Foundational Services
Science

The Tools Needed to Bring NGSS to the Classroom

Participant Workbook

The following statements relate to the Science Foundational Service training:

The Tools Needed to Bring NGSS to the Classroom

Please indicate your comfort level with the following:

4 = Fully Agree
3 = Agree
2 = Somewhat Agree
1 = Disagree
NA = Not Applicable to this training session

Science	Pre	Post
I can distinguish the difference between a traditional science classroom and an NGSS classroom.		
I can read the performance expectations and identify where to go for more information regarding those performance expectations.		
I can examine the disciplinary core ideas to determine a focus for curriculum.		
I can identify and compile phenomena that students will investigate using three-dimensional learning.		
I can examine the crosscutting concepts to determine how to implement them into instruction.		
I can utilize the crosscutting concepts to enhance students' observation and investigation of phenomena.		
I can examine the practices to determine how to implement them into instruction.		
I can utilize the practices to engage students in three-dimensional learning and exploration of phenomena.		

Reflection Questions following post survey:

1. What areas did you grow the most?

2. What areas do you need further development?

3. What next steps do you plan to take to further develop your knowledge and skills related to NGSS?

What Can I Take Away?

Foundational Services for Science – *The Tools Needed to Bring NGSS to the Classroom* focuses on equipping educators with valuable skills to make sense of and implement NGSS. Following each session, we will take a few moments to consider next steps and a plan of action. Use the spaces below each session tile for your reflections.

Session 1

Session 2

Session 3

Session 4

Session 5

SESSION I

LET'S TAKE A LOOK IN A CLASSROOM…

Student Edition

IQWST

Physical Science

Can I Believe My Eyes?

Second Edition

Physical Science 1 (PS1)
Can I Believe My Eyes?
Light Waves, Their Role in Sight, and Interaction with Matter

ISBN-13: 978-1-937846-47-3

About the Publisher

Sangari Active Science Corporation is a mission-driven company that is passionate about STEM education. We make it easy for teachers to teach with quality, investigation-centered science curriculum, tools, and technology. For more information about what we do, please visit our website at http://www.sangariglobaled.com.

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LESSON 2

What Do We Need to See an Object?

ACTIVITY 2.1 – PROBING IDEAS: SEEING OBJECTS AROUND THE ROOM

What Will We Do?

We will explore some of the things humans need in order to see. We will try to explain why we can see some objects but not others.

Procedure

1. Look at the image your teacher projects. Why can the girl see the tree?

2. Look at the image your teacher projects. Why doesn't the girl see the car?

3. As your teacher names objects in the room, record them in the data table. Then put a check mark (✓) in the appropriate column. You will not be able to see everything your teacher names. It is important that you keep your body and your eyes in the same position as you collect data.

Objects around the Classroom		
Object	**I CAN See**	**I CANNOT See**

Making Sense

4. What factors affect whether you can see an object or not?

ACTIVITY 2.2 – DETERMINING THE CONDITIONS FOR SIGHT – THE LIGHT BOX

What Will We Do?

We will gather evidence about what needs to happen in order for people to see an object.

Procedure 1

Follow your teacher's directions. Record your observations from each step before you move on to the next step.

A. Look into the light box. Be sure the lid and the flap remain closed. In the data table, draw what you see.

B. Keep the light box lid closed. Open the side flap. Look into the light box. In the table, draw what you see.

Data

Light Box Activity Results

	First: Lid Closed and Flap Closed	Second: Lid Closed and Flap Open
Observation		

Making Sense

1. Compare your observations.

2. Why were your observations different?

Procedure 2

Your teacher will add a divider to your light box. Keep the box lid closed and the side flap open. Draw what you see in the following space. Include as much detail as you can.

Making Sense

1. Compare your drawing with other students' drawings. How can you explain the differences?

2. List the conditions that need to be met in order for people to see an object. This list should be agreed upon by the whole class.

3. Imagine that you look out the door of your science class just as a friend walks by and waves to you. Explain how you can see your friend in the hall. Be sure to use all of the conditions you previously listed in your explanation.

LESSON 3

Constructing Models of How People See

ACTIVITY 3.1 – PREPARING TO DEVELOP MODELS

What Will We Do?

We will construct physical models of how people see. Our models will represent the key components and relationships that we have learned so far.

Part A: Evaluating a Model

A model can be good or not-so-good, depending on what it is being used for. When you use a model to explain an idea to someone, the best model is usually a simple one. A good model for explaining something includes all the key components and the relationships between them. It is important that a model only includes those things and not extra parts that do not help explain something. It is also important that your model is accurate. You should look carefully at your model to be sure you have represented the components and the relationships correctly. Your teacher showed you a model of light using a clay light bulb and some toy cars.

1. How can you use this model to explain how people see?

2. How could you improve this model of light? Think about the components and the relationships between them. For each part of the model, ask yourself if you could explain how people see without considering that component. Also ask yourself if there is some part of seeing that your model does not represent.

Part B: Plan Your Model

3. A model needs to be consistent with all the evidence. In Lesson 2, you gathered evidence that a model of seeing needs to include four key components: a light source; an object; an eye; and paths between the light, the object, and the eye. Look at the supplies your teacher has provided. What will you use to represent each of these parts?

Part C: Build and Evaluate Your Model

4. No model is perfect. Every model has strengths and weaknesses. What are the strengths and weaknesses of your model?

5. What did you learn as you made your light model?

ACTIVITY 3.2 – BUILDING THE CONSENSUS MODEL

What Will We Do?

We will combine the parts of our models that we agree about into one model called a consensus model. The consensus model will be a diagram instead of a physical model.

Questions

1. Models have advantages and they have disadvantages. What did you think were the best parts of other students' models? Why?

2. How does your drawn model compare with the consensus model your class created? Describe what is similar and what is different about them.

3. Use your class consensus model to explain why you cannot see your grandma in the other room.

4. What do you still need to know about how light helps you see? What do you still want to know about how light helps you see?

Name: ______________________

Date: ____/ ____/ ____ Period: ____

Physical Science:
Can I Believe My Eyes?

1. In the photo, the girl is reading a book.

   On the lines below, make a list of the conditions or components that allow the girl to see the book.

2. Students took measurements of light in various locations in the school. Their results are included in the table below.

Location	Light (Lux)	Location	Light (Lux)
Science Classroom – Lights On	9,000 lux	Hallway – Upstairs	22,000 lux
Science Classroom – Lights Off	800 lux	Hallway – Downstairs	8,000 lux
Science Storage Room – Lights On	8,000 lux	Math Classroom – Lights On	15,000 lux
Science Storage Room – Lights Off	0 lux	Math Classroom – Lights Off	6,000 lux

Observe the data above and make inferences to explain the following questions:

What causes different areas of the school to have more or less light?	In what areas of the school is it easier to see clearly?

3. **Student #1 and Students #2 cannot see each other's face during this discussion. Explain how student #1 cannot see the face of student #2.**

4. **In the space below, develop and use a model to explain one of the following phenomena.**
   - **How does a student see the homework on the whiteboard?**
   - **How does a student see the clock on the wall of the classroom?**
   - **How does a student see the pages of a book?**

5. **On the next page, use the writing organizer to explain your model.**

Scientific Explanations of Models

Name: ______________________ **Period:** ________ **Date:** ___/___/___ **Due Date:** ___/___/___

Introductory Sentence for the Model: *This is a model of* ______________________

____

Main Idea/Topic Sentence: *In this model, you will see these components (pieces):* ______________________

____

____

Explanation/Body:

Model Component	Explanation of the Component

Model Component	**Explanation of the Component**

Conclusion Sentence (Include the *Crosscutting Concept Lens* we are looking through to create this model):

The model works together to show ____________________

____

____

____

LJHS Science Assessment Rubric

Learning Expectation:

4-PS4-2: Develop a model to describe that light reflecting from objects and entering the eye allows objects to be seen.

Name/Team #: ______________________________ **Date:** _____/_____/_____ **Due Date:** _____/_____/_____ **Period:** _____

Element	Criteria		Beginning	Developing	Proficient	Exemplary
			0	1	2	3
Components of Model	☐ Light source and light. ☐ Object. ☐ The straight path that light follows. ☐ The eye.	Accuracy	No model is provided. OR The model is inaccurate.	The components of the model are missing or inaccurate.	The components of the model are present and mostly accurate.	All the components of the model are present and accurate.
		Clearness	No model is provided. OR The model is inaccurate.	The model is misunderstood because more than one component is complicated, unclear, or unlabeled.	The model is understood because most of the components are simple, clear, or labeled.	The model is easily understood because all the components are simple, clear, and labeled.
Relationship of Components in Model	☐ Objects can be seen only if light follows a path between a light source, the object, and the eye.		The relationship is not depicted in the model.	The relationship is inaccurately depicted in the model.	Most of the relationship is accurately depicted in the model.	The relationship is accurately depicted in the model.
	☐ Light reflects off of objects, and then can travel and enter the eye.		The relationship is not depicted in the model.	The relationship is inaccurately depicted in the model.	Most of the relationship is accurately depicted in the model.	The relationship is accurately depicted in the model.
	☐ Light enters the eye, allowing objects to be seen.		The relationship is not depicted in the model.	The relationship is inaccurately depicted in the model.	Most of the relationship is accurately depicted in the model.	The relationship is accurately depicted in the model.

Rubric Total ☐ → **Mastery Score for Standard** ☐

Not Meeting		Meeting	Exceeding	
1	2	3	4	5
66 – F	74 – D+	84 – C+	92 – B+	100 – A+

Rubric Points	0	1-4	5	6-9	10-13	14-15
Mastery Score	0	1	2	3	4	5

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

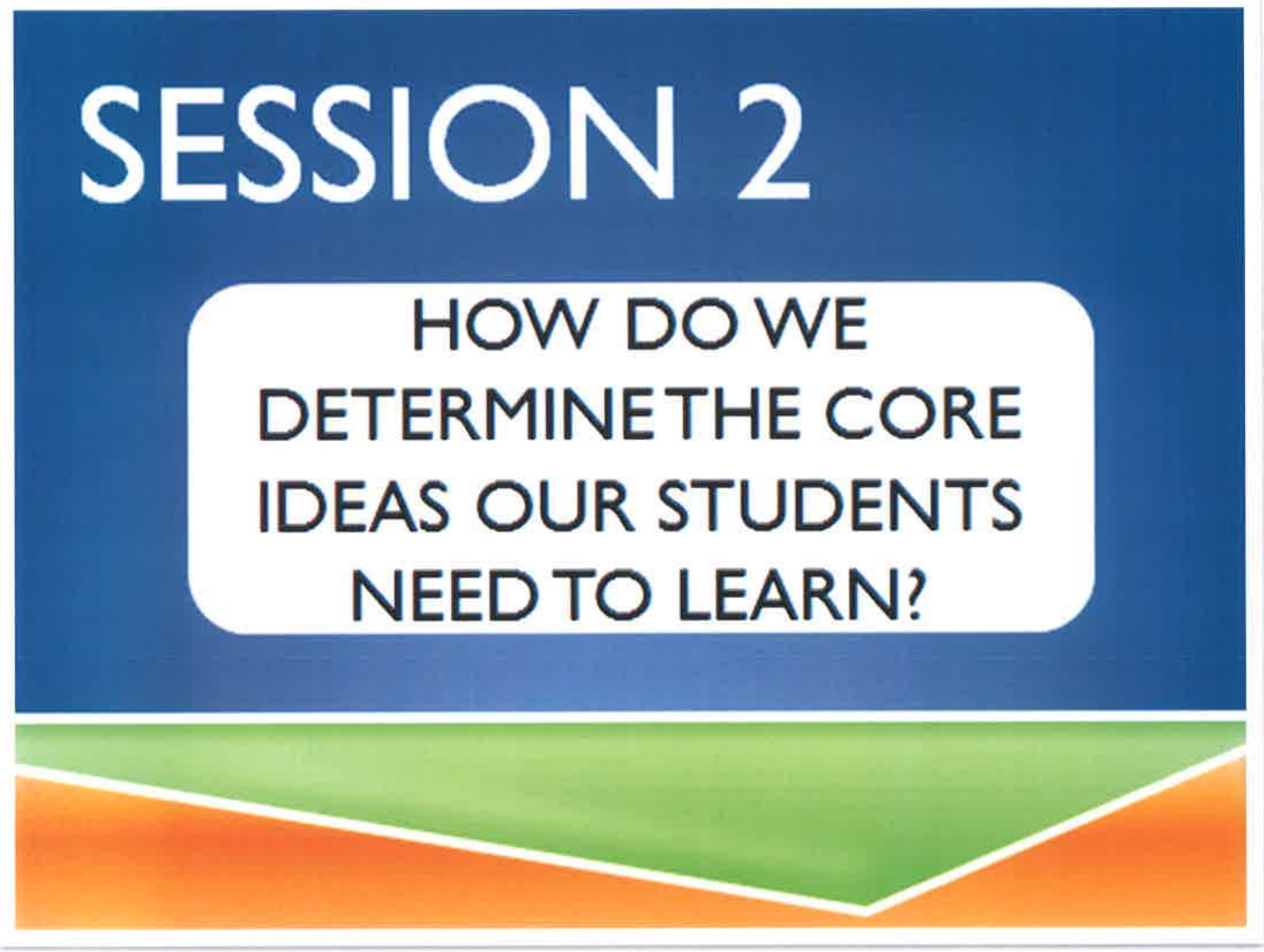
Students who demonstrate understanding can:

