Unit Summary
Why has digital technology replaced analog technology?   In this unit of study, students are able to apply their understanding of wave properties to make sense of how electromagnetic radiation can be used to transfer information across long distances, store information, and be used to investigate nature on many scales. Models of electromagnetic radiation as both a wave of changing electrical and magnetic fields or as particles are developed and used. Students also demonstrate their understanding of engineering ideas by presenting information about how technological devices use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy. The crosscutting concepts of *systems and system models*; *stability and change*; *interdependence of science, engineering, and technology; and influence of engineering, technology, and science on society and the natural world* are highlighted as organizing concepts. Students are expected to demonstrate proficiency in *asking questions, engaging in argument from evidence, and obtaining, evaluating, and communicating information*, and they are expected to use these practices to demonstrate understanding of the core ideas.
Student Learning Objectives
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-PS4-3**)
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-PS4-4**)
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.]* (**HS-PS4-5**)
Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants. (HS-ETS1-1)
Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts. (HS-ETS1-3)
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-PS4-2**)

Part A: How can electromagnetic radiation be both a wave and a particle at the same time?

Concepts	Formative Assessment
• 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. • 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. • A wave model or a particle model (e.g., physical, mathematical, computer models) can be used to describe electromagnetic radiation—including energy, matter, and information flows—within and between systems at different scales. • A wave model and a particle model of electromagnetic radiation are based on a body of facts that have been repeatedly confirmed through observation and experiment, and 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.	*Students who understand the concepts are able to:* • 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. • Evaluate experimental evidence 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. • Use models (e.g., physical, mathematical, computer models) to simulate electromagnetic radiation systems and interactions—including energy, matter, and information flows—within and between systems at different scales.

Part B: Should we encourage the board of education to install solar panels?

Concepts	Formative Assessment
• 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. • Cause-and-effect relationships can be suggested and predicted for	*Students who understand the concepts are able to:* • Evaluate the validity and reliability of multiple claims in published materials about the effects that different frequencies of electromagnetic radiation have when absorbed by matter.

electromagnetic radiation systems when matter absorbs different frequencies of light by examining what is known about smaller scale mechanisms within the system.	• Evaluate the validity and reliability of claims that photons associated with different frequencies of light have different energies and that the damage to living tissue from electromagnetic radiation depends on the energy of the radiation. • Give qualitative descriptions of how photons associated with different frequencies of light have different energies and how the damage to living tissue from electromagnetic radiation depends on the energy of the radiation. • Suggest and predict cause-and-effect relationships for electromagnetic radiation systems when matter absorbs different frequencies of light by examining what is known about smaller scale mechanisms within the system.

Part C:
- ✓ How does the International Space Station power all of its equipment
- ✓ How do astronauts communicate with people on the ground?

Concepts	Formative Assessment
• Solar cells are human-made devices that capture the sun's energy and produce electrical energy. • 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. • Photoelectric materials emit electrons when they absorb light of a high enough frequency. • 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. • 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.	*Students who understand the concepts are able to:* • Communicate qualitative 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. • Communicate technical information or ideas about technological devices that use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy in multiple formats (including orally, graphically, textually, and mathematically). • Analyze technological devices that use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy by specifying criteria and constraints for successful solutions. • Evaluate a solution offered by technological devices that use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations.

• Humanity faces major global challenges today, such as the need for supplies of clean water and food and for energy sources that minimize pollution, which can be addressed through engineering. These global challenges also may have manifestations in local communities. • When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts. • Wave interaction with matter systems can be designed to transmit and capture information and energy. • Science and engineering complement each other in the cycle known as research and development (R&D). • Modern civilization depends on major technological systems. • New technologies can have deep impacts on society and the environment, including some that were not anticipated. Analysis of costs and benefits is a critical aspect of decisions about technology.	

