Middle School Topics Model Course III – Bundle 2
Energy in Waves

This is the second bundle of the Middle School Topics Model Course III. Each bundle has connections to the other bundles in the course, as shown in the Course Flowchart.

Bundle 1 Question: This bundle is assembled to address the question "How do waves transfer energy and information?"

Summary

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

Connections between bundle concepts

While applying energy concepts to waves, students will develop a deeper understanding of how waves work and their applications and influences on many facets of their lives. All waves have some features in common. A simple wave has a repeating pattern with a specific wavelength, frequency, and amplitude (PS4.A as in MS-PS4-1). Waves can be combined with other waves of the same type to produce complex information-containing patterns, and digitized signals are a more reliable way to encode and transmit information (PS4.C as in MS-PS4-3).

A wave model of light is useful for explaining brightness, color, and the frequency-dependent bending of light at a surface between media (PS4.B as in MS-PS4-2). When light shines on an object, it is reflected, absorbed, or transmitted through the object, depending on the object's material and the frequency of the light (PS4.B as in MS-PS4-2). The path that light travels can be traced as straight lines, except at surfaces between different transparent materials where the light path bends (PS4.B as in MS-PS4-2). However, because light can travel through space, it cannot be a matter wave, like sound or water waves (PS4.B as in MS-PS4-2), because a sound wave needs a medium through which it is transmitted (PS4.A as in MS-PS4-2).

The engineering design idea that there are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of a problem (ETS1.B as in MS-ETS1-2) could connect to many different science ideas, such as that an object's material and frequency affects whether light is reflected, absorbed, or transmitted through the object (PS4.B as in MS-PS4-2) or that digitized signals are a more reliable way to encode and transmit information (PS4.C as in MS-PS4-3). Connections could be made through an engineering design task such as evaluating the alignment between solutions (such as radios versus cell phones) and the criteria and constraints of problems, such as the need to transmit signals through various objects or over different distances.

Additionally, the engineering design ideas that models of all kinds are important for testing solutions (ETS1.B as in MS-ETS1-4) and the iterative process of testing the most promising solutions and modifying what is proposed on the basis of the test results leads to greater refinement and ultimately to an optimal solution (ETS1.C as in MS-ETS1-4) could connect to many different science ideas, such as how an object's material and frequency affects whether light is reflected, absorbed, or transmitted through the object (PS4.B as in MS-PS4-2), or how digitized signals are a more reliable way to encode and transmit information (PS4.C as in MS-PS4-3). Connections could be made through an engineering design task, such as using computer programs to model solutions for the color quality of pictures taken from digital cameras and cell phones or to iteratively test and improve the sound quality of hearing aids or musical instruments.

Bundle Science and Engineering Practices

Instruction leading to this bundle of PEs will help students build toward proficiency in elements of the practices of developing and using models (MS-PS4-2 and MS-ETS1-4); using mathematical representations (MS-PS4-1); engaging in argument (MS-ETS1-2); and obtaining, evaluating, and communicating information (MS-PS4-3). Many other practice elements can be used in instruction.

