PS4: Waves and their applications in technologies for information transfer		
1	1.PS4.1	Use a model to describe how light is required to make objects visible. Summarize how Illumination could be from an external light source or by an object giving off its own light.
	1.PS4.2	Determine the effect of placing objects made with different materials (transparent, translucent, opaque, and reflective) in the path of a beam of light.
2	2.PS4.1	Plan and conduct investigations to demonstrate the cause and effect relationship between vibrating materials (tuning forks, water, bells) and sound.
	2.PS4.2	Use tools and materials to design and build a device to understand that light and sound travel in waves and can send signals over a distance.
	2.PS4.3	Observe and demonstrate that waves move in regular patterns of motion by disturbing the surface of shallow and deep water.
4	4.PS4.1	Use a model of a simple wave to explain regular patterns of amplitude, wavelength, and direction.
	4.PS4.2	Describe how the colors of available light sources and the bending of light waves determine what we see.
	4.PS4.3	Investigate how lenses and digital devices like computers or cell phones use waves to enhance human senses.
8	8.PS4.1	Develop and use models to represent the basic properties of waves including frequency, amplitude, wavelength, and speed.
	8.PS4.2	Compare and contrast mechanical waves and electromagnetic waves based on refraction, reflection, transmission, absorption, and their behavior through a vacuum and/or various media.
	8.PS4.3	Evaluate the role that waves play in different communication systems.

1.PS4: Waves and Their Applications in Technologies for Information Transfer			
1.PS4.1	Use a model to describe how light is required to make objects visible. Summarize how illumination could be from an external light source or by an object giving off its own light. **COMPONENT IDEA:** *B. Electromagnetic Radiation*	**EXPLANATION:** Objects become visible when light from an external light source is reflected off the surface of an object. In the absence of any external light source, no light reflects off the surface of the object, and we cannot detect the object using our sense of sight. Some objects (such as fires, or the Sun) get hot enough that they can give off their own sources of light. Example experiences may include the inability to observe objects in a completely dark room. Pinhole viewers may be constructed using tubes from paper towel rolls or empty tubes from chips and used to observe a candelabra light bulb or trees or objects outdoors. Students can then diagram the events necessary to create the image projected on the back of the pinhole camera/viewer. *(The speed of light and wave properties should not be discussed, merely the idea that light travels in straight paths.)*	**CROSSCUTTING CONCEPT:** **Pattern** *Students recognize, classify, and record the patterns they observe in nature or man-made objects.* **SCIENCE AND ENGINEERING PRINCIPLE:** **Developing and using models** *Students make drawings, displays, and simple representations for events they experience through their senses, incorporating relative scales when appropriate.*
1.PS4.2	Determine the effect of placing objects made with different materials (transparent, translucent, opaque, and reflective in the path of a beam of light). **COMPONENT IDEA:** *B. Electromagnetic Radiation*	**EXPLANATION:** Some objects may appear invisible (such as glass) when they do not absorb any light, others may absorb all light and therefore be easier to see, while others can redirect the pathway of light allowing the otherwise straight path to be diverted. If pinhole viewers are constructed, students can place these materials in front of the pinhole and observe the effects. Shadows are created when the path of light is blocked before it strikes a surface, but mirrored surfaces can be used to redirect a beam of light around obstacles. *(The scattering of light by rough surfaces may be discussed but is not a principle part of this standard.)*	**CROSSCUTTING CONCEPT:** **Cause and Effect** *Students identify cause and effect relationships through observable patterns, utilizing simple tests to provide evidence that supports or refutes their ideas.* **SCIENCE AND ENGINEERING PRINCIPLE:** **Analyzing and interpreting data** *Students set a foundation for data analysis by recording their thoughts and observations about patterns and events in a manner that can be shared with others.*