Part D: How does my hard drive store information?	
Concepts	**Formative Assessment**
• 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. • Systems for transmission and storage of information can be designed for greater or lesser stability. • Modern civilization depends on systems for transmission and storage of information. • Engineers continuously modify these technological systems for transmission and storage of information by applying scientific knowledge and engineering design practices to increase benefits while decreasing costs and risks.	*Students who understand the concepts are able to:* • Evaluate questions about the advantages of using digital transmission and storage of information by challenging the premise of the advantages of digital transmission and storage of information, interpreting data, and considering the suitability of digital transmission and storage of information. • Consider advantages and disadvantages in the use of digital transmission and storage of information.

What it Looks Like in the Classroom

To build on understandings from the previous unit, students should explore what happens to waves when they meet. They should develop an understanding of how waves can add or cancel one another as they cross, depending on their relative phase, but that they emerge unaffected by each other. Students should have opportunities to explore constructive and destructive interference and the principle of superposition. In the classroom, students might investigate water waves interfering in a ripple tank, create wave pulses in a slinky when one end is fixed, and play sounds of near-similar (different) frequencies from speakers side by side and listen for “beats.”

Students should then be introduced to the idea that electromagnetic radiation 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. Students should have an understanding of the wave model from their work in the previous unit. Because all observations cannot be explained with one model, students should explore the wave and particle models and make determinations about which is most appropriate in which situations. Students might begin the unit by exploring the history of the wave and particle models—for example, by researching the Michelson–Morley experiment and previous misconceptions about the concept of ether. In their research, students should evaluate the hypotheses, data, analysis, and conclusions in text and cite evidence to support their analysis. Students should also be able to support claims, evidence, and reasoning with mathematical expressions representing wave and particle models of electromagnetic radiation, rearranging formulas to highlight a quantity of interest, and making sense of quantities and relationships.

Students must be able to determine which model is most appropriate under which circumstances by evaluating experimental evidence, claims, evidence, and reasoning. Students may research this question and present their findings in an argumentative essay. Students might consider particular phenomena, such as diffraction, and determine whether the wave or particle model provides the best explanation. Using a Venn diagram, students could differentiate between phenomena and models. Students should use models (e.g., physical, mathematical, computer models) to simulate electromagnetic radiation systems and interactions.

Some wave applications include:

- Diffraction—Students can be shown how waves bend around obstacles in a wave tank or explore using a prism and a laser.
- Michelson–Morley experiment—This can either be replicated in class or demonstrated via computer simulation.
- Polarization—Students could explore this phenomenon through its use in 3D movies, computer monitors, cell phones, and sunglasses.
- Doppler shift—Students can consider applications of Doppler shift in astronomy and weather.
- Wave interference—A wave tank or computer simulation could be used to illustrate interference.
- Transmission—Wave transmission can be modeled using computer simulations. Some **particle** applications include:
- Refraction—Students can explore light bending as changes in media using prisms or water. They can also use Snell’s Law to describe the relationship between angles of incidence and refraction.
- Reflection—Students should develop an understanding of incident rays and reflected rays using the law of reflection. They might explore this concept using a wave tank.
- Geometric optics—Students can explore lens ray diagrams. This can be performed as a demonstration, lab experiment, using pencil and paper, or through computer simulation.

- Ray diagrams—Students can create lens ray diagrams on paper.
- Photoelectric effect—Students can explore solar cells to understand this phenomenon. Note that if this course is sequenced before chemistry, students will not have an understanding of electrons.
- Piezoelectric effect—Students might research this phenomenon using solar cells and ultrasound analogies.

Students should develop an understanding that waves can transport energy across distances and at different scales. An example to consider might include a sports broadcaster speaking into a microphone. The sound waves from the broadcaster's voice become electromagnetic waves, which then bounce off the ionosphere, and then to an antenna, where they are transformed back into sound waves heard through an AM radio.

Information from waves can be stored as digital or analog signals. Other examples could be explored using computer simulations, research, or classroom lab activities.