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Bundle Crosscutting Concepts Instruction leading to this bundle of PEs will help students build toward proficiency in elements of the crosscutting concepts of Patterns (MS-PS4-1) and Structure and Function (MS-PS4-2 and MS-PS4-3). Many other crosscutting concept elements can be used in instruction. *All instruction should be three-dimensional.*	
Performance Expectations	MS-PS4-1. **Use mathematical representations to describe a simple model for waves that includes how the amplitude of a wave is related to the energy in a wave.** [Clarification Statement: Emphasis is on describing waves with both qualitative and quantitative thinking.] [Assessment Boundary: Assessment does not include electromagnetic waves and is limited to standard repeating waves.] MS-PS4-2. **Develop and use a model to describe that waves are reflected, absorbed, or transmitted through various materials.** [Clarification Statement: Emphasis is on both light and mechanical waves. Examples of models could include drawings, simulations, and written descriptions.] [Assessment Boundary: Assessment is limited to qualitative applications pertaining to light and mechanical waves.] MS-PS4-3. **Integrate qualitative scientific and technical information to support the claim that digitized signals are a more reliable way to encode and transmit information than analog signals.** [Clarification Statement: Emphasis is on a basic understanding that waves can be used for communication purposes. Examples could include using fiber optic cable to transmit light pulses, radio wave pulses in wifi devices, and conversion of stored binary patterns to make sound or text on a computer screen.] [Assessment Boundary: Assessment does not include binary counting. Assessment does not include the specific mechanism of any given device.] MS-ETS1-2. **Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.** MS-ETS1-4. **Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved.**
Example Phenomena	You can see rainbows by shining when through a prism. I can see and hear my favorite music and television shows using the internet.
Additional Practices Building to the PEs	**Asking Questions and Defining Problems** • Ask questions to clarify and/or refine a model, an explanation, or an engineering problem. Students could *ask questions to refine a model* [for how] ***when light shines on an object, it is reflected, absorbed, or transmitted through the object***. MS-PS4-2 **Developing and Using Models** • Develop and/or revise a model to show the relationships among variables, including those that are not observable but predict observable phenomena. Students could *develop a model to show the relationships* [between the] ***wavelength, frequency, and amplitude*** [of a] ***wave***. MS-PS4-1 **Planning and Carrying Out Investigations** • Plan an investigation individually and collaboratively, and in the design: identify independent and dependent variables and controls, what tools are needed to do the gathering, and how many data are needed to support a claim. Students could *plan an investigation* [to determine whether] ***digitized signals are a more reliable way to encode and transmit information*** [than are analog signals]. MS-PS4-3

Additional Practices Building to the PEs (Continued)	**Analyzing and Interpreting Data** • Analyze and interpret data to provide evidence for phenomena. Students could *analyze and interpret data to provide evidence for* [the] ***repeating pattern*** [of a] ***simple wave.*** MS-PS4-1 **Using Mathematical and Computational Thinking** • Use digital tools (e.g., computers) to analyze very large data sets for patterns and trends. Students could *use digital tools to analyze very large data sets for patterns and trends* [to determine whether] ***digital signals are a more reliable way to encode and transmit information*** [than are analog signals]**.** MS-PS4-3 **Constructing Explanations and Designing Solutions** • Construct an explanation using models or representations. Students could *construct an explanation using representations* [of how] ***the path that light travels can be traced as straight lines, except at surfaces between different transparent materials where the light path bends***. MS-PS4-2 **Engaging in Argument from Evidence** • Compare and critique two arguments on the same topic and analyze whether they emphasize similar or different evidence and/or interpretations of facts. Students could *compare and critique two arguments* [for how] ***a wave model of light is useful for explaining brightnes****s and analyze whether they emphasize similar or different evidence*. MS-PS4-2 **Obtaining, Evaluating, and Communicating Information** • Evaluate data, hypotheses, and/or conclusions in scientific and technical texts in light of competing information or accounts. Students could *evaluate data, hypotheses, and/or conclusions in scientific and technical texts in light of competing information* [about how] ***when light shines on an object, it is reflected, absorbed, or transmitted through the object***. MS-PS4-2
Additional Crosscutting Concepts Building to the PEs	**Cause and Effect** • Cause and effect relationships may be used to predict phenomena in natural or designed systems. Students could construct an argument from evidence for how the *cause and effect relationship* [between an] ***object's material and reflection, absorption, or transmission of light*** *may be used to predict a phenomenon*. MS-PS4-2 **Systems and System Models** • Models can be used to represent systems and their interactions—such as inputs, processes and outputs—and energy, matter, and information flows within systems. Students could develop a model to *represent* ***frequency-dependent bending of light at a surface between media*** *as a system,* [including] *its inputs, processes, and outputs.* MS-PS4-2