2.PS4: Waves and Their Applications in Technologies for Information Transfer			
2.PS4.1	Plan and conduct investigations to demonstrate the cause and effect relationship between vibrating materials (tuning forks, water, bells) and sound. **COMPONENT IDEA:** *A. Wave Properties: Mechanical and Electromagnetic*	**EXPLANATION:** All waves are repeating patterns of highs and lows that transfer energy from one place to another. Investigations of waves moving across the surface of a pool of water should result in students noting that objects (such as corks) floating on the surface of the water move up and down as the wave passes beneath them, but the objects do not travel along with the wave. Students might note that surfers or objects caught near the shore move back and forth. Such instances are not exceptions and can be explained by differentiating between waves in relatively deep or shallow water. In the case of sound, it is a variation between high pressure pockets of air and low pressure pockets of air. Students should focus on the connection that when objects vibrate back and forth, they make sound. Stopping the vibration causes the sound to end. Examples of vibrating materials that make sound may include a tuning fork or plucking a stretched rubber band or guitar string. To observed sound making an object vibrate, hold a piece of paper next to a speaker playing loud music.	**CROSSCUTTING CONCEPT:** **Cause and Effect** *Students identify cause and effect relationships through observable patterns, utilizing simple tests to provide evidence that supports or refutes their ideas.* **SCIENCE AND ENGINEERING PRINCIPLE:** **Planning and carrying out controlled investigations** *Students carry out investigations in groups, making decisions about suitable measurements for data collection in order to answer a question.*
2.PS4.2	Use tools and materials to design and build a device to understand that light and sound travel in waves and can send signals over distances. **COMPONENT IDEA:** C. Information Technologies and Instrumentation	**EXPLANATION:** Since early times, humans have been communicating over long distances through systems such as smoke signals or Morse code. There are several historical lessons on information theory, such as those found on Khan Academy, which discuss unique approaches to sending messages over distance. Now, digital signals can be sent using waves. Students might devise a device which is capable of transmitting a message (spoken or encoded) over a distance. Options may include, flashes of light in a darkened room, two cups joined by a string, or even a focused light source shining on a solar cell connected to an amplified speaker. Challenges to this activity to inspire creativity might include increasing the complexity of the message, or using the device to conduct a two-way exchange resulting in some action taken from the recipients at either end.	**CROSSCUTTING CONCEPT:** **Structure and Function** *Students identify and describe parts and their roles in the inner workings as part of a larger system/object.* **SCIENCE AND ENGINEERING PRINCIPLE:** **Constructing explanations and designing solutions** *Students design and/or build a device that solves a specific given problem and evaluate competing solutions.*

2.PS4.3	Observe and demonstrate that waves move in regular patterns of motion by disturbing the surface of shallow and deep water. **COMPONENT IDEA:** *A. Wave Properties: Mechanical and Electromagnetic*	**EXPLANATION:** Deep or shallow waters are relative to the height of a wave, not an absolute measured depth. Water can be described as deep whenever its depth is greater than half the wave amplitude. Waves moving through deep water cause the surface of the water to move up and down as the wave passes. Individual water molecules don't travel away from their original position; they move in place, in a circular pattern. An object floating on the surface of this water will bob up and down and shift right to left in the same pattern as the water particles beneath it. However, over a period of time, it can be seen that the object never travels across the surface of the water. Table tennis balls and under-bed storage bins can be used as demonstrations. If a wave travels into shallow water (water that is <1/2 of the wave's amplitude), it will topple (e.g., waves rolling onto beaches, or a boat wake at the edge of a river or lake.	**CROSSCUTTING CONCEPT:** **Pattern** *Students recognize, classify, and record the patterns they observe in nature or man-made objects.* **SCIENCE AND ENGINEERING PRINCIPLE:** **Developing and using models** *Students make drawings, displays, and simple representations for events they experience through their senses, incorporating relative scales when appropriate.*