Students should understand that the energy in a wave depends on its frequency as well as its amplitude (energy is proportional to amplitude squared). Different frequencies of electromagnetic radiation also have different abilities to penetrate matter. 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. For example ultraviolet light penetrates the skin and can cause skin cancer, while X-rays and gamma rays can permeate deep tissue and cause radiation poisoning. Students should explore these cause-and-effect relationships through an investigation of scientific text. They should cite evidence from multiple sources; evaluate hypotheses, data, analysis, and conclusions; and assess strengths and limitations.

Students should evaluate claims about photons, different light frequencies, and energies. They might do this through an examination of how colors are perceived. For example, human retinas have red, green, and blue cones. Seeing the color magenta means the red and blue cones are activated. Students should be able to predict what colors will be seen when different combinations of cones are activated. This can be further explored using computer simulations.

To explore color and energy, students could explore Herschel's experiment in which thermometers were placed in different colors to see which color was "hottest." It turned out that Herschel's control, placed in what is now known as infrared, was the hottest of all. This demonstrated that there are wavelengths of electromagnetic radiation beyond the visible spectrum.

Excitation energy and Fraunhofer emission and absorption spectra should also be explored. Photons incident on a hydrogen atom excite electrons, and when they fall back to lower energy levels, these photons emit different spectra like Balmer, Lyman, and Paschen spectra. If this course is sequenced before the chemistry course, students may not have an understanding of electron configuration. This example is only appropriate for students taking physics after the chemistry course.

Students should perform research on how different spectra of light interact with matter. Specifically, they should evaluate the validity and reliability of source material and determine cause-and-effect relationships. The final product could be a written essay, presentation, model, or oral debate. Research topics might include:

- Additive/subtractive color processes—stage lighting, vision in humans or animals, visual arts, optical illusions, Renaissance-era pigments versus modern pigments, light bulbs, etc.
- Spectra—spectra of different elements, astronomical spectroscopy, the cause for atoms to create spectra, etc.
- Effects of electromagnetic radiation on the human body—effects of nuclear disasters on plant workers (Chernobyl, Fukushima, Three Mile Island),

skin cancer, medical X-rays, diagnostic imaging technology, etc.

The engineering component of this unit includes exploring how technological devices use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy. Students might investigate solar cells and how they work, including a qualitative description of the photoelectric effect. Students should also evaluate the efficiency and cost-effectiveness of modern solar cell technology. Given existing solar cells, students may consider how they rate in terms of one-time purchase, aesthetics, maintenance, and overall total cost of ownership.

Photoelectric materials emit electrons when they absorb light of a high enough frequency. This is another opportunity to discuss solar cells. Other technologies that use the photoelectric effect include automatic doors, safety lights, television camera tubes, light-activated counters, intrusion alarms, and streetlights.

Students should analyze, evaluate, and communicate technical information about how devices that use the principles of wave behavior and wave interactions with matter transmit and capture information and energy. They should also evaluate a solution offered by a technological device using scientific knowledge, student- generated sources of evidence, prioritized criteria, and tradeoff considerations. Examples of devices include solar cells, medical imaging, and communications technologies.

Students will also develop an understanding that information can be digitized—for example, a picture stored as the values of an array of pixels. In this form, information can be stored reliably in computer memory (CDs, DVDs, etc.) and sent over long distances as a series of wave pulses (infrared remote controls, radio waves, bounced off of satellites, etc.).

The advantages and disadvantages of various electromagnetic frequencies in modern technology should be explored using examples such as astronomical telescopes (microwave, infrared, visible, etc.), lidar, solar panel cells, CDs, Blu-ray, infrared remote controls or car fobs, infrared motion detection cameras, computer memory storage, or fiber optics. Students should be able to create models of the interactions in these common types of systems and explain their model using either written or oral media.