Additional Crosscutting Concepts Building to the PEs (Continued)	**Stability and Change** • Small changes in one part of a system might cause large changes in another part. Students could obtain, evaluate, and communicate information [about how] *small changes in one part of a* ***digitized signal*** *(**sent as wave pulses**) might cause large changes in another part*. MS-PS4-3
Additional Connections to Nature of Science	**Scientific Knowledge is Based on Empirical Evidence** • Science knowledge is based upon logical and conceptual connections between evidence and explanations. Students could construct an argument that *science knowledge is based on logical and conceptual connections between evidence and explanations*, [using as evidence scientists' understanding that] ***a wave model of light is useful for explaining brightness, color, and the frequency-dependent bending of light at a surface between media***. MS-PS4-2 **Science is a Human Endeavor** • Scientists and engineers rely on human qualities such as persistence, precision, reasoning, logic, imagination and creativity. Students could obtain and evaluate information about how *engineers rely on human qualities such as logic, imagination, and creativity*, [using as evidence how engineers have developed new ways to use] ***digitized signals to encode and transmit information***. MS-PS4-3

MS-PS4-1 Waves and Their Applications in Technologies for Information Transfer

Students who demonstrate understanding can:

MS-PS4-1. **Use mathematical representations to describe a simple model for waves that includes how the amplitude of a wave is related to the energy in a wave.** [Clarification Statement: Emphasis is on describing waves with both qualitative and quantitative thinking.] [*Assessment Boundary: Assessment does not include electromagnetic waves and is limited to standard repeating waves.*]

The performance expectation above was developed using the following elements from the NRC document *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 6–8 level builds on K–5 and progresses to identifying patterns in large data sets and using mathematical concepts to support explanations and arguments. • Use mathematical representations to describe and/or support scientific conclusions and design solutions. - ***Connections to Nature of Science*** **Scientific Knowledge is Based on Empirical Evidence** • Science knowledge is based upon logical and conceptual connections between evidence and explanations.	**PS4.A: Wave Properties** • A simple wave has a repeating pattern with a specific wavelength, frequency, and amplitude.	**Patterns** • Graphs and charts can be used to identify patterns in data.

Observable features of the student performance by the end of the course:			
1	Representation		
	a	Students identify the characteristics of a simple mathematical wave model of a phenomenon, including:	
		i.	Waves represent repeating quantities.
		ii.	Frequency, as the number of times the pattern repeats in a given amount of time (e.g., beats per second).
		iii.	Amplitude, as the maximum extent of the repeating quantity from equilibrium (e.g., height or depth of a water wave from average sea level).
		iv.	Wavelength, as a certain distance in which the quantity repeats its value (e.g., the distance between the tops of a series of water waves).
2	Mathematical modeling		
	a	Students apply the simple mathematical wave model to a physical system or phenomenon to identify how the wave model characteristics correspond with physical observations (e.g., frequency corresponds to sound pitch, amplitude corresponds to sound volume).	
3	Analysis		
	a	Given data about a repeating physical phenomenon that can be represented as a wave, and amounts of energy present or transmitted, students use their simple mathematical wave models to identify patterns, including:	
		i.	That the energy of the wave is proportional to the square of the amplitude (e.g., if the height of a water wave is doubled, each wave will have four times the energy).
		ii.	That the amount of energy transferred by waves in a given time is proportional to frequency (e.g., if twice as many water waves hit the shore each minute, then twice as much energy will be transferred to the shore).
	b	Students predict the change in the energy of the wave if any one of the parameters of the wave is changed.	