4-PS4-2. **Develop a model to describe that light reflecting from objects and entering the eye allows objects to be seen.** *[Assessment Boundary: Assessment does not include knowledge of specific colors reflected and seen, the cellular mechanisms of vision, or how the retina works.]*

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 3–5 builds on K–2 experiences and progresses to building and revising simple models and using models to represent events and design solutions. • Develop a model to describe phenomena.	**PS4.B: Electromagnetic Radiation** • An object can be seen when light reflected from its surface enters the eyes.	**Cause and Effect** • Cause and effect relationships are routinely identified.

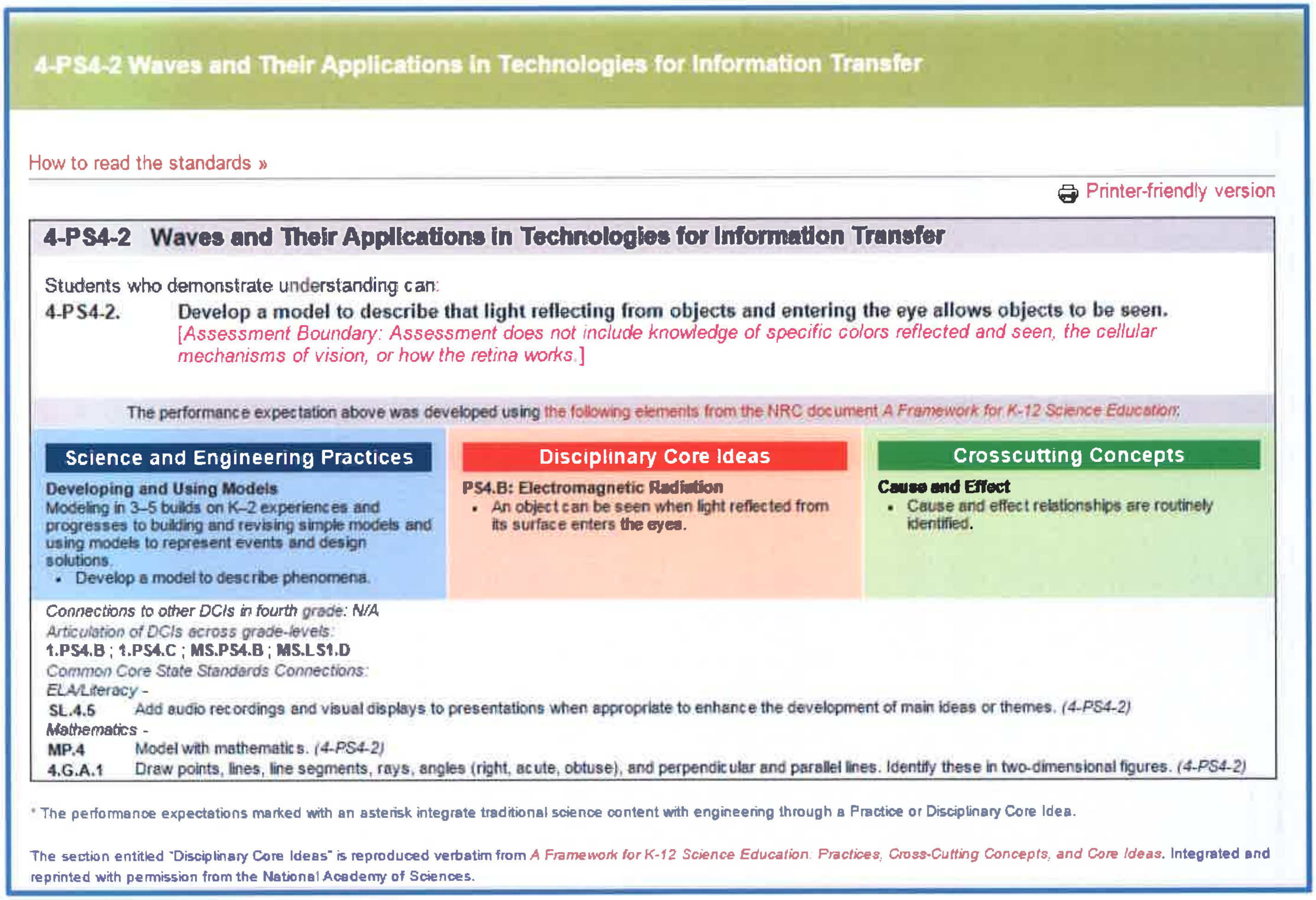
Observable features of the student performance by the end of the grade:			
1	Components of the model		
	a	Students develop a model to make sense of a phenomenon involving the relationship between light reflection and visibility of objects. In the model, students identify the relevant components, including:	
		i.	Light (including the light source).
		ii.	Objects.
		iii.	The path that light follows.
		iv.	The eye.
2	Relationships		
	a	Students identify and describe* causal relationships between the components, including:	
		i.	Light enters the eye, allowing objects to be seen.
		ii.	Light reflects off of objects, and then can travel and enter the eye.
		iii.	Objects can be seen only if light follows a path between a light source, the object, and the eye.
3	Connections		
	a	Students use the model to describe* that in order to see objects that do not produce their own light, light must reflect off the object and into the eye.	
	b	Students use the model to describe* the effects of the following on seeing an object:	
		i.	Removing, blocking, or changing the light source (e.g., a dimmer light).
		ii.	Closing the eye.
		iii.	Changing the path of the light (e.g., using mirrors to direct the path of light to allow the visualization of a previously unseen object or to change the position in which the object can be seen, using an opaque or translucent barrier between 1) the light source and the object or 2) the object and the eye to change the path light follows and the visualization of the object).



SESSION 2

HOW DO WE DETERMINE THE CORE IDEAS OUR STUDENTS NEED TO LEARN?

Make Sense of the Standards: Performance Expectations



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

How to read the standards »

Printer-friendly version

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

Students who demonstrate understanding can:

4-PS4-2. **Develop a model to describe that light reflecting from objects and entering the eye allows objects to be seen.** *[Assessment Boundary: Assessment does not include knowledge of specific colors reflected and seen, the cellular mechanisms of vision, or how the retina works.]*

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

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Connections to other DCIs in fourth grade: N/A

Articulation of DCIs across grade-levels:

1.PS4.B ; **1.PS4.C** ; **MS.PS4.B** ; **MS.LS1.D**

Common Core State Standards Connections:

ELA/Literacy -

SL.4.5 Add audio recordings and visual displays to presentations when appropriate to enhance the development of main ideas or themes. *(4-PS4-2)*

Mathematics -

MP.4 Model with mathematics. *(4-PS4-2)*

4.G.A.1 Draw points, lines, line segments, rays, angles (right, acute, obtuse), and perpendicular and parallel lines. Identify these in two-dimensional figures. *(4-PS4-2)*

* The performance expectations marked with an asterisk integrate traditional science content with engineering through a Practice or Disciplinary Core Idea.

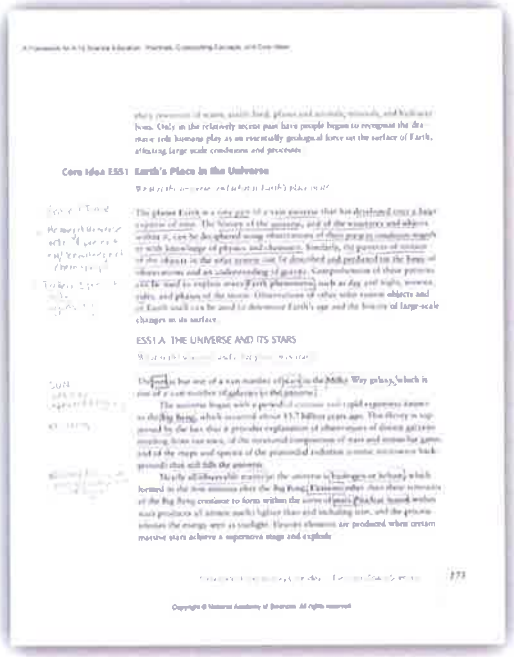
The section entitled "Disciplinary Core Ideas" is reproduced verbatim from *A Framework for K-12 Science Education: Practices, Cross-Cutting Concepts, and Core Ideas*. Integrated and reprinted with permission from the National Academy of Sciences.

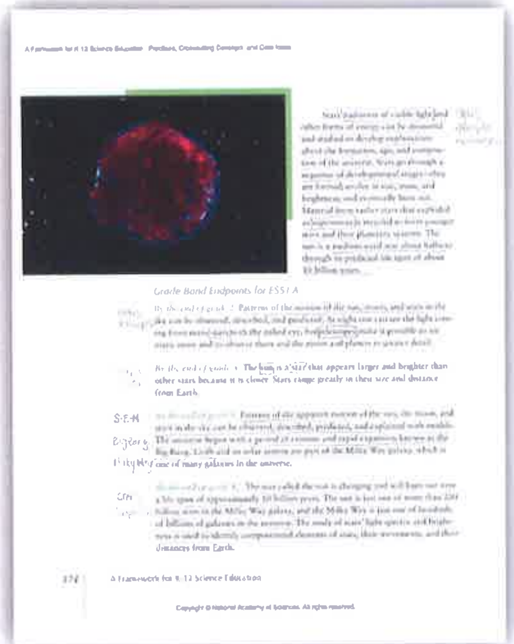
Performance expectations are statements that clarify what students should be able to do at the end of instruction in regards to the standards. In reviewing this performance expectation, foundation boxes, and connections, what do you think students need to learn?

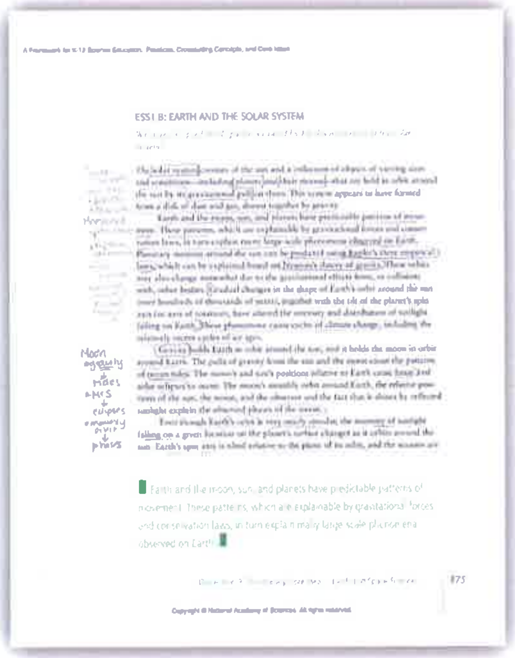
What is explicit?	
What is implicit?	