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, body scanners at airports) and in scientific research. They are essential tools for producing, transmitting, and capturing signals and for storing and interpreting the information contained in them. Concerns regarding this technology that must be considered include cost, safety, reliability, aesthetics, and social, cultural, and environmental impacts. Students should be able to argue, using evidence, whether the costs of and concerns about certain technologies meet the requirements set by society.

New technologies can have deep impacts on society and the environment, including some that were not anticipated. Analysis of costs and benefits is a critical aspect of decisions about technology. These concerns are addressed through the iterative process of research and development. Students should be able to evaluate the effectiveness of a solution to a given problem. For example, students could determine how much antenna is enough for picking up digital versus analog transmissions.

Modern civilization depends on systems for transmission and storage of information, which can be designed for greater or lesser stability. Examples of these systems could include data security, magnetic tape, vaults of hard drives, hard drive failure, solid-state storage such as flash drives, cloud storage, remote hacking into cameras, RFID readers, EZ pass, credit card magnetic strips, etc. Engineers continuously modify these technological systems for transmission and storage of information by applying scientific knowledge and engineering design practices to increase benefits while decreasing costs and risks. Students must be able to argue for or against the suitability of digital storage and transmission in various media.

Integration of engineering-

Students communicate technical information about technological devices that use the principles of wave behavior and wave integrations with matter to transmit and capture information and energy. No specific ETS connections are called for, but ETS1-1 and ETS1-3 are identified as appropriate connections so that students can analyze a major global challenge and evaluate a solution to a complex real-world problem.

Integration of DCI from prior units-

This unit ties in with the unit on waves. Wave properties were discussed in the Waves Unit, and all those properties are true of electromagnetic waves. The main difference is that this unit focuses specificallyon electromagnetic waves. In both units, the properties of waves traveling through different media are explored.

Leveraging English Language Arts/Literacy and Mathematics

English Language Arts/Literacy

- Assess the extent to which the reasoning and evidence in a text supports the author's claim 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.
- Cite specific textual evidence to support the wave model or particle model in describing electromagnetic radiation, attending to important distinctions the author makes and to any gaps or inconsistencies in the account.
- Evaluate the hypotheses, data, analysis, and conclusions in a science or technical text relating 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, verifying the data when possible and corroborating or challenging conclusions with other sources of information.
- Assess the extent to which the reasoning and evidence in a text describing the effects that different frequencies of electromagnetic radiation have when absorbed by matter support the author's claim or recommendation.
- Cite textual evidence to support analysis of science and technical texts describing the effects that different frequencies of electromagnetic radiation have when absorbed by matter, attending to important distinctions the author makes and to any gaps or inconsistencies in the account.
- Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., qualitative data, video multimedia) in order to address the effects that different frequencies of electromagnetic radiation have when absorbed by matter.
- Evaluate the hypotheses, data, analysis, and conclusions in a science or technical text describing the effects that different frequencies of electromagnetic radiation have when absorbed by matter, verifying the data when possible and corroborating or challenging conclusions with other sources of information.
- Gather relevant information from multiple authoritative print and digital sources describing the effects that different frequencies of electromagnetic radiation have when absorbed by matter, using advanced searches effectively; assess the strengths and limitations of each source in terms of the specific task, purpose, and audience; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and overreliance on any one source and following a standard format for citation.
- Write informative/explanatory texts about technological devices that use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy, including the narration of scientific procedures, experiments, or technical processes.
- Integrate and evaluate multiple sources of information about technological devices that use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy, presented in diverse formats and media (e.g., quantitative data, video, multimedia), in order to address a

question or solve a problem.

- Evaluate the hypotheses, data, analysis, and conclusions in a science or technical text describing technological devices that use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy, verifying the data when possible and corroborating or challenging conclusions with other sources of information.
- Synthesize information about technological devices that use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy from a range of sources. (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible.
- Assess the extent to which the reasoning and evidence in a text support the advantages of using digital transmission and storage of information.
- Cite specific textual evidence to support the advantages of using digital transmission and storage of information, attending to important distinctions the author makes and to any gaps or inconsistencies in the account.
- Evaluate advantages of using digital transmission and storage of information in text, verifying the data when possible and corroborating or challenging conclusions with other sources of information.

