additional Crosscutting Concepts Building to PEs	**Patterns** • Patterns of performance of designed systems can be analyzed and interpreted to reengineer and improve the system. Students could *analyze and interpret performance patterns of designed systems to reengineer and improve* ***a technological tool that produces, transmits, and captures signals as well as stores and interprets the information contained in them***. HS-PS4-5 **Scale, Proportion, and Quantity** • Algebraic thinking is used to examine scientific data and predict the effect of a change in one variable on another. Students could use *algebraic thinking to examine scientific data and predict the effect of a change* ***in the medium through which a wave is passing on the speed of travel of the wave.*** HS-PS4-1 **Structure and Function** • The functions and properties of natural and designed objects and systems can be inferred from their overall structure, the way their components are shaped and used, and the molecular substructures of its various materials. Students could investigate the functions and properties of designed objects ***based on an understanding of*** [how] ***tools can produce, transmit, and capture signals and store and interpret the information contained in them***. HS-PS4-5
Additional Connections to Nature of Science	**Scientific Investigations Use a Variety of Methods (SEP):** • New technologies advance scientific knowledge. Students could communicate how *new technologies advance scientific knowledge* [about how] ***electromagnetic radiation can be modeled as a wave of changing electric and magnetic fields.*** HS-PS4-3 **Science is a Way of Knowing (CCC):** • Science knowledge has a history that includes the refinement of, and changes to, theories, ideas, and beliefs over time. Students could obtain, evaluate, and communicate information for how ***electromagnetic radiation can be modeled as a wave of changing electric and magnetic fields or as particles called photons*** [and how the ideas about] **electromagnetic radiation** *have changed over time*. HS-PS4-3

HS-PS2-5

Students who demonstrate understanding can:

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.*]

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

Science and Engineering Practices

Planning and Carrying Out Investigations

Planning and carrying out investigations to answer questions or test solutions to problems in 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.

Disciplinary Core Ideas

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. (HS-PS2-4)
- 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.

PS3.A: Definitions of Energy

- "Electrical energy" may mean energy stored in a battery or energy transmitted by electric currents. *(secondary)*

Crosscutting Concepts

Cause and Effect

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

Observable features of the student performance by the end of the course:			
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		
	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	Planning for the investigation		
	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	Collecting the data	
	a	Students measure and record electric currents and magnetic fields.
5	Refining the design	
	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.

HS-PS2-6

Students who demonstrate understanding can:

HS-PS2-6. **Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.*** [Clarification Statement: Emphasis is on the attractive and repulsive forces that determine the functioning of the material. Examples could include why electrically conductive materials are often made of metal, flexible but durable materials are made up of long chained molecules, and pharmaceuticals are designed to interact with specific receptors.] [*Assessment Boundary: Assessment is limited to provided molecular structures of specific designed materials.*]

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

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
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 scientific and technical information (e.g., about the process of development and the design and performance of a proposed process or system) in multiple formats (including oral, graphical, textual and mathematical).	**PS2.B: Types of Interactions** • 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.	**Structure and Function** • Investigating or designing new systems or structures requires a detailed examination of the properties of different materials, the structures of different components, and connections of components to reveal its function and/or solve a problem.

Observable features of the student performance by the end of the course:			
1	Communication style and format		
	a	Students use at least two different formats (including oral, graphical, textual and mathematical) to communicate scientific and technical information, including fully describing* the structure, properties, and design of the chosen material(s). Students cite the origin of the information as appropriate.	
2	Connecting the DCIs and the CCCs		
	a	Students identify and communicate the evidence for why molecular level structure is important in the functioning of designed materials, including:	
		i.	How the structure and properties of matter and the types of interactions of matter at the atomic scale determine the function of the chosen designed material(s); and
		ii.	How the material's properties make it suitable for use in its designed function.
	b	Students explicitly identify the molecular structure of the chosen designed material(s) (using a representation appropriate to the specific type of communication — e.g., geometric shapes for drugs and receptors, ball and stick models for long-chained molecules).	
	c	Students describe* the intended function of the chosen designed material(s).	
	d	Students describe* the relationship between the material's function and its macroscopic properties (e.g., material strength, conductivity, reactivity, state of matter, durability) and each of the following:	
		i.	Molecular level structure of the material;
		ii.	Intermolecular forces and polarity of molecules; and
		iii.	The ability of electrons to move relatively freely in metals.
	e	Students describe* the effects that attractive and repulsive electrical forces between molecules have on the arrangement (structure) of the chosen designed material(s) of molecules (e.g., solids, liquids, gases, network solid, polymers).	
	f	Students describe* that, for all materials, electrostatic forces on the atomic and molecular scale results in contact forces (e.g., friction, normal forces, stickiness) on the macroscopic scale.	

HS-PS4-1

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.*]

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

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
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.	**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.	**Cause and Effect** • Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects.

Observable features of the student performance by the end of the course:			
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.	

HS-PS4-2

Students who demonstrate understanding can:

HS-PS4-2. **Evaluate questions about the advantages of using a 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.]

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

Science and Engineering Practices

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.

Disciplinary Core Ideas

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.

Crosscutting Concepts

Stability and Change

- Systems can be designed for greater or lesser stability.

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Connections to Engineering, Technology, and Applications of Science

Influence of Engineering, Technology, and Science 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.

Observable features of the student performance by the end of the course:			
1	Addressing phenomena or scientific 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	Evaluating empirical testability		
		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.	

HS-PS4-3

Students who demonstrate understanding can:

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.] [*Assessment Boundary: Assessment does not include using quantum theory.*]

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

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.

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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.

Disciplinary Core Ideas

PS4.A: Wave Properties

- [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.)

PS4.B: Electromagnetic Radiation

- 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.

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.

Observable features of the student performance by the end of the course:			
1	Identifying the given explanation and associated claims, evidence, and reasoning		
	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-PS4-5

Students who demonstrate understanding can:

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.*]

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

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).

Disciplinary Core Ideas

PS3.D: Energy in Chemical Processes

- Solar cells are human-made devices that likewise capture the sun's energy and produce electrical energy. *(secondary)*

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.

PS4.B: Electromagnetic Radiation

- Photoelectric materials emit electrons when they absorb light of a high-enough frequency.

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.

Crosscutting Concepts

Cause and Effect

- Systems can be designed to cause a desired effect.

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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.

Observable features of the student performance by the end of the course:		
1	Communication style and format	
	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	Connecting the DCIs and the CCCs	
	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 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 real-world problem it solves or need it addresses, 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.