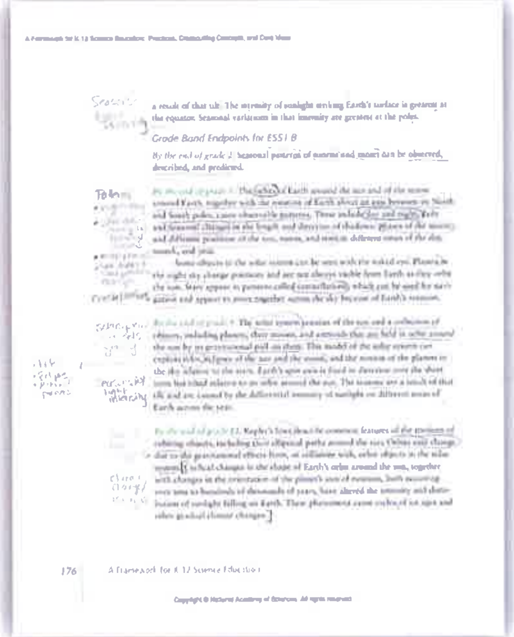
Unpacking the Ideas by Close Reading

Using the excerpt copy of the Framework on the following pages, determine the core ideas within our performance expectation. Read and make notes. Underline the most important ideas that you find. Write questions or thoughts in the margins. Read "between the lines" to see what understandings are implicit. Be prepared to explain the core ideas to your small group.



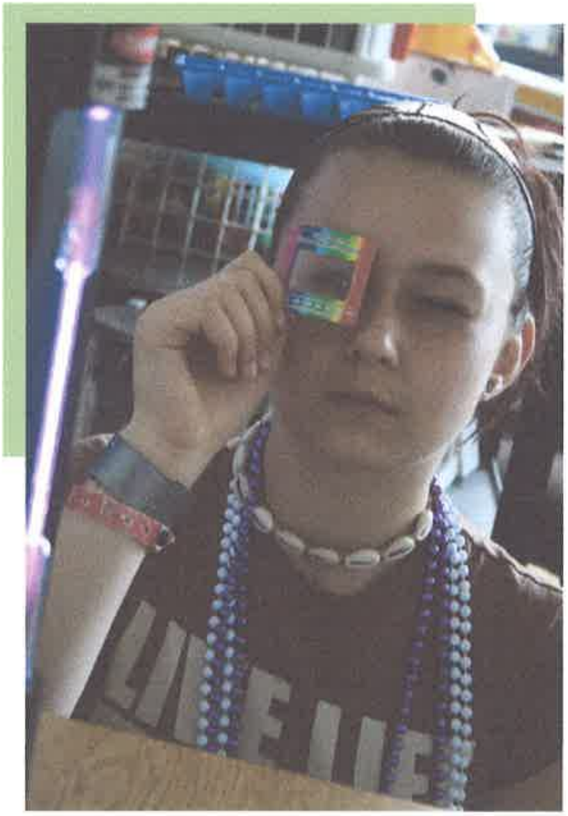






(e.g., a picture stored as the values of an array of pixels); in this form, it can be stored reliably in computer memory and sent over long distances as a series of wave pulses.

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

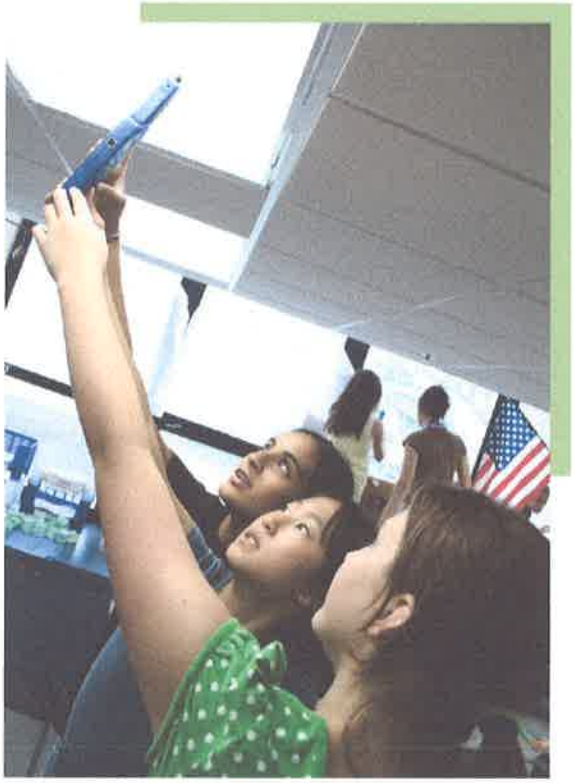


PS4.B: ELECTROMAGNETIC RADIATION

What is light?
How can one explain the varied effects that involve light?
What other forms of electromagnetic radiation are there?

Electromagnetic radiation (e.g., radio, microwaves, light) can be modeled as a wave pattern of changing electric and magnetic fields or, alternatively, as particles. Each model is useful for understanding aspects of the phenomenon and its interactions with matter, and quantum theory relates the two models. Electromagnetic

> By understanding wave properties and the interactions of electromagnetic radiation with matter, scientists and engineers can design systems for transferring information across long distances, storing information, and investigating nature on many scales—some of them far beyond direct human perception.



waves can be detected over a wide range of frequencies, of which the visible spectrum of colors detectable by human eyes is just a small part. Many modern technologies are based on the manipulation of electromagnetic waves.

All electromagnetic radiation travels through a vacuum at the same speed, called the speed of light. Its speed in any given medium depends on its wavelength and the properties of that medium. At the surface between two media, like any wave, light can be reflected, refracted (its path bent), or absorbed. What occurs depends on properties of the surface and the wavelength of the light. When shorter wavelength electromagnetic radiation (ultraviolet, X-rays, gamma rays) is absorbed in matter, it can ionize atoms and cause damage to living cells. However, because X-rays can travel through soft body matter for some distance but are more rapidly absorbed by denser matter, particularly bone, they are useful for medical imaging. Photovoltaic materials emit electrons when they absorb light of a high-enough frequency. This phenomenon is used in barcode scanners and "electric eye" systems, as well as in solar cells. It is best explained using a particle model of light.

Any object emits a spectrum of electromagnetic radiation that depends on its temperature. In addition, atoms of each element emit and preferentially absorb characteristic frequencies of light. These spectral lines allow identification of the presence of the element, even in microscopic quantities or for remote objects, such as a star. Nuclear transitions that emit or absorb gamma radiation also have distinctive gamma ray wavelengths, a phenomenon that can be used to identify and trace specific radioactive isotopes.

Grade Band Endpoints for PS4.B

By the end of grade 2. Objects can be seen only when light is available to illuminate them. Very hot objects give off light (e.g., a fire, the sun).

Some materials allow light to pass through them, others allow only some light through, and others block all the light and create a dark shadow on any surface beyond them (i.e., on the other side from the light source), where the light cannot reach. Mirrors and prisms can be used to redirect a light beam. (Boundary: The idea that light travels from place to place is developed through experiences with light sources, mirrors, and shadows, but no attempt is made to discuss the speed of light.)

By the end of grade 5. A great deal of light travels through space to Earth from the sun and from distant stars.

An object can be seen when light reflected from its surface enters the eyes; the color people see depends on the color of the available light sources as well as the properties of the surface. (Boundary: This phenomenon is observed, but no attempt is made to discuss what confers the color reflection and absorption properties on a surface. The stress is on understanding that light traveling from the object to the eye determines what is seen.)

Because lenses bend light beams, they can be used, singly or in combination, to provide magnified images of objects too small or too far away to be seen with the naked eye.

By the end of grade 8. 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. Lenses and prisms are applications of this effect.

A wave model of light is useful for explaining brightness, color, and the frequency-dependent bending of light at a surface between media (prisms). However, because light can travel through space, it cannot be a matter wave, like sound or water waves.

By the end of grade 12. Electromagnetic radiation (e.g., radio, microwaves, light) can be modeled as a wave of changing electric and magnetic fields or as particles called photons. The wave model is useful for explaining many features of electromagnetic radiation, and the particle model explains other features. Quantum theory relates the two models. (Boundary: Quantum theory is not explained further at this grade level.)

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

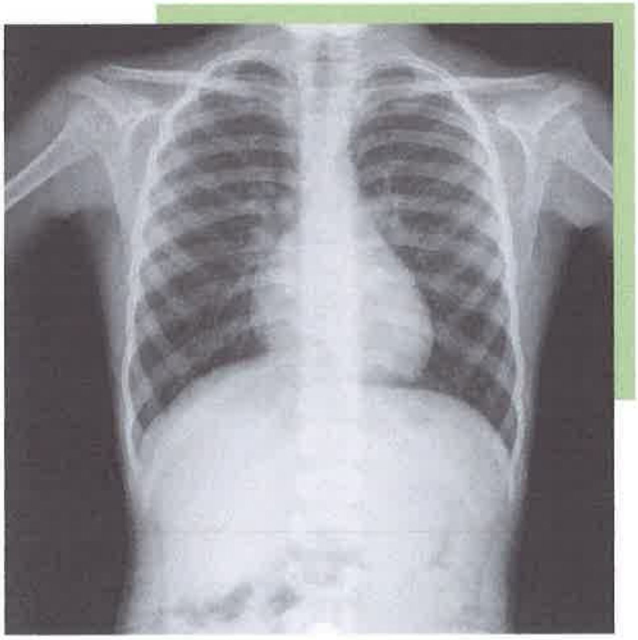
When light or longer wavelength electromagnetic radiation is absorbed in matter, it is generally converted into thermal energy (heat). Shorter wavelength electromagnetic radiation (ultraviolet, X-rays, gamma rays) can ionize atoms and cause damage to living cells. Photovoltaic materials emit electrons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

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

PS4.C: INFORMATION TECHNOLOGIES AND INSTRUMENTATION

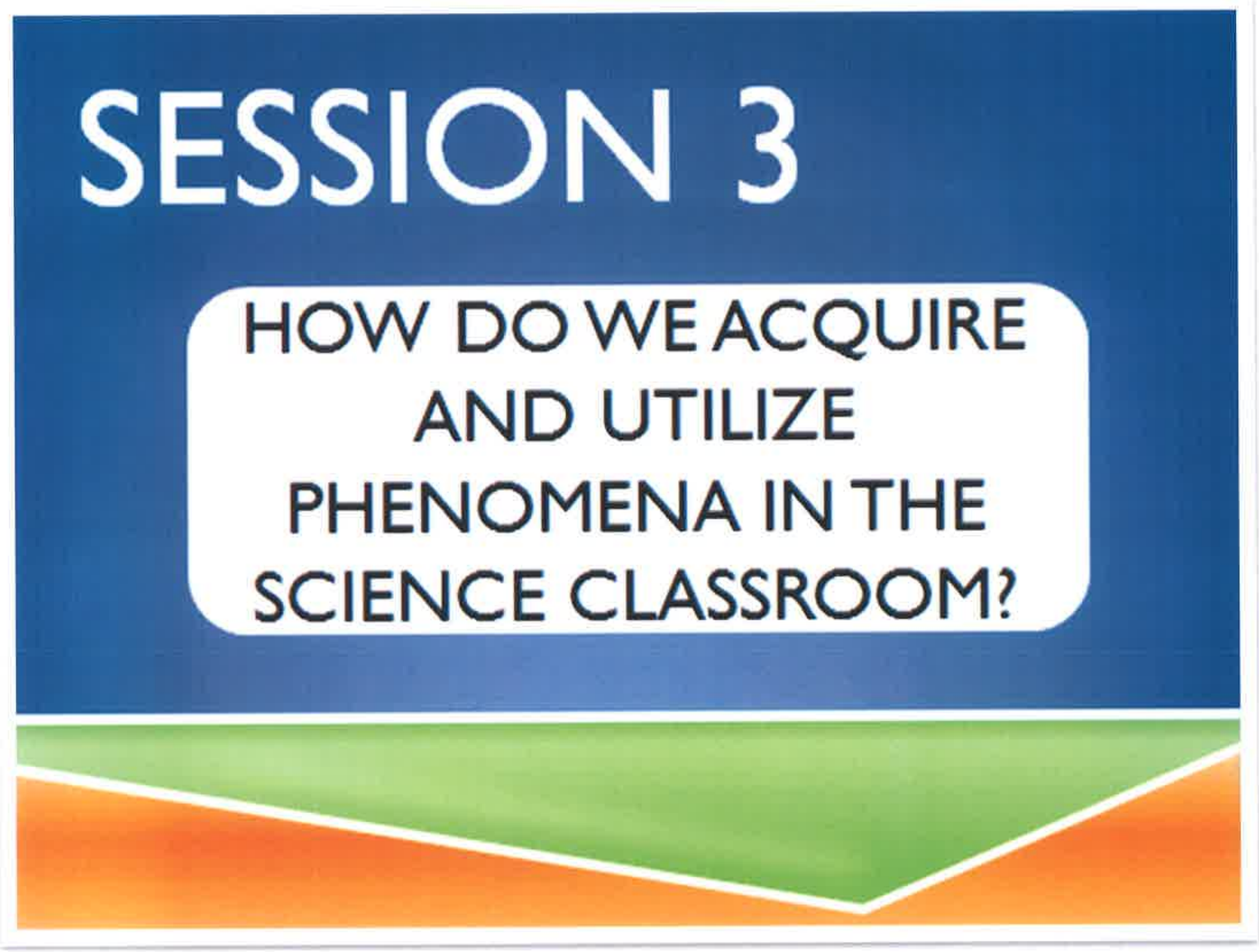
How are instruments that transmit and detect waves used to extend human senses?