4.PS4: Waves and Their Applications in Technologies for Information Transfer			
4.PS4.1	Use a model of a simple wave to explain regular patterns of amplitude, wavelength, and direction. **COMPONENT IDEA:** *A. Wave Properties: Mechanical and Electromagnetic*	**EXPLANATION:** Student models should explore the patterns in the shapes of both longitudinal and transverse waves as well as patterns occurring when two waves interact. Students should be able to both identify amplitude within a model for a wave, as well as identify patterns for how amplitude changes when waves interact. Students should note the effects on the direction a wave travels when it intersects another wave while traveling through a medium. Waves can be observed traveling through an elongated spring that is quickly jerked sideways and returned to center on a tile floor. Floor tiles can be used as reference points where a wave might have an amplitude of one floor tile. (Students are not responsible for boundary behaviors of waves such as reflection at a fixed end.)	**Crosscutting Concept:** **Pattern** *Students recognize, classify, and record patterns involving rates of change.* **SCIENCE AND ENGINEERING PRINCIPLE:** **Developing and using models** *Student models begin to become abstract and metaphorical, incorporating relationships between events and predictive aspects for recurring events.*
4.PS4.2	Describe how the colors of available light sources and the bending of light waves determine what we see. **COMPONENT IDEA:** *B. Electromagnetic Radiation*	**EXPLANATION:** In first grade, students discussed the idea that objects are visible because they either reflect or emit their own light. Light was treated as a beam of light and color was not addressed in first grade. This standard provides students the opportunity to see that white light is composed of a combination of red, green, and blue light. Students can examine and record how the appearances of objects (solid-color and multi-color) change depending on the light source. Prisms can be used to bend light so that it is separated into component colors. Lenses and combinations of lenses can bend light to magnify or focus light for objects that cannot be seen with the naked eye. (Students are not responsible for explaining the properties of materials that cause them to absorb/reflect certain colors.)	**Crosscutting Concept:** **Cause and Effect** *Students routinely search for cause and effect relationships in systems they study.* **SCIENCE AND ENGINEERING PRINCIPLE:** **Analyzing and interpreting data.** *Students should be able to organize experimental data to reveal patterns and utilize data using simple graph-to-form explanations.*

4.SP4.3	Investigate how lenses and digital devices like computers or cell phones use waves to enhance human senses. **COMPONENT IDEA:** *C. Information Technologies and Instrumentation*	**EXPLANATION:** In 4.PS4.2, students are exposed to the bending of light as it crosses over the boundary between two materials. Students could investigate or construct varying arrangements of lenses to determine how they are utilized in devices such as eyeglasses, microscopes, or telescopes. Digital devices are devices/components of devices that are either on or off. An LCD (computer/smartphone) screen is a series of tiny lightbulbs (pixels) that can be turned on or off individually to create a picture. A model of this process might be crowds at a stadium holding pieces of colored paper above their heads to create a mosaic when viewed from above. Computers store information about which pixels are turned on an off to display an image. This stored digital information can be transmitted using waves to share pictures remotely.	**Crosscutting Concept:** **Structure and Function** *Students begin to attribute the shapes of sub-components to the function of the part.* **SCIENCE AND ENGINEERING PRINCIPLE:** **Obtaining, evaluating, and communicating information** *(O/E) Students can read and summarize text and embedded, non-text elements from multiple sources synthesizing an understanding on a scientific idea. (C) Students can communicate scientific information in writing utilizing embedded elements.*

8.PS4: Waves and Their Applications in Technologies for Information Transfer			
8.PS4.1	Develop and use models to represent the basic properties of waves including frequency, amplitude, wavelength and speed. **COMPONENT IDEA:** *A. Wave Properties: Mechanical and Electromagnetic*	**EXPLANATION:** The speed of a wave is dependent on properties of the medium that the wave travels through. In a given medium, a specific type of wave will have a set speed. (E.g. the speed of sound is approximately 340m/s) Given that the speed of the wave is set, waves of differing frequencies will have different wavelengths, as these two factors describe the propagation of a wave. The amplitude of a wave is dependent on the amount of energy being transported by the wave. Students have diagrammed waves and labeled parts for both longitudinal and transverse waves in fourth grade while exploring interference patterns when two waves intersect. Students should now be performing quantitative analysis of wave behaviors.	**CROSSCUTTING CONCEPT:** **Scale, Proportion, and Quantity** *Students develop models to investigate scales that are beyond normal experiences.* **SCIENCE AND ENGINEERING PRINCIPLE:** **Developing and using models** *Students create models which are responsive and incorporate features that are not visible in the natural world, but have implications on the behavior of the modeled systems and can identify limitations of their models.*