Mathematics-

- Represent symbolically 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, and manipulate the representing symbols.
- Make sense of quantities and relationships between the wave model and the particle model of electromagnetic radiation.
- Interpret expressions that represent the wave model and particle model of electromagnetic radiation in terms of the usefulness of the model depending on the situation.
- Choose and produce an equivalent form of an expression to reveal and explain properties of electromagnetic radiation.
- Rearrange formulas representing electromagnetic radiation to highlight a quantity of interest, using the same reasoning as in solving equations.
- Represent the principles of wave behavior and wave interactions with matter to transmit and capture information and energy symbolically, considering criteria and constraints, and manipulate the representing symbols. Make sense of quantities and relationships in the principles of wave behavior and wave interactions with matter to transmit and capture information and energy.
- Use a mathematical model to describe the principles of wave behavior and wave interactions with matter to transmit and capture information and energy and to predict the effects of the design on systems and/or interactions between systems. Identify important quantities in the principles of wave behavior and wave interactions with matter to transmit and capture information and energy, and map their relationships using tools. Analyze those relationships mathematically to draw conclusions, reflecting on the results and improving the model if it has not served its purpose

Modifications
Teacher Note: Teachers identify the modifications that they will use in the unit. The unneeded modifications can then be deleted from the list. • Restructure lesson using UDL principals (http://www.cast.org/our-work/about-udl.html#.VXmoXcfD_UA) • Structure lessons around questions that are authentic, relate to students' interests, social/family background and knowledge of their community. • Provide students with multiple choices for how they can represent their understandings (e.g. multisensory techniques-auditory/visual aids; pictures, illustrations, graphs, charts, data tables, multimedia, modeling). • Provide opportunities for students to connect with people of similar backgrounds (e.g. conversations via digital tool such as SKYPE, experts from the community helping with a project, journal articles, and biographies). • Provide multiple grouping opportunities for students to share their ideas and to encourage work among various backgrounds and cultures (e.g. multiple representation and multimodal experiences). • Engage students with a variety of Science and Engineering practices to provide students with multiple entry points and multiple ways to demonstrate their understandings. • Use project-based science learning to connect science with observable phenomena. • Structure the learning around explaining or solving a social or community-based issue. • Provide ELL students with multiple literacy strategies. • Collaborate with after-school programs or clubs to extend learning opportunities.

Research on Student Learning
Students who have not received any systematic instruction about light tend to identify light with its source (e.g., light is in the bulb) or its effects (e.g., patch of light). They do not have a notion of light as something that travels from one place to another. As a result, these students have difficulties explaining the direction and formation of shadows, and the reflection of light by objects. For example, some students simply note the similarity of shape between the object and the shadow or say that the object hides the light. Students often accept that mirrors reflect light but, at least in some situations, reject the idea that ordinary objects reflect light. Many students do not believe that their eyes receive light when they look at an object. Students' conceptions of vision vary from the notion that light fills space ("the room is full of light") and the eye "sees" without anything linking it to the object to the idea that light illuminates surfaces that we can see by the action of our eyes on them. The conception that the eye sees without anything linking it to the object persists after traditional instruction in optics. Students can understand seeing as "detecting" reflected light after specially designed instruction (NSDL, 2015).