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



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

Medical imaging devices collect and interpret signals from waves that can travel through the body and are affected by, and thus gather information about, structures and motion within it (e.g., ultrasound, X-rays). Sonar (based on sound pulses) can be used to measure the depth of the sea, and a system based on laser pulses can measure the distance to objects in space, because it is



SESSION 3

HOW DO WE ACQUIRE AND UTILIZE PHENOMENA IN THE SCIENCE CLASSROOM?

Phenomena in NGSS

Working as a whole group, let's consider our experiences in the first session to brainstorm a list of phenomena from these experiences. Begin by jotting a few notes in your packet.

Read and make notes in the attached article, *Anchoring Events that Can Organize* Science Instruction. As you read, consider the following questions:

- Why would we use an anchoring event?
- What relationship exists between anchoring phenomenon and underlying casual explanation?
- How does the practice of "Asking Questions" relate to phenomenon?
- When selecting anchoring phenomenon, what should we consider?

Anchoring Events that can Organize Science Instruction

Consider three very common problems for students trying to learn science:

1) Students often experience instruction as a series of unrelated and isolated lessons, one after another. They don't understand how readings or new concepts fit in with bigger science ideas.

2) They don't know why they are doing particular science activities—when asked they will say "Because the teacher wants me to."

3) They don't see how science relates to their everyday experiences or how their lived experiences can be used as resources to help them and others learn important science ideas.

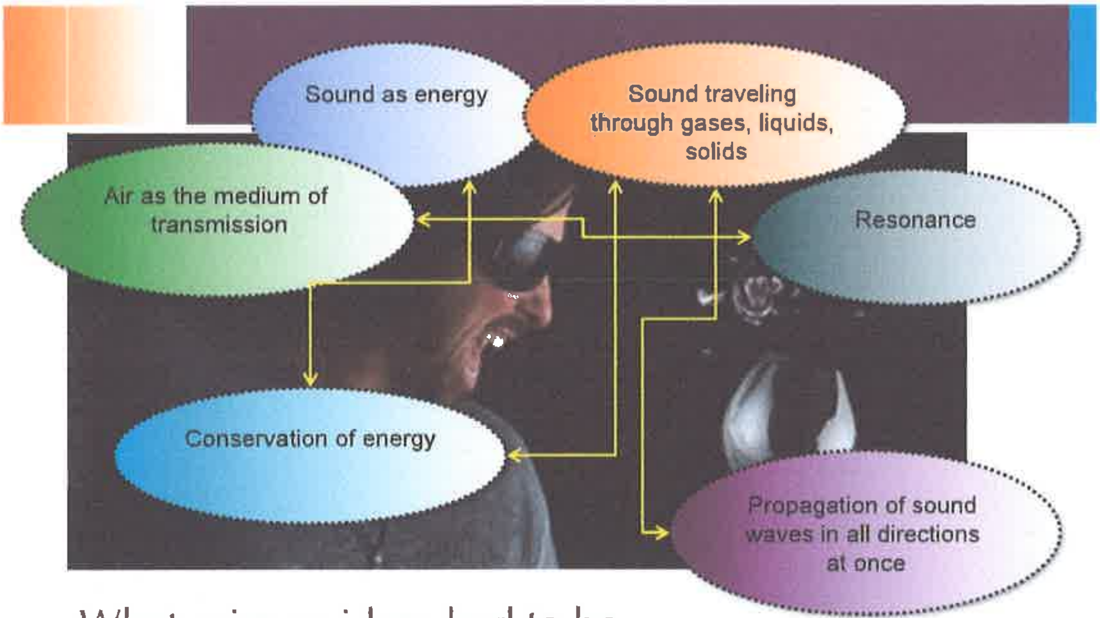
The root of all three of these problems is that there is *nothing on the horizon* for students to focus on. There is no genuine puzzlement, interest, or larger learning goal that they are aware of. Consequently the motivation for learning dissipates and they disengage from learning activities.

Let's imagine though a different scenario. That a teacher decides to organize a unit of instruction around an event or process that is puzzling but also challenging to explain. Or example involves a 3rd grade teacher whose students were about to investigate sound as energy. She considered a phenomenon (event or process) that could anchor her unit (when we say units, we refer to two to three weeks of instruction focusing on a related set of core science ideas).

This teacher chose the situation of a singer breaking a glass with the sound energy from his voice. She thought that, as students were developing an explanatory model for this phenomenon, they would have to wrestle with the ideas of sound as energy, air as a medium of transmission, the characteristics of sound waves at the unobservable level (wavelength, amplitude, frequency) and at the observable level (pitch, volume, the propagation of sound in all directions at once) and resonance. Her third graders would not only have to "know about" each of these ideas, but they would have to coordinate each of these ideas in an explanatory model for why the glass broke—in a particular way, at a particular moment, and under particular conditions. This is what we mean by selecting a phenomenon that is contextualized, and not generic. This is also what makes carefully designed units, based on causal explanations, far more rigorous than simply "covering curriculum."

Her pre-planning also helped her see what parts of the curriculum kit would be relevant to students' final explanations and which parts would be set aside. The teacher started her unit with the video of the singer. Students were immediately intrigued and they offered observations without prompting: "He yelled right at the glass", "I saw the glass shaking", "Only the top of the glass broke!" After some conversation about what they could see and hear in the video, the teacher shifted their attention to what they thought was going on that they could not directly observe. Following this discussion students drew some initial models using a before-during-after template supplied by the teacher.

Following the first day of the unit this teacher engaged students in a series of lessons, some involving combinations of: introducing new ideas (such as air being made out of molecules), activities (using tuning forks to understand what frequency means), discussions (about why they think sound is energy), and debates (about whether sound travels equally fast in all directions from the source). Much of her standard curriculum was used, but some lesson were re-arranged, some were re-purposed, and some thrown out entirely because they contributed little to the final explanation. All these decisions were based on two considerations: 1) What ideas and experiences were necessary for the final explanations, and 2) What were students thinking currently?



What science ideas had to be "pulled together" by our 3rd graders?

As you can see in this example, anchoring events can help you organize your instruction over multiple lessons and helps students understand that everything they are doing has a larger purpose. They are keeping their eye on the horizon.

But even for experienced teachers, coming up with anchoring events requires extra reading, a constant focus on learning goals, and regular reflection on how those learning goals match up with your evolving big ideas. The process will *test your content knowledge to its limits* and inevitably *push you to deepen* your understanding of even the most fundamental ideas of science.

If you look at the table of contents in any science curriculum, you will see a list of topics. Some of these topics are usually one or two word labels like: ecosystems, optics, chemical bonding, earthquakes, or inheritance. Some topics are thematic and cut across different subject matter. Examples of these might be: cycles in nature, conservation of energy, or the relationship between form and function.

This guide will help you think about moving from a curriculum topic to a big idea worth teaching. We will address the following questions:

- What *is* it about the topics [earthquakes, optics, inheritance, or acids and bases] that are so important?"
- Is it the *topic* that is important? Or is it something *more fundamental and dynamic* about the topic that my students should really understand?
- What are important observable phenomena that students will need to interpret or explain?
- How might we represent a model that organizes and helps us make sense of the ideas in a curriculum?
- How can anchoring events be made relevant to kids' interests and lives?

What is an anchoring event?

Big ideas in science are about the relationships between a *natural phenomenon* and a *causal explanation* that helps us understand why a class of phenomena unfolds the way it does. *Phenomena* are events or processes ("things that happen") that are observable by the senses, or detectable by instruments.

- If you are a biology teacher, examples of phenomena might be the evolution of different shapes of finches' beaks, water moving into or out of a cell, or the invasion of non-native species into a habitat.

- If you are teaching earth science, examples of phenomena might be an earthquake, the process of sedimentation, or lunar eclipses.

- If you are a chemistry teacher, examples of phenomena might be phase changes in samples of water, the diffusion of dye in a beaker, or the rusting of iron.

- If you are teaching physics, examples of phenomena might be motion of a pendulum, the changing temperature of a cup of coffee left on a countertop, or the way light behaves when it passes though lenses.

Studying events or process rather than things intrigues students. For example, to engage students in understanding cells, high school teachers we have worked with have asked young learners to draw and refine models of the spread of cancer in human body tissues. Although students certainly need to know the names and functions of particular cell organelles, we do not ask them to re-create textbook representations of these parts, using plastic baggies and pipe cleaners. We focus them instead on how and why cell structures contribute to healthy functioning or to disease. To cite another example, the earth-moon-sun system is a thing. It is possible to create scale models of it's parts—many students do—but this is not the kind of modeling that scientists do, nor does it engage students to do more than simply reproduce textbook ideas. In contrast, it is possible to use the earth-moon-sun system to identify an event or process that one could create a dynamic explanation of, then test and revise it over time. Such events might be captured in the questions "What causes the seasons?", "Why are there no seasons if you live near the equator?", "Why do planets and moons maintain the orbits they currently have?", or "Why are solar eclipses so rare?"

Important! The anchoring event should be context-rich, meaning that it is about a *specific* event that happens in a *specific* place and time under *specific* conditions. These "specifics" are precisely what make the situation interesting to kids. Explaining how all these contextual features affect the event is also what makes the explanations much more rigorous (not copy-able from a textbook).

What is an underlying explanation?