8.PS4.2	Compare and contrast mechanical waves and electromagnetic waves based on refraction, reflection, transmission and absorption and their behavior through a vacuum and/or various media. **COMPONENT IDEA:** *A. Wave Properties: Mechanical and Electromagnetic*	**EXPLANATION:** Wave speed is dependent on the properties of the medium. Phenomena such as refraction occur when a wave travels out of one medium and into a different medium, resulting in a change to the wave speed. Regardless of type, waves are a means of transferring energy from one location to another. It is electromagnetic waves that carry energy from the sun to our planet. While sound waves travel through a medium, ultimately transferring energy to ear drums creating the sensation of hearing. The principal difference between wave types is the ability to propagate without a medium in the case of electromagnetic waves. However, even mechanical waves leave the medium undisturbed after passing through. (Students should be exposed to the varying frequencies for EM waves, but memorization of specific frequencies/wavelengths is not expected.)	**CROSSCUTTING CONCEPT:** **Energy and Matter** *Students track energy changes through transformations in a system.* **SCIENCE AND ENGINEERING PRINCIPLE:** **Constructing explanations and designing solutions** *Students form explanations using source (including student developed investigations) which show comprehension of parsimony, utilize quantitative and qualitative models to make predictions, and can support or cause revisions of a particular conclusion.*

8.PS4.3	Evaluate the role that waves play in different communication systems. **COMPONENT IDEA:** *C. Information Technologies and Instrumentation*	**EXPLANATION:** Digitizing is the process of converting information into a series of binary ones and zeroes. Once digitized, information can be transmitted as wave pulses and stored reliably so that the information can be recreated at a later time. This process can be demonstrated for students by connecting a solar cell to a small amplified speaker. A laser pointer flashed on and off striking the surface of the solar cell will make an audible popping noise. For a more profound demonstration, the laser pointer can then be connected to the headphone jack of an audio player and music can be played across open spaces. Interrupting the beam will stop the sound. Students should explore similar applications of information transfer in the functioning of radios, televisions, cellphones, and wireless computer networks.	**CROSSCUTTING CONCEPT:** **Structure and Function** *Students design systems, selecting materials for their relevant properties.* **SCIENCE AND ENGINEERING PRINCIPLE:** **Obtaining, evaluating, and communicating information** *(Observe) Students can evaluate text, media, and visual displays of information with the intent of clarifying claims and reconciling explanations. Students can communicate scientific information in writing utilizing embedded tables, charts, figures, graphs* *Students can communicate technical information about proposed design solutions using tables, graphs, and diagrams.*

PHYS.PS4: Waves and Their Applications in Technologies for Information Transfer			
PHYS.PS4.1	Know wave parameters (i.e. velocity, period, amplitude, frequency, angular frequency) as well as how these quantities are defined in the cases of longitudinal and transverse waves. **COMPONENT IDEA:** *A. Wave Properties: Mechanical and Electromagnetic*	**EXPLANATION:** Standard 4.PS4.1 is a student's introduction to waves. At this time, students address the properties of amplitude, wavelength and direction of a wave and principles of superposition of waves, but not by name. In 8.PS4.1, students revisit the topic adding frequency to their models and beginning to consider wave speed, but without mentioning factors affecting the speed of the waves. PHYS.PS2.3 includes discussion of rotational motion which can pair with discussions of simple harmonic motion to clarify angular velocity and angular speed. Discussions regarding the origin of waves can fully develop these ideas.	**CROSSCUTTING CONCEPT:** **Systems and System Models** *Students create and manipulate a variety of different models: physical, mathematical, computational.* **SCIENCE AND ENGINEERING PRINCIPLE:** **Constructing explanations and designing solutions** *Students form explanations that incorporate sources (including models, peer reviewed publications, their own investigations), invoke scientific theories, and can evaluate the degree to which data and evidence support a given conclusion.*