MS-PS4-2 Waves and Their Applications in Technologies for Information Transfer

Students who demonstrate understanding can:

MS-PS4-2. Develop and use a model to describe that waves are reflected, absorbed, or transmitted through various materials. [Clarification Statement: Emphasis is on both light and mechanical waves. Examples of models could include drawings, simulations, and written descriptions.] [*Assessment Boundary: Assessment is limited to qualitative applications pertaining to light and mechanical waves.*]

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

Science and Engineering Practices

Developing and Using Models

Modeling in 6–8 builds on K–5 and progresses to developing, using, and revising models to describe, test, and predict more abstract phenomena and design systems.

- Develop and use a model to describe phenomena.

Disciplinary Core Ideas

PS4.A: Wave Properties

- A sound wave needs a medium through which it is transmitted.

PS4.B: Electromagnetic Radiation

- 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.

Crosscutting Concepts

Structure and Function

- Structures can be designed to serve particular functions by taking into account properties of different materials, and how materials can be shaped and used.

Observable features of the student performance by the end of the course:		
1	Components of the model	
	a	Students develop a model to make sense of a given phenomenon. In the model, students identify the relevant components, including:
		i. Type of wave.
		1. Matter waves (e.g., sound or water waves) and their amplitudes and frequencies.
		2. Light, including brightness (amplitude) and color (frequency).
		ii. Various materials through which the waves are reflected, absorbed, or transmitted.
		iii. Relevant characteristics of the wave after it has interacted with a material (e.g., frequency, amplitude, wavelength).
		iv. Position of the source of the wave.
2	Relationships	
	a	In the model, students identify and describe* the relationships between components, including:
		i. Waves interact with materials by being:
		1. Reflected.
		2. Absorbed.
		3. Transmitted.
		ii. Light travels in straight lines, but the path of light is bent at the interface between materials when it travels from one material to another.
		iii. Light does not require a material for propagation (e.g., space), but matter waves do require a material for propagation.
3	Connections	
	a	Students use their model to make sense of given phenomena involving reflection, absorption, or transmission properties of different materials for light and matter waves.

	b	Students use their model about phenomena involving light and/or matter waves to describe* the differences between how light and matter waves interact with different materials.
	c	Students use the model to describe* why materials with certain properties are well-suited for particular functions (e.g., lenses and mirrors, sound absorbers in concert halls, colored light filters, sound barriers next to highways).

MS-PS4-3 Waves and Their Applications in Technologies for Information Transfer

Students who demonstrate understanding can:

MS-PS4-3. **Integrate qualitative scientific and technical information to support the claim that digitized signals are a more reliable way to encode and transmit information than analog signals.** [Clarification Statement: Emphasis is on a basic understanding that waves can be used for communication purposes. Examples could include using fiber optic cable to transmit light pulses, radio wave pulses in wifi devices, and conversion of stored binary patterns to make sound or text on a computer screen.] [*Assessment Boundary: Assessment does not include binary counting. Assessment does not include the specific mechanism of any given device.*]

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

Science and Engineering Practices

Obtaining, Evaluating, and Communicating Information

Obtaining, evaluating, and communicating information in 6-8 builds on K-5 and progresses to evaluating the merit and validity of ideas and methods.

- Integrate qualitative scientific and technical information in written text with that contained in media and visual displays to clarify claims and findings.

Disciplinary Core Ideas

PS4.C: Information Technologies and Instrumentation

- Digitized signals (sent as wave pulses) are a more reliable way to encode and transmit information.

Crosscutting Concepts

Structure and Function

- Structures can be designed to serve particular functions.

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Connections to Engineering, Technology, and Applications of Science

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

- Technologies extend the measurement, exploration, modeling, and computational capacity of scientific investigations.

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Connections to Nature of Science

Science is a Human Endeavor

- Advances in technology influence the progress of science and science has influenced advances in technology.