Every anchoring event or process should have an underlying explanation. These explanations—also known as *explanatory models*—always involve things that are not directly observable. Causal explanations or explanatory models have the following characteristics:

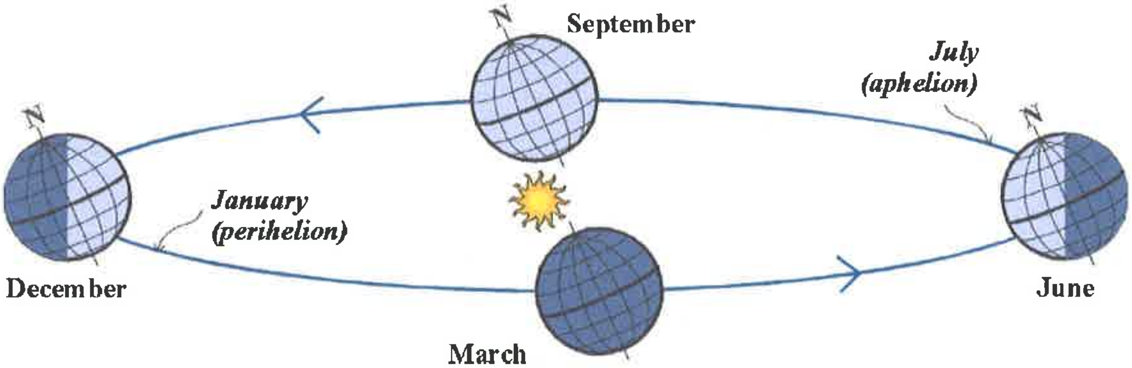
- They portray storylines about *why* observable events happen, not just descriptions of *how* they happen or *that* they happen.
- They almost always involve a cast of unseen characters, events, and processes that operate at a more fundamental level than the phenomenon itself. These characters, events, and processes may not be directly observable for several reasons:
    - they exist at such a small scale (atomic bonding)
    - they happen so quickly (electricity moving through a circuit)
    - they happen so slowly (evolution, glaciations)
    - they are inaccessible (the interior of the earth, neurons firing in the brain),
    - they are abstract (like unbalanced forces, concentration gradients, or alleles).
- These causal explanations may take several forms, they may be labeled drawings, written paragraphs, flow charts, or physical models.
- The causal storyline—or the "why" explanation—is powerful in science because it helps us understand a whole *range of related phenomena* in the world.

Developing causal explanations is a centerpiece of classroom activity. This is because explanations for natural events is at the core of what scientists do. But it is also because this is the most demanding kind of intellectual work you can ask students to do. The major struggle by students is to develop rich, gapless explanations. This requires that they link many science ideas together and understand how evidence supports particular claims more than others. The development of these types of explanations take two to three weeks, and require students to explore many ideas along the way.

Here's an example of a rich, gapless explanation about what causes the seasons. It is what a middle school teacher might produce before a unit starts, in order to select activities and readings for students, as they develop their own explanations (rather than just reproducing yours). You likely have seen "explanations" for the seasons before, they look something like this: "The seasons occur because the Earth is tiled at 23 degrees." Or, "Different parts of the Earth get more direct sunlight than others at different times of the year." Both of these are weak, not just because they are brief, but because they lack any causal storyline. They fail to include the basic mechanisms that produce the effect we call the seasons; consequently there are lots of gaps. Accepting these types of explanations really lets kids off the hook for thinking. It paints an overly simplistic view of how the world really works. Students can reproduce such explanations with no scientific understanding whatsoever—having learned nothing.

Now let's try for a richer, more gapless storyline, something that would help a teacher plan a unit. Let's start with how the earth and sun are situated in space. The Earth revolves around the sun. The Earth is roughly on the same plane as all the other planets. This is the plane of the ecliptic. The earth travels around the sun, taking a year to make a round trip. As it travels through space it also spins on its axis.

But the axis is not aligned straight up and down in comparison to the plane of the ecliptic. The North and South Poles are tilted at 23 degrees from vertical. This tilt never varies, there are no forces that could cause the tilt to change during the year. Because of this tilt, during the winter part of the round trip that the Earth makes, the northern hemisphere is pointed slightly away from the sun's rays. During another part of the year (about six moths later), the Northern hemisphere it pointed slightly more directly towards the sun's rays.



There's more. The radiant energy that the sun produces has a range that we call the electromagnetic spectrum, but only visible light (generally speaking) and radio waves actually make it through our atmosphere. It is the visible light that can strike surfaces like land and water and get transformed to heat energy.

However, because of the tilt of the earth at different times during the year, these rays of visible light interact with the Earth differently. It is like a flashlight that is pointed directly down at a floor from a distance of about 5 feet. You can see the energy from the flashlight concentrated in a beam a few inches in diameter. But if you put the flashlight at an angle, let's say 45 degrees (still 5 feet away), then look at how the light hits the floor, you can see that the same amount of energy is now spread out over a much larger area. This latter example is like the Northern hemisphere during winter, when it is tilted away from the sun. The sun's rays are spread out over a much larger area—they are less concentrated, even though the total amount of light from the sun remains the same all year. During our winter the light also has to cut at a more oblique angle through more of our atmosphere, many more miles of it, before it reaches the Earth's surface. This also decreases the amount of light energy that reaches the surface.

During the winter, cold air masses build up over North America, Europe, and Asia, due to the low intensity of sunlight. The oceanic air masses are much less affected by the seasons because circulations in the upper ocean replenish warm surface water if it has been cooled.

All these events, starting at the sun's surface and ending in the air and water masses of the earth, contribute to the day length, the warmer temperatures, the different patterns of weather in our summer, and all the biological effects that we collectively characterize the seasons.

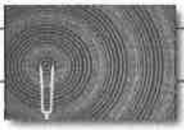
At this point we want to be clear—anchoring events are always developed out of some type of explanatory model. Even though it is phenomena that tends to capture the students' interests—like the exploding hydrogen balloon, the tornado video, the dilating pupil of the eye—your instruction should focus on what unseen mechanisms are at work. By the end of the unit, you want your students to have linked explanatory models to your anchoring event. This is what makes an idea or model powerful in science—its *generalizability*—that it can be used to explain and even unify a range of different phenomena.

Developing essential questions to go with your anchoring events

To maximize student engagement teachers can "hang" all activities in a unit on an essential question that is written to relate to students' lives and previous experiences. An essential question cannot be answered with a yes/no response, but rather it requires a complex synthesis of concepts learned. Each activity students do in a unit of instruction is in service of answering this question, and students constantly revisit this question throughout the unit. By constantly revisiting a relevant essential question, teachers are able to do more than just "hook" students at the beginning of a unit. A sample essential question for a unit on cells in biology might be "What makes wounds heal in different ways?" For a unit on the respiratory system an essential question might be "Why is asthma so prevalent in poor urban comminuties?" For a unit on oxidation in chemistry an essential question might be "What keeps things from rusting, and why?" For a unit on forces in physical science an essential question might be "How does a pulley help me lift something heavier than I am?"

Some examples

Here we present three different cases of how a typical ***topic*** found in a curriculum or textbook, might be linked to a ***anchoring event*** of importance, and a ***causal story*** (explanatory model) for that phenomenon, what you really want your students to understand, and ***another phenomenon*** that the explanatory model can be generalized to.

Physics example 	
Topic found in text or curriculum	Sound
Anchoring event of interest that can motivate students	The teacher could show a video of a person breaking a glass with their voice, and a video of a glass vibrating from sound. Students would then try and explain why sound is capable of breaking glass, and what kinds of sound might be able to do this.
Causal story (explanatory model)	How can sound cause a glass to distort and eventually break? A glass has a natural resonance, a frequency at which it will vibrate easily. To find the resonance of the glass, ping the glass with your finger or tuning fork and listen to the sound. In order to induce vibrations in the glass, one can replicate the natural frequency of the glass using sound waves. Sound waves (like all waves) have energy. When the sound waves hit the glass, the energy of the sound waves is transmitted to the glass, thus causing the molecules in the glass to vibrate. However, the frequency alone is not the only factor – amplitude (volume) is also important. The louder the sound (i.e. the greater the amplitude of the sound waves), the larger the vibrations of the glass will be. When the amplitude of the sound waves causes the glass to vibrate so much that the glass exceeds its elastic limit, the glass will shatter. The elastic limit is exceeded when the vibrations cause the bonds between molecules to break apart.
What you rally want students to understand	The big idea that underlies this phenomenon is the relationship between waves and energy. Waves have energy and can travel through different media. When the wave encounters an object, the energy of the wave can be transferred to the object. Students need to understand that phenomena often have unobservable underlying causes. In this example, students need to understand that the sound waves emitted by the person or the device can travel through air and have energy. If students can understand that waves travel through a medium and that waves have energy, and that energy can be transferred from the wave to an object, students could explain why, for example, hitting a tuning fork and then placing the tuning fork near water causes water to splash.
Another phenomenon causal model could explain	How car radios that have very loud speakers installed can make objects at a distance shake., OR, how the mechanisms behind how loud noises can cause deafness.

Chemistry example	
Topic found in text or curriculum	Chemical reactions: specifically oxidation-reduction
Anchoring event that can motivate students	The teacher could tell a story about leaving a bicycle out in the rain and the metal rusting. The teacher could also distribute nails to students prior to the unit and have them place one in a location where they believe it will rust, and one in a location where it will not rust.
Causal story (explanatory model)	Rust forms due to a reaction between iron and water, and is called **oxidation**. If water is absent, iron will still corrode. However, if water is present, it can speed up the rusting process. Water molecules can penetrate the microscopic cracks in metal. The hydrogen atoms present in water combine with other elements in the metal alloy to form acids, which eventually expose the iron in the metal alloy to oxygen. Once oxygen comes into contact with iron, the oxidation process begins. There are always two distinct chemical reactions when iron corrodes. The first is the **dissolution** of iron into **solution** (water): Fe -----> Fe_2+ + 2e-. Next, there is a **reduction** of oxygen dissolved into water: O_2 + $2H_2O$ + 4e- ----> 4OH-. The final reaction between iron and hydroxide is: Fe_2+ + 2OH- -----> $Fe(OH)_2$. As the iron oxide continues to react with oxygen, the reddish color appears as the iron corrodes. The original iron (Fe) is not longer iron, and has changed to a new substance.
What you really want students to understand	The big idea here is that chemical processes can cause a change in the chemical, and therefore physical, properties of substances. Students need to understand that chemical reactions result in different products than were originally used. If students can understand that chemical reactions can cause a change in one substance, they should be able to say why, for example, acid rain causes corrosion of various substances, given information about the chemistry of the substances.
Another phenomenon causal model could explain	How did acid rain cause damage to this statue at the top of this table?

Biology example	
Topic found in text	Inheritance from sexual reproduction
Anchoring event	Students bring in pictures of their parents when they were in high school. The students compare and contrast their physical features with their parents' physical features. Students hypothesize why they do not look exactly like their parents.
Causal story (explanatory model)	Since the DNA from the egg and the DNA from the sperm combine together to form new chromosomes, the new DNA includes a combination of genes from both the mother and father. Genes are comprised of different **alleles**, and each allele can be either **dominant** or **recessive**. If a physical feature is determined by a dominant allele, the gene only needs to have 1 dominant allele for the trait to be displayed. If a physical feature is determined by recessive alleles, the gene must have 2 recessive alleles for the trait to be displayed. Each individual sperm and egg carries a different and random combination of alleles. When the zygote is formed, the alleles combine to form new genes, which will determine the physical characteristics of the offspring, depending on the combination of dominant and recessive alleles from the sperm and the egg.
What you really want students to understand	Parents' alleles, which form genes, are randomly combined together when sperm and egg combine to make a baby. Therefore, the baby will have a different, but similar, combination of alleles as their parents. Students need to understand that each sex cell has a random combination of alleles, and that different combinations of sex cells would result in different combinations of alleles, and hence, different physical characteristics. If students know that genes, made of alleles, are passed on to offspring by each parent, and that each offspring can look different, students should be able to explain, for example, why a litter of puppies can look drastically different.
Another phenomenon causal model could explain	The teacher can show students this picture of multiple puppies that were born in the same litter. Students can explain why do puppies look so different from each other.