PHYS.PS4. 2	Describe parameters of a medium that affect the propagation of a sound wave through it. **COMPONENT IDEA:** *A. Wave Properties: Mechanical and Electromagnetic*	**EXPLANATION:** The focus of this discussion should be properties of the medium, specifically the density of the material. The density becomes a factor in optics and considering transmission of electromagnetic waves. Students can be led to make their descriptions by experimenting with coiled springs stretched to varying lengths. The topic of linear mass density can be used to explore analogous properties in the air.	**CROSSCUTTING CONCEPT:** **Structure and Function** *Students apply patterns in structure and function to unfamiliar phenomena.* **SCIENCE AND ENGINEERING PRINCIPLE:** **Planning and carrying out controlled investigations** *Students plan and perform investigations to aid in the development of a predictive model for interacting variables, considering the quantity of data with respect to experimental uncertainty, and select methods for collection and analysis of data.*

PHYS.PS4. 3	Understand that the reflection, refraction, and transmission of waves at an interference between two media can be modeled on the basis of the characteristics of specific wave parameters and parameters of the medium. **COMPONENT IDEA:** *A. Wave Properties: Mechanical and Electromagnetic*	**EXPLANATION:** The focus of this standard is on developing an understanding for the behavior of waves at a boundary. To demonstrate these principles, it is suggested that students create waves on a coiled spring or string and send these waves towards either a free or fixed end or through a different weight of string. For instance, wave can be created in a section of a lighter string then transmitted towards a point where that string terminates into a heavier segment of string. In doing so, it is possible to observe the effects on wave amplitude and a discussion of energy differences. Students should extend their observations of these mechanical waves to wave behaviors at other scales.	**CROSSCUTTING CONCEPT:** **Cause and Effect** *Students use cause and effect models at one scale to make predictions about the behavior of systems at different scales.* **SCIENCE AND ENGINEERING PRINCIPLE:** **Analyzing and interpreting data.** *Students can differentiate between the appropriateness of quantitative and qualitative data.*

PHYS.PS4.4	Communicate scientific and technical information about how the principle of superposition explains the resonance and harmonic phenomena in air columns on strings and common sound devices. **COMPONENT IDEA:** *C. Information Technologies and Instrumentation*	**EXPLANATION:** In 4.PS4.1, students examine the effects of superposition of waves, but do not explore the behavior of waves at boundaries. Building on 4.PS4.3, the behavior of a wave at a free or fixed boundaries can create patterns where successive waves produced by a source interact with those reflected off a boundary. Discussions should include general development of the idea of harmonics. Once established, this topic can be extended to the specific function of stringed instruments such as guitars of simple open or closed tubes. The phenomena of resonance can be produced using a tuning fork held above a section of rigid tubing which is lowered or lifted into a pail of water. Resonance can be heard clearly at multiple points, providing an opportunity to model the source of resonance and relate the resonance points to the wavelength of the wave produced. The phenomenon of beats can be used to provide an introduction to this topic as it too is an audible phenomenon. Quick demonstrations of beats can be performed without tuning forks using multiple open windows in a browser simultaneously playing different frequencies.	**CROSSCUTTING CONCEPT:** **Pattern** *Students recognize, classify, and record patterns in quantitative data from empirical research and mathematical representations.* **SCIENCE AND ENGINEERING PRINCIPLE:** **Obtaining, evaluating, and communicating information** *Students can provide written and oral explanations for phenomena and multi-part systems using models, graphs, data tables, and diagrams.*

PHYS.PS4. 5	Evaluate the characteristics of the electromagnetic spectrum by communicating the similarities and differences among the different bands. Research and determine methods and devices used to measure these characteristics. **COMPONENT IDEA:** *B. Electromagnetic Radiation*	**EXPLANATION:** The visible portion of the electromagnetic spectrum will be familiar to students, as will the ideas of x-rays, microwaves, and radiowaves. However, students often struggle to see these phenomena as multiple manifestations of the same principles. It may be beneficial to relate these discussions to the physiology of the human eye, specifically the function of the rhodopsin photopigment. As a demonstration: the light bulbs on the front of remote controls emit light outside of the visible spectrum; however, inexpensive cell phone cameras lack IR filters (as well as some front facing cameras on more current cell phones). Rendering the IR light visible can help student to understand that many devices function by capturing the energy of electromagnetic waves. An additional option would be the creation of a crystal radio using a germanium diode.	**CROSSCUTTING CONCEPT:** **Pattern** *Students recognize, classify, and record patterns in quantitative data from empirical research and mathematical representations.* **SCIENCE AND ENGINEERING PRINCIPLE:** **Analyzing and interpreting data.** *Students should use data to revise and optimize devices already in operation.*