Prior Learning
Physical science • A simple wave has a repeating pattern with a specific wavelength, frequency, and amplitude. • A sound wave needs a medium through which it is transmitted. • When light shines on an object, it is reflected, absorbed, or transmitted through the object, depending on the object's material and the frequency (color) of the light. • The path that light travels can be traced as straight lines, except at surfaces between different transparent materials (e.g., air and water, air and glass) where the light path bends. • A wave model of light is useful for explaining brightness, color, and the frequency-dependent bending of light at a surface between media. • However, because light can travel through space, it cannot be a matter wave, like sound or water waves. • Digitized signals (sent as wave pulses) are a more reliable way to encode and transmit information. *Life science* • Plants, algae (including phytoplankton), and many microorganisms use the energy from light to make sugars (food) from water and carbon dioxide from the atmosphere, through the process of photosynthesis, which also releases oxygen. These sugars can be used immediately or stored for growth or later use. • Within individual organisms, food moves through a series of chemical reactions in which it is broken down and rearranged to form new molecules to support growth or to release energy. *Earth and space science* • Weather and climate are influenced by interactions involving sunlight, the ocean, the atmosphere, ice, landforms, and living things. These interactions vary with latitude, altitude, and local and regional geography, all of which can affect oceanic and atmospheric flow patterns. • Because these patterns are so complex, weather can only be predicted probabilistically. • The ocean exerts a major influence on weather and climate by absorbing energy from the sun, releasing it over time, and globally redistributing it through ocean currents.

Connections to Other Courses
Physical science- • Nuclear processes, including fusion, fission, and radioactive decays of unstable nuclei, involve release or absorption of energy. The total number of neutrons plus protons does not change in any nuclear process. • 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. • 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. • Although energy cannot be destroyed, it can be converted to less useful forms—for example, to thermal energy in the surrounding environment. *Earth and space sciences-* • The star called the sun is changing and will burn out over a lifespan of approximately 10 billion years. • The study of stars' light spectra and brightness is used to identify compositional elements of stars, their movements, and their distances from Earth. • The Big Bang theory is supported by observations of distant galaxies receding from our own, by the measured composition of stars and nonstellar gases, and by the maps of spectra of the primordial radiation (cosmic microwave background) that still fills the universe. • Other than the hydrogen and helium formed at the time of the Big Bang, nuclear fusion within stars produces all atomic nuclei lighter than and including iron, and the process releases electromagnetic energy. Heavier elements are produced when certain massive stars achieve a supernova stage and explode. • The foundation for Earth's global climate systems is the electromagnetic radiation from the sun, as well as its reflection, absorption, storage, and redistribution among the atmosphere, ocean, and land systems, and this energy's re-radiation into space. • Gradual atmospheric changes were due to plants and other organisms that captured carbon dioxide and released oxygen. • Changes in the atmosphere due to human activity have increased carbon dioxide concentrations and thus affect climate.

Samples of Open Education Resources for this Unit
Introduction to the Electromagnetic Spectrum: NASA background resource Technology for Imaging the Universe: NASA background resource NASA LAUNCHPAD: Making Waves: NASA e-Clips activity on the electromagnetic spectrum Radio Waves and Electromagnetic Fields: Phet simulation demonstrating wave generation, propagation and detection with antennas. Refraction: https://phet.colorado.edu/en/simulation/wave-interferencePHeT simulation addressing refraction of light at an interface. Wave Interference: Phet simulation of both mechanical and optical wave phenomena Thin Film Interference: OSP simulation of thin film interference for various wavelengths of visible light Photoelectric Effect Phet: Phet simulation addressing evidence for particle nature of electromagnetic radiation Photoelectric Effect OSP: Open Source Physics simulation of the photoelectric effect. Interaction of Molecules with Electromagnetic Radiation: Phet simulation exploring the effect of microwave, infrared, visible and ultraviolet radiation on various molecules. Wave/Particle Dualism: Phet simulation of wave and particle views of interference phenomena. X-ray Technology: OSP Simulation of optimization of X-ray contrast by varying energy of X-rays, materials characteristics and measurement parameters

Appendix A: NGSS and Foundations for the Unit

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

Science and Engineering Practices

Engaging in Argument from Evidence

- 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

- 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)

Asking Questions and Defining Problems

- Analyze complex real-world problems by specifying criteria and constraints for successful solutions. (HS-ETS1-1)
- 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)