Anchoring events always have conceptual content

Because anchoring events are always paired with their explanatory models, it means that there should always be some conceptual content involved with the event or process—that is, something to explain. This means that the following ***do not count*** as anchoring events:

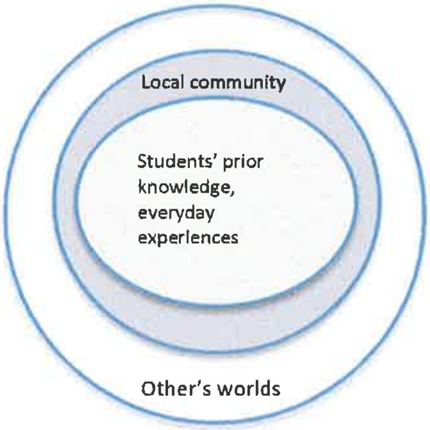
- practices such as experimentation, developing hypotheses, or evidence-based arguments
- safety in the classroom
- learning how to calculate things like molarities, how much force is needed to

move an object, or where the epicenter of an earthquake is located
- creating and interpreting graphs
- using conceptual tools like Punnett Squares, vector diagrams, or half-life tables
- building technological solutions to everyday problems

We are *not* saying that these ideas are unimportant, rather we are saying that ideas like methods of gathering data, lab safety, or using equations should always be *taught in the context of some larger "big ideas" with conceptual content.* All other ideas support the development of explanations for the anchoring event.

Making anchoring events relevant

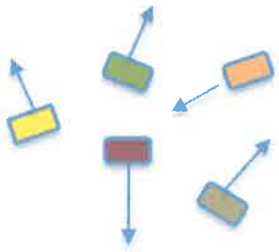
Anchoring events not only need to be important scientifically, but should be realtable to students' interests as well. This ensures that students are motivated to learn and have the best opportunity to capitalize on their background knowledge and everyday experiences. There are three ways to think about relevance to students' lives. Picture a dart board and reference the diagram below. The most relevant context for study would be some aspect of most students' lived experiences (i.e. relating to students' home, school, or peer culture). The second most relevant context is one's local context (i.e. relating to local community or physical geography or the history of a region where students' live). The third most relevant context may not currently be connected to students' worlds but it could be important to their interactions beyond school. All three contexts are important and could be a part of a unit.

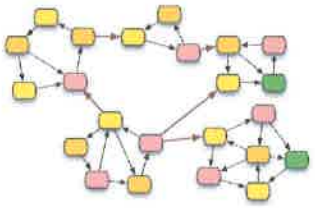


Starting to work with anchoring events

When you start working on anchoring events, you'll reach the limit of your own subject matter understanding very quickly. You should begin looking at various resources on the Web or in texts to expand what you know about the topic. As professionals we can never assume that we know enough about the subject to teach from what's already in our heads. It is important also to work with your colleagues, asking them how they understand the explanations, models, and other ideas related to the topic in the curriculum.

One habit of mind that all great teachers have is that they take the opportunity to test and deepen their own content knowledge on a regular basis. They think of big ideas as the focus of what and how they plan, teach, and assess.





Research on how beginning teachers plan instruction clearly shows the importance of recognizing big ideas in science. In short, being able to identify anchoring events and their explanatory models is a fundamental skill for teachers. Anchoring events help you organize your instruction over multiple lessons and helps students understand why they are learning particular ideas.

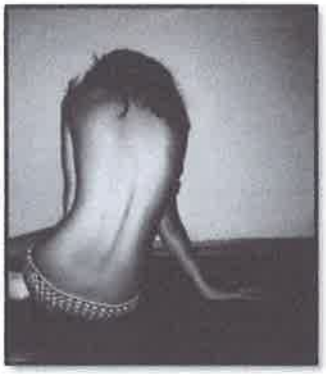
Final examples of successful anchoring events

Here we leave you with seven examples of complex phenomena that anchored units of instruction successfully in science classrooms. We provide the original science topic, the event, and the essential question the teacher posed (or students proposed).

Topic from curriculum: Homeostasis
Anchoring event: Local boy brought back to life after drowning
Essential question: How can this boy's body systems come back to life after 30 minutes under water?

Topic from curriculum: Gas Laws
Anchoring event: Railroad tanker car implodes after being steam cleaned
Essential question: Where did the energy come from to make this steel car collapse on itself?

Topic from curriculum: Ecosystems
Anchoring event: Orca population declines in Puget Sound
Essential question: What is out of whack in this aquatic ecosystem?



Topic from curriculum: Homeostasis
Anchoring event: These are comparative cases—a female ultra-marathoner and a female with bulimia, how their bodies respond to stress over time
Essential question: How can a woman who is a "picture of athletic health' and a woman who is a "picture of disease" have experience the same responses to physical stress over time?

Topic from curriculum: Force and motion
Anchoring event: Boy runs up to wall and does a back flip, lands on feet
Essential question: How can he do this, what is required?

Topic from curriculum: Sound as energy
Anchoring event: Blind young men are able to echo-locate around objects
Essential question: How can these boys "see" if they are blind?

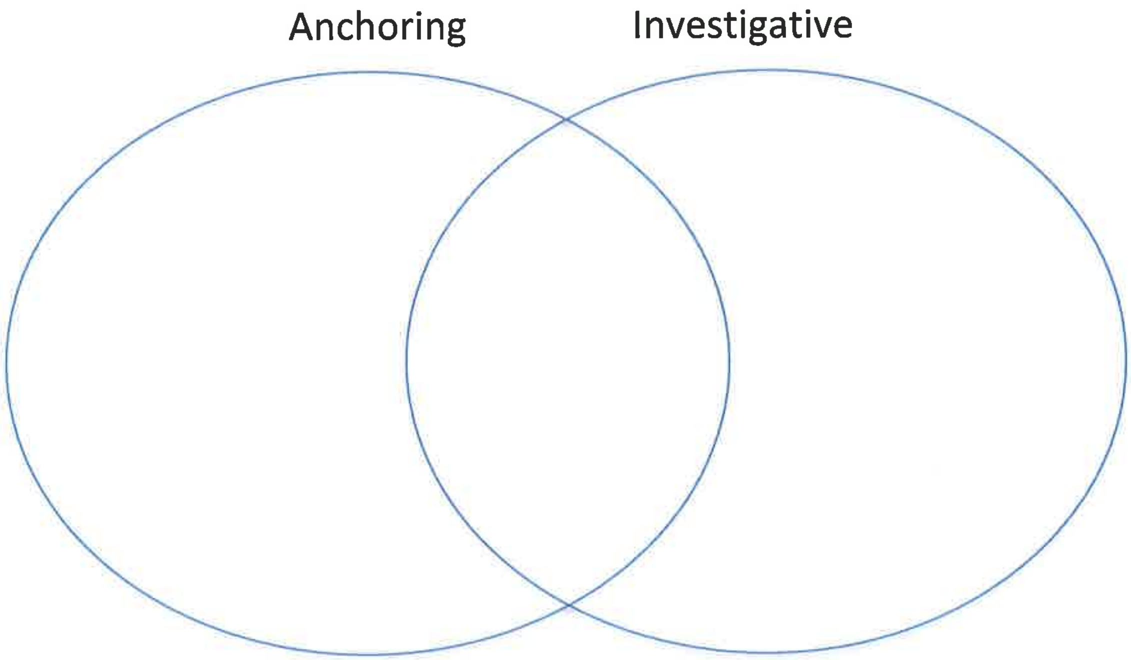
Topic from curriculum: Solar system
Anchoring event: Pluto's erratic orbit
Essential question: How does gravity shape our solar system?

Understanding Phenomena

Phenomena

What makes phenomena worth using in instruction?

Phenomena

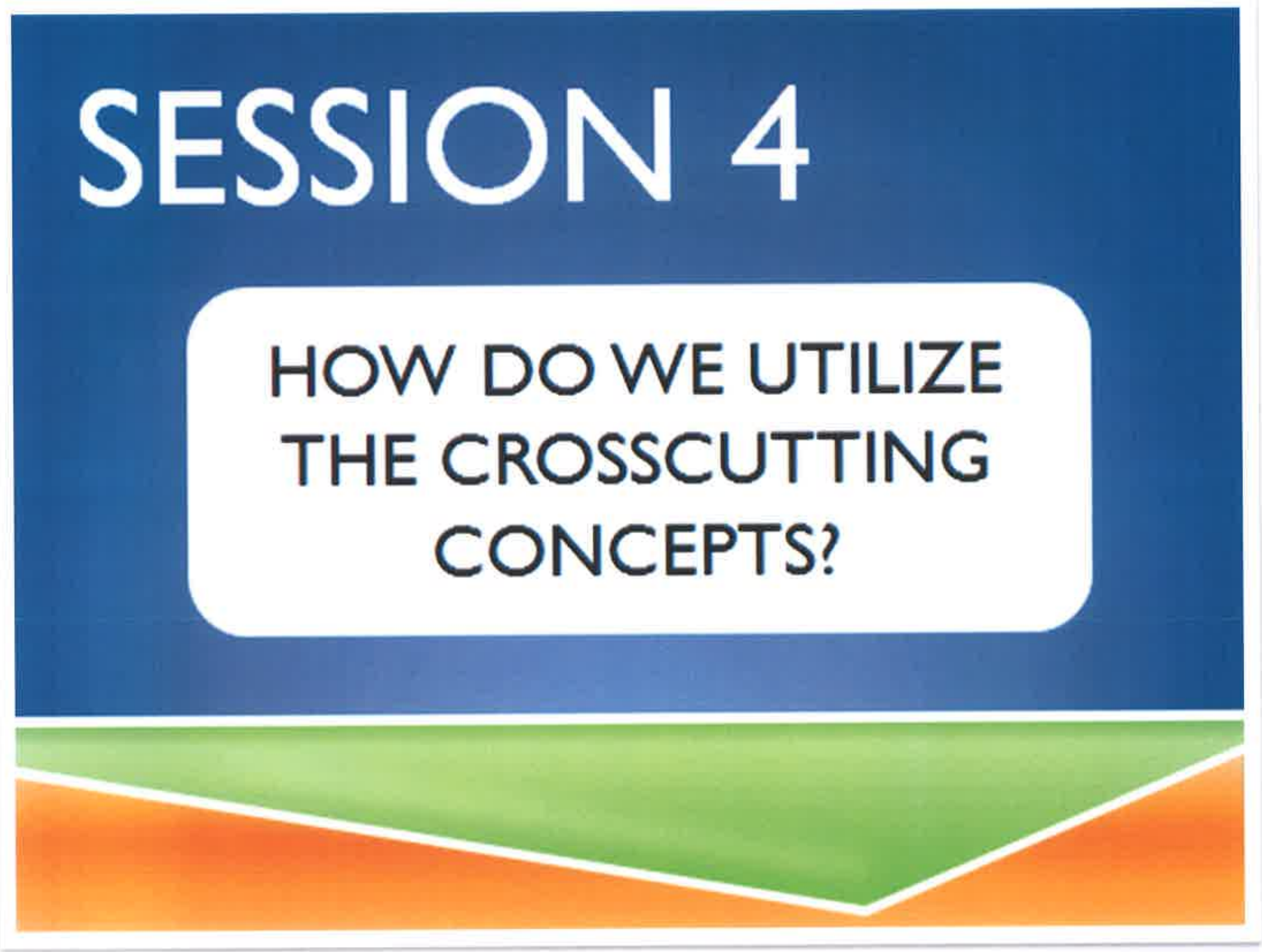


How Do We Find Phenomenon?

Source	Notes
Framework	
Laboratory Investigations	
Publications	
News	
Media	
Websites & Youtube	
Technology	
Natural World	
Informal Education	

Utilizing Phenomenon

Scientific Idea	Phenomenon	Apparatus
This is the "Science." • This is the Scientific Principle students need to learn. • Based on the Disciplinary Core Ideas.	This is a reoccurring event that can be observed. • This is: "Wow! How did that happen? " • The event that needs to be explained.	These are the physical materials the students will investigate with and model from in order to explain the phenomenon. • Objects • Lab Equipment



SESSION 4

HOW DO WE UTILIZE THE CROSSCUTTING CONCEPTS?

Crosscutting Concepts

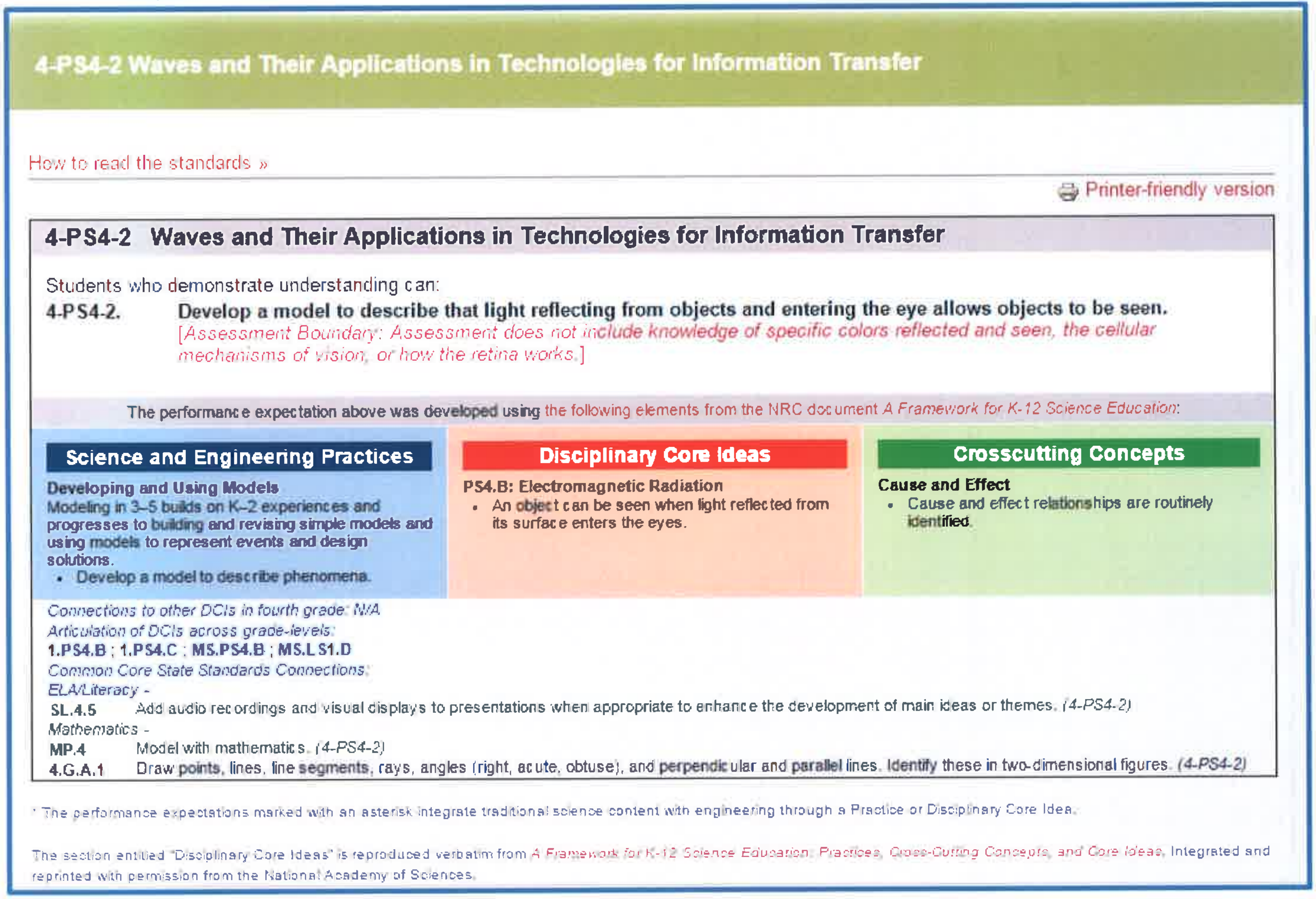
Crosscutting Concepts	Concepts in Science
Patterns	
Cause and Effect	
Scale, Proportion, and Quantity	
Systems and System Models	
Energy and Matter	
Structure and Function	
Stability and Change	

Crosscutting Concepts	Connections
Cause and Effect	
Structure and Function	
Systems and System Models	
Scale, Proportion, and Quantity	
Stability and Change	
Energy and Matter	
Patterns	

Guiding Principles of Crosscutting Concepts

Crosscutting Concepts...	Notes
• Help students understand core ideas in science and engineering.	
• Help students better understand science and engineering practices.	
• Need to be repeated in different contexts.	
• Grow in complexity and sophistication across the grades.	
• Provide a common vocabulary for science and engineering.	
• Should not be assessed separately from practices or core ideas	
• In the Performance expectations, all capabilities associated with a crosscutting concept are not present.	
• Are for all students.	

Making Sense of the Standard



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

How to read the standards »

Printer-friendly version

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

Students who demonstrate understanding can:

4-PS4-2. **Develop a model to describe that light reflecting from objects and entering the eye allows objects to be seen.** *[Assessment Boundary: Assessment does not include knowledge of specific colors reflected and seen, the cellular mechanisms of vision, or how the retina works.]*

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 3–5 builds on K–2 experiences and progresses to building and revising simple models and using models to represent events and design solutions. • Develop a model to describe phenomena.	**PS4.B: Electromagnetic Radiation** • An object can be seen when light reflected from its surface enters the eyes.	**Cause and Effect** • Cause and effect relationships are routinely identified.

Connections to other DCIs in fourth grade: N/A

Articulation of DCIs across grade-levels:

1.PS4.B ; **1.PS4.C** ; **MS.PS4.B** ; **MS.LS1.D**

Common Core State Standards Connections:

ELA/Literacy -

SL.4.5 Add audio recordings and visual displays to presentations when appropriate to enhance the development of main ideas or themes. *(4-PS4-2)*

Mathematics -

MP.4 Model with mathematics. *(4-PS4-2)*

4.G.A.1 Draw points, lines, line segments, rays, angles (right, acute, obtuse), and perpendicular and parallel lines. Identify these in two-dimensional figures. *(4-PS4-2)*

* The performance expectations marked with an asterisk integrate traditional science content with engineering through a Practice or Disciplinary Core Idea.

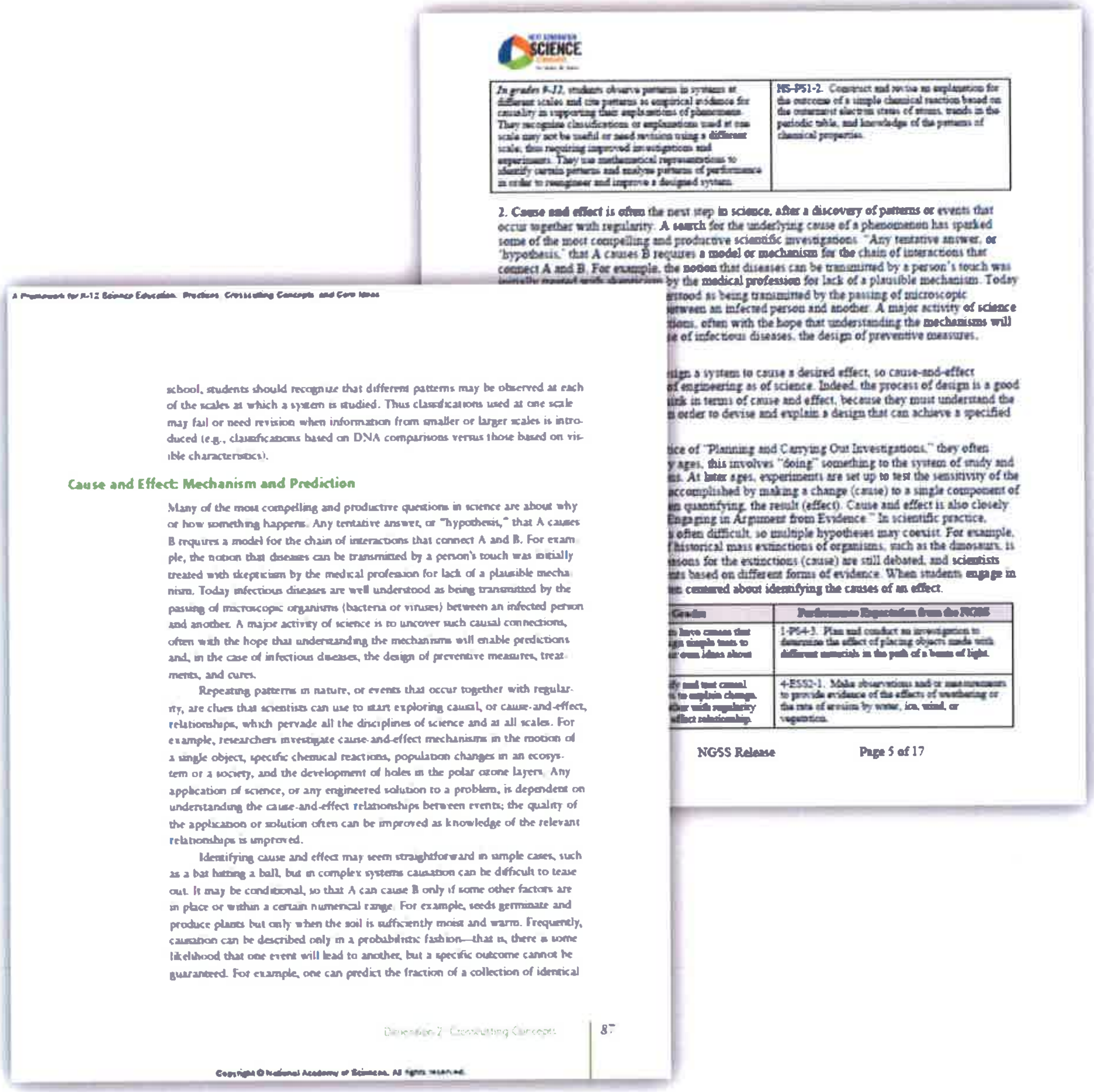
The section entitled "Disciplinary Core Ideas" is reproduced verbatim from *A Framework for K-12 Science Education: Practices, Cross-Cutting Concepts, and Core Ideas*. Integrated and reprinted with permission from the National Academy of Sciences.

Performance expectations are statements that clarify what students should be able to do at the end of instruction in regards to the standards. In reviewing this performance expectation, foundation boxes, and connections, what do you think students need to learn in terms of cause and effect?

What is explicit?	
What is implicit?	

Unpacking the Concepts

Using the excerpt copy of the *Framework* and *Appendix G*, determine what is intended by the crosscutting concept of "Cause and Effect." Read and make notes. Underline the most important ideas you find. Write questions or thoughts in the margins. Read "between the lines" to see what understandings are implicit.



In grades 9-12, students observe patterns in systems at different scales and cite patterns as empirical evidence for causality in supporting their explanations of phenomena. They recognize classifications or explanations used at one scale may not be useful or need revision using a different scale, thus requiring improved investigations and experiments. They use mathematical representations to identify certain patterns and analyze patterns of performance in order to reengineer and improve a designed system.	HS-PS1-2. Construct and revise an explanation for the outcome of a simple chemical reaction based on the outermost electron states of atoms, trends in the periodic table, and knowledge of the patterns of chemical properties.

2. Cause and effect is often the next step in science, after a discovery of patterns or events that occur together with regularity. A search for the underlying cause of a phenomenon has sparked some of the most compelling and productive scientific investigations. "Any tentative answer, or 'hypothesis,' that A causes B requires a model or mechanism for the chain of interactions that connect A and B. For example, the notion that diseases can be transmitted by a person's touch was initially treated with skepticism by the medical profession for lack of a plausible mechanism. Today
rstood as being transmitted by the passing of microscopic
etween an infected person and another. A major activity of science
tions, often with the hope that understanding the mechanisms will
e of infectious diseases, the design of preventive measures.

sign a system to cause a desired effect, so cause-and-effect
of engineering as of science. Indeed, the process of design is a good
ink in terms of cause and effect, because they must understand the
n order to devise and explain a design that can achieve a specified

tice of "Planning and Carrying Out Investigations," they often
y ages, this involves "doing" something to the system of study and
s. At later ages, experiments are set up to test the sensitivity of the
accomplished by making a change (cause) to a single component of
en quantifying the result (effect). Cause and effect is also closely
Engaging in Argument from Evidence." In scientific practice,
s often difficult, so multiple hypotheses may coexist. For example,
f historical mass extinctions of organisms, such as the dinosaurs, is
asons for the extinctions (cause) are still debated, and scientists
nts based on different forms of evidence. When students engage in
ent centered about identifying the causes of an effect.

Grades	Performance Expectation from the NGSS
to have causes that ign simple tests to ir own ideas about	1-PS4-3. Plan and conduct an investigation to determine the effect of placing objects made with different materials in the path of a beam of light.
fy and test causal s to explain change. ether with regularity effect relationship.	4-ESS2-1. Make observations and/or measurements to provide evidence of the effects of weathering or the rate of erosion by water, ice, wind, or vegetation.

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A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas

school, students should recognize that different patterns may be observed at each of the scales at which a system is studied. Thus classifications used at one scale may fail or need revision when information from smaller or larger scales is introduced (e.g., classifications based on DNA comparisons versus those based on visible characteristics).

Cause and Effect: Mechanism and Prediction

Many of the most compelling and productive questions in science are about why or how something happens. Any tentative answer, or "hypothesis," that A causes B requires a model for the chain of interactions that connect A and B. For example, the notion that diseases can be transmitted by a person's touch was initially treated with skepticism by the medical profession for lack of a plausible mechanism. Today infectious diseases are well understood as being transmitted by the passing of microscopic organisms (bacteria or viruses) between an infected person and another. A major activity of science is to uncover such causal connections, often with the hope that understanding the mechanisms will enable predictions and, in the case of infectious diseases, the design of preventive measures, treatments, and cures.

Repeating patterns in nature, or events that occur together with regularity, are clues that scientists can use to start exploring causal, or cause-and-effect, relationships, which pervade all the disciplines of science and at all scales. For example, researchers investigate cause-and-effect mechanisms in the motion of a single object, specific chemical reactions, population changes in an ecosystem or a society, and the development of holes in the polar ozone layers. Any application of science, or any engineered solution to a problem, is dependent on understanding the cause-and-effect relationships between events; the quality of the application or solution often can be improved as knowledge of the relevant relationships is improved.

Identifying cause and effect may seem straightforward in simple cases, such as a bat hitting a ball, but in complex systems causation can be difficult to tease out. It may be conditional, so that A can cause B only if some other factors are in place or within a certain numerical range. For example, seeds germinate and produce plants but only when the soil is sufficiently moist and warm. Frequently, causation can be described only in a probabilistic fashion—that is, there is some likelihood that one event will lead to another, but a specific outcome cannot be guaranteed. For example, one can predict the fraction of a collection of identical

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school, students should recognize that different patterns may be observed at each of the scales at which a system is studied. Thus classifications used at one scale may fail or need revision when information from smaller or larger scales is introduced (e.g., classifications based on DNA comparisons versus those based on visible characteristics).

Cause and Effect: Mechanism and Prediction

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Identifying cause and effect may seem straightforward in simple cases, such as a bat hitting a ball, but in complex systems causation can be difficult to tease out. It may be conditional, so that A can cause B only if some other factors are in place or within a certain numerical range. For example, seeds germinate and produce plants but only when the soil is sufficiently moist and warm. Frequently, causation can be described only in a probabilistic fashion—that is, there is some likelihood that one event will lead to another, but a specific outcome cannot be guaranteed. For example, one can predict the fraction of a collection of identical atoms that will undergo radioactive decay in a certain period but not the exact time at which a given atom decays.

One assumption of all science and engineering is that there is a limited and universal set of fundamental physical interactions that underlie all known forces and hence are a root part of any causal chain, whether in natural or designed systems. Such "universality" means that the physical laws underlying all processes are the same everywhere and at all times; they depend on gravity, electromagnetism, or weak and strong nuclear interactions. Underlying all biological processes—the inner workings of a cell or even of a brain—are particular physical and chemical processes. At the larger scale of biological systems, the universality of life manifests itself in a common genetic code.

Causation invoked to explain larger scale systems must be consistent with the implications of what is known about smaller scale processes within the system, even though new features may emerge at large scales that cannot be predicted from knowledge of smaller scales. For example, although knowledge of atoms is not sufficient to predict the genetic code, the replication of genes must be understood as a molecular-level process. Indeed, the ability to model causal processes in complex multipart systems arises from this fact; modern computational codes incorporate relevant smaller scale relationships into the model of the larger system, integrating multiple factors in a way that goes well beyond the capacity of the human brain.

In engineering, the goal is to design a system to cause a desired effect, so cause-and-effect relationships are as much a part of engineering as of science. Indeed, the process of design is a good place to help students begin to think in terms of cause and effect, because they must understand the underlying causal relationships in order to devise and explain a design that can achieve a specified objective.

One goal of instruction about cause and effect is to encourage students to see events in the world as having understandable causes, even when these causes are beyond human control. The ability to distinguish between scientific causal claims and nonscientific causal claims is also an important goal.

Progression

In the earliest grades, as students begin to look for and analyze patterns—whether in their observations of the world or in the relationships between different quantities in data (e.g., the sizes of plants over time)—they can also begin to consider what might be causing these patterns and relationships and design tests that gather more evidence to support or refute their ideas. By the upper elementary grades, students should have developed the habit of routinely asking about cause-and-effect relationships in the systems they are studying, particularly when something occurs that is, for them, unexpected. The questions "How did that happen?" or "Why did that happen?" should move toward "What mechanisms caused that to happen?" and "What conditions were critical for that to happen?"

In middle and high school, argumentation starting from students' own explanations of cause and effect can help them appreciate standard scientific theories that explain the causal mechanisms in the systems under study. Strategies for this type of instruction include asking students to argue from evidence when attributing an observed phenomenon to a specific cause. For example, students exploring why the population of a given species is shrinking will look for evidence in the ecosystem of factors that lead to food shortages, overpredation, or other factors in the habitat related to survival; they will provide an argument for how these and other observed changes affect the species of interest.

Scale, Proportion, and Quantity

In thinking scientifically about systems and processes, it is essential to recognize that they vary in size (e.g., cells, whales, galaxies), in time span (e.g., nanoseconds, hours, millennia), in the amount of energy flowing through them (e.g., lightbulbs, power grids, the sun), and in the relationships between the scales of these different quantities. The understanding of relative magnitude is only a starting point. As noted in *Benchmarks for Science Literacy*, "The large idea is that the way in which things work may change with scale. Different aspects of nature change at different rates with changes in scale, and so the relationships among them change, too" [4]. Appropriate understanding of scale relationships is critical as well to engineering—no structure could be conceived, much less constructed, without the engineer's precise sense of scale.

From a human perspective, one can separate three major scales at which to study science: (1) macroscopic scales that are directly observable—that is, what one can see, touch, feel, or manipulate; (2) scales that are too small or fast to observe directly; and (3) those that are too large or too slow. Objects at the atomic scale, for example, may be described with simple models, but the size of atoms and the number of atoms in a system involve magnitudes that are difficult to imagine. At the other extreme, science deals in scales that are equally difficult to imagine because they are so large—continents that move, for example, and galaxies in which the nearest star is 4 years away traveling at the speed of

In grades 9-12, students observe patterns in systems at different scales and cite patterns as empirical evidence for causality in supporting their explanations of phenomena. They recognize classifications or explanations used at one scale may not be useful or need revision using a different scale; thus requiring improved investigations and experiments. They use mathematical representations to identify certain patterns and analyze patterns of performance in order to reengineer and improve a designed system.	HS-PS1-2. Construct and revise an explanation for the outcome of a simple chemical reaction based on the outermost electron states of atoms, trends in the periodic table, and knowledge of the patterns of chemical properties.

2. Cause and effect is often the next step in science, after a discovery of patterns or events that occur together with regularity. A search for the underlying cause of a phenomenon has sparked some of the most compelling and productive scientific investigations. "Any tentative answer, or 'hypothesis,' that A causes B requires a model or mechanism for the chain of interactions that connect A and B. For example, the notion that diseases can be transmitted by a person's touch was initially treated with skepticism by the medical profession for lack of a plausible mechanism. Today infectious diseases are well understood as being transmitted by the passing of microscopic organisms (bacteria or viruses) between an infected person and another. A major activity of science is to uncover such causal connections, often with the hope that understanding the mechanisms will enable predictions and, in the case of infectious diseases, the design of preventive measures, treatments, and cures." (p. 87)

"In engineering, the goal is to design a system to cause a desired effect, so cause-and-effect relationships are as much a part of engineering as of science. Indeed, the process of design is a good place to help students begin to think in terms of cause and effect, because they must understand the underlying causal relationships in order to devise and explain a design that can achieve a specified objective." (p.88)

When students perform the practice of "Planning and Carrying Out Investigations," they often address cause and effect. At early ages, this involves "doing" something to the system of study and then watching to see what happens. At later ages, experiments are set up to test the sensitivity of the parameters involved, and this is accomplished by making a change (cause) to a single component of a system and examining, and often quantifying, the result (effect). Cause and effect is also closely associated with the practice of "Engaging in Argument from Evidence." In scientific practice, deducing the cause of an effect is often difficult, so multiple hypotheses may coexist. For example, though the occurrence (effect) of historical mass extinctions of organisms, such as the dinosaurs, is well established, the reason or reasons for the extinctions (cause) are still debated, and scientists develop and debate their arguments based on different forms of evidence. When students engage in scientific argumentation, it is often centered about identifying the causes of an effect.

Progression Across the Grades	Performance Expectation from the NGSS
In grades K-2, students learn that events have causes that generate observable patterns. They design simple tests to gather evidence to support or refute their own ideas about causes.	1-PS4-3. Plan and conduct an investigation to determine the effect of placing objects made with different materials in the path of a beam of light.
In grades 3-5, students routinely identify and test causal relationships and use these relationships to explain change. They understand events that occur together with regularity might or might not signify a cause and effect relationship.	4-ESS2-1. Make observations and/or measurements to provide evidence of the effects of weathering or the rate of erosion by water, ice, wind, or vegetation.

In grades 6-8, students classify relationships as causal or correlational, and recognize that correlation does not necessarily imply causation. They use cause and effect relationships to predict phenomena in natural or designed systems. They also understand that phenomena may have more than one cause, and some cause and effect relationships in systems can only be described using probability.	MS-PS1-4. Develop a model that predicts and describes changes in particle motion, temperature, and state of a pure substance when thermal energy is added or removed.
In grades 9-12, students understand that empirical evidence is required to differentiate between cause and correlation and to make claims about specific causes and effects. They suggest cause and effect relationships to explain and predict behaviors in complex natural and designed systems. They also propose causal relationships by examining what is known about smaller scale mechanisms within the system. They recognize changes in systems may have various causes that may not have equal effects.	HS-LS3-2. Make and defend a claim based on evidence that inheritable genetic variations may result from: (1) new genetic combinations through meiosis, (2) viable errors occurring during replication, and/or (3) mutations caused by environmental factors.

3. Scale, Proportion and Quantity are important in both science and engineering. These are fundamental assessments of dimension that form the foundation of observations about nature. Before an analysis of function or process can be made (the *how* or *why*), it is necessary to identify the *what*. These concepts are the starting point for scientific understanding, whether it is of a total system or its individual components. Any student who has ever played the game "twenty questions" understands this inherently, asking questions such as, "Is it bigger than a bread box?" in order to first determine the object's size.

An understanding of scale involves not only understanding systems and processes vary in size, time span, and energy, but also different mechanisms operate at different scales. In engineering, "no structure could be conceived, much less constructed, without the engineer's precise sense of scale... At a basic level, in order to identify something as bigger or smaller than something else—and how much bigger or smaller—a student must appreciate the units used to measure it and develop a feel for quantity." (p. 90)

"The ideas of ratio and proportionality as used in science can extend and challenge students' mathematical understanding of these concepts. To appreciate the relative magnitude of some properties or processes, it may be necessary to grasp the relationships among different types of quantities—for example, speed as the ratio of distance traveled to time taken, density as a ratio of mass to volume. This use of ratio is quite different than a ratio of numbers describing fractions of a pie. Recognition