PHYS.PS4. 6	Plan and conduct controlled scientific investigations to construct explanations of light's behavior (reflection, refraction, transmission, interference) including the use of ray diagrams. **COMPONENT IDEA:** *B. Electromagnetic Radiation*	**EXPLANATION:** In PHYS.PS4.3 students examine the behaviors of mechanical waves moving through a medium. Though the terminology in this standard is comparable, this standard focuses on optics of light. Students should work with lenses and mirrors to build an understanding of the behaviors of light as it interacts with surfaces (reflection, refraction, transmission). In 4.PS4.1 and PHYS.PS4.1, students investigated interference patterns with mechanical waves. Using a pair of speakers and an online tone/frequency generator, it is possible to demonstrate that sound waves, like mechanical waves, can interfere with each other. In such a demonstration, students are able to hear variations in the volume of the sound as they walk in a straight line across the field of sound created by the speakers.	**CROSSCUTTING CONCEPT:** **Structure and Function** *Students apply patterns in structure and function to unfamiliar phenomena.* **SCIENCE AND ENGINEERING PRINCIPLE:** **Developing and using models** *Student models are functioning prototypes and are able to generate data useful for both computation and problem solving.*

PHYS.PS4. 7	Evaluate the claims, evidence, and reasoning behind the idea that electromagnetic radiation can be described either by a wave model or a particle model. **COMPONENT IDEA:** *B. Electromagnetic Radiation*	**EXPLANATION:** Most students willingly accept the particle behavior of light. As early as first grade, students have experimented with the behavior of light and observed that shadows can be created if some of the particles of light are blocked. Introductory explanations of the photoelectric effect can provide more advanced evidence for the particle behavior. Properties of wave behavior can be demonstrated by observing interference patterns in Young's double slit experiment. Simple models using strips of paper to represent waves can provide a more tangible experience to understand the interference phenomena.	**CROSSCUTTING CONCEPT:** **Pattern** *Students recognize, classify, and record patterns in quantitative data from empirical research and mathematical representations.* **SCIENCE AND ENGINEERING PRINCIPLE:** **Obtaining, evaluating, and communicating information** *(Observe/Evaluate) Students can critically read scientific literature, integrating, extracting, and accurately simplifying main ideas from multiple sources while maintaining accuracy and validating data whenever possible.*
PHYS.PS4. 8	Obtain information to construct explanations on how waves are used to produce, transmit, and capture signals and store and interpret information. **COMPONENT IDEA:** *C. Information Technologies and Instrumentation*	**EXPLANATION:** In 8.PS4.3 students are introduced to the use of waves in communication systems. Further development of these discussions might include a distinction between the differences between analog and digital signals and necessity for digital signals in communication. Additionally, waves can be used for detection in x-rays or ultrasound. Information that is digitized can be stored with very little loss to the quality of the data itself.	**CROSSCUTTING CONCEPT:** **Structure and Function** *Students infer the function of a component of a system based on its shape and interactions with other components.* **SCIENCE AND ENGINEERING PRINCIPLE:** **Constructing explanations and designing solutions** *Students form explanations that incorporate sources (including models, peer reviewed publications, their own investigations), invoke scientific theories, and can evaluate the degree to which data and evidence support a given conclusion.*

PHYS.PS4. 9	Investigate how information is carried in optical systems and use Snell's law to describe the properties of optical fibers. **COMPONENT IDEA:** *C. Information Technologies and Instrumentation*	**EXPLANATION:** As light travels from one medium to another, the path of light is bent. Snell's law can be used to determine the critical angle for a medium. This angle represents the angle at which the light does not exit the medium but instead is reflected back into the medium. Fiber optic cables utilize this phenomena by transmitting light that reflects off of the internal walls of the cable rather than escaping the cable.	**CROSSCUTTING CONCEPT:** **Cause and Effect** *Students design a system to produce a desired outcome.* **SCIENCE AND ENGINEERING PRINCIPLE:** **Asking questions (for science) and defining problems (for engineering)** *Questions should facilitate empirical investigation.*