Constructing Explanations and Designing Solutions

- Evaluate a solution to a complex real world problem, based on scientific knowledge,

Disciplinary Core Ideas

PS4.A: Wave Properties

- 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)
- 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)
- 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)

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. (HS-PS4-3)
- 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)
- Photoelectric materials emit electrons when they

Crosscutting Concepts

Systems and System Models

- Models (e.g., physical, mathematical, computer models) can be used to simulate systems and interactions—including energy, matter, and information flows—within and between systems at different scales. (HS-PS4-3)

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. (HS-PS4-4)
- Systems can be designed to cause a desired effect. (HS-PS4-5)

Stability and Change

- Systems can be designed for greater or lesser stability. (HS-PS4-2)

Interdependence of Science, Engineering, and Technology

- Science and engineering complement each other in the cycle known as research and development (R&D). (HS-PS4-5)

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

- Modern civilization depends on major technological systems. (HS-PS4-5, HS-PS4-2)
- New technologies can have deep impacts on society and the environment, including some that were not anticipated. Analysis of costs and

student-generated sources of evidence, prioritized criteria, and tradeoff considerations. (HS-ETS1-3)	absorb light of a high-enough frequency. (HS-PS45) **PS3.D: Energy in Chemical Processes** • Solar cells are human-made devices that likewise capture the sun's energy and produce electrical energy. (secondary to HS-PS4-5) **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) **ETS1.A: Defining and Delimiting Engineering Problems** • 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. (HS-ETS1-1) • Humanity faces major global challenges today, such as the need for supplies of clean water and food or for energy sources that minimize pollution, which can be addressed through engineering. These global challenges also may have manifestations in local communities. (HS-ETS1-1) **ETS1.B: Developing Possible Solutions** • When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts. (HS-ETS1-3)	benefits is a critical aspect of decisions about technology. (HS-ETS1-3) • Engineers continuously modify these technological systems by applying scientific knowledge and engineering design practices to increase benefits while decreasing costs and risks. (HSPS4-2) **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. (HS-PS4-3)

Embedded English Language Arts/Literacy and Mathematics	
English Language Arts/Literacy Assess the extent to which the reasoning and evidence in a text support the author's claim or a recommendation for solving a scientific or technical problem. (HS-PS4-3), (HS-PS4-4),(HS-PS4-2) **RST.9-10.8** Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account. (HS-PS4-3), (HS-PS4-4),(HS-PS4-2) **RST.11-12.1** Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem. (HS-PS4-4),(HS-ETS1-1),(HS-ETS1-3) **RST.11-12.7** Evaluate the hypotheses, data, analysis, and conclusions in a science or technical text, verifying the data when possible and corroborating or challenging conclusions with other sources of information. (HS-PS4-3), (HS-ETS1-1), (HS-ETS1-3),(HS-PS4-2) **RST.11-12.8** Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible. (HS-ETS1-1), (HS-ETS1-3) **RST.11-12.9** Write informative/explanatory texts, including the narration of historical events, scientific procedures/experiments, or technical processes. (HS-PS4-5) **WHST.11-12.2** Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the strengths and limitations of each source in terms of the specific task, purpose, and audience; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and overreliance on any one source and following a standard format for citation. (HS-PS4-4) **WHST.11-12.8**	*Mathematics* Reason abstractly and quantitatively. (HS-PS4-3), (HS-ETS1-1), (HS-ETS1-3) **MP.2** Model with mathematics. (HS-ETS1-1),(HS-ETS1-3) **MP.4** Interpret expressions that represent a quantity in terms of its context. (HS-PS4-3) **HSA-SSE.A.1** Choose and produce an equivalent form of an expression to reveal and explain properties of the quantity represented by the expression. (HS-PS4-3) **HSA-SSE.B.3** Rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations. (HS-PS4-3) **HAS.CED.A.4**