Observable features of the student performance by the end of the course:				
1	Obtaining information			
	a	Given materials from a variety of different types of sources of information (e.g., texts, graphical, video, digital), students gather evidence sufficient to support a claim about a phenomenon that includes the idea that using waves to carry digital signals is a more reliable way to encode and transmit information than using waves to carry analog signals.		
2	Evaluating information			
	a	Students combine the relevant information (from multiple sources) to support the claim by describing*:		
		i.	Specific features that make digital transmission of signals more reliable than analog transmission of signals, including that, when in digitized form, information can be:	
			1.	Recorded reliably.
			2.	Stored for future recovery.
			3.	Transmitted over long distances without significant degradation.
		ii.	At least one technology that uses digital encoding and transmission of information. Students should describe* how the digitization of that technology has advanced science and scientific investigations (e.g., digital probes, including thermometers and pH probes; audio recordings).	

MS-ETS1-2 Engineering Design

Students who demonstrate understanding can:

MS-ETS1-2. Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.

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

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Engaging in Argument from Evidence Engaging in argument from evidence in 6–8 builds on K–5 experiences and progresses to constructing a convincing argument that supports or refutes claims for either explanations or solutions about the natural and designed world. • Evaluate competing design solutions based on jointly developed and agreed-upon design criteria.	**ETS1.B: Developing Possible Solutions** • There are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of a problem.	

Observable features of the student performance by the end of the course:			
1	Identifying the given design solution and associated claims and evidence		
	a	Students identify the given supported design solution.	
	b	Students identify scientific knowledge related to the problem and each proposed solution.	
	c	Students identify how each solution would solve the problem.	
2	Identifying additional evidence		
	a	Students identify and describe* additional evidence necessary for their evaluation, including:	
		i.	Knowledge of how similar problems have been solved in the past.
		ii.	Evidence of possible societal and environmental impacts of each proposed solution.
	b	Students collaboratively define and describe* criteria and constraints for the evaluation of the design solution.	
3	Evaluating and critiquing evidence		
	a	Students use a systematic method (e.g., a decision matrix) to identify the strengths and weaknesses of each solution. In their evaluation, students:	
		i.	Evaluate each solution against each criterion and constraint.
		ii.	Compare solutions based on the results of their performance against the defined criteria and constraints.
	b	Students use the evidence and reasoning to make a claim about the relative effectiveness of each proposed solution based on the strengths and weaknesses of each.	

MS-ETS1-4 Engineering Design

Students who demonstrate understanding can:

MS-ETS1-4. Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved.

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

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Developing and Using Models Modeling in 6–8 builds on K–5 experiences and progresses to developing, using, and revising models to describe, test, and predict more abstract phenomena and design systems. • Develop a model to generate data to test ideas about designed systems, including those representing inputs and outputs.	**ETS1.B: Developing Possible Solutions** • A solution needs to be tested, and then modified on the basis of the test results, in order to improve it. • Models of all kinds are important for testing solutions. **ETS1.C: Optimizing the Design Solution** • The iterative process of testing the most promising solutions and modifying what is proposed on the basis of the test results leads to greater refinement and ultimately to an optimal solution.	

Observable features of the student performance by the end of the course:			
1	Components of the model		
	a	Students develop a model in which they identify the components relevant to testing ideas about the designed system, including:	
		i.	The given problem being solved, including criteria and constraints.
		ii.	The components of the given proposed solution (e.g., object, tools, or process), including inputs and outputs of the designed system.
2	Relationships		
	a	Students identify and describe* the relationships between components, including:	
		i.	The relationships between each component of the proposed solution and the functionality of the solution.
		ii.	The relationship between the problem being solved and the proposed solution.
		iii.	The relationship between each of the components of the given proposed solution and the problem being solved.
		iv.	The relationship between the data generated by the model and the functioning of the proposed solution.
3	Connections		
	a	Students use the model to generate data representing the functioning of the given proposed solution and each of its iterations as components of the model are modified.	
	b	Students identify the limitations of the model with regards to representing the proposed solution.	
	c	Students describe* how the data generated by the model, along with criteria and constraints that the proposed solution must meet, can be used to optimize the design solution through iterative testing and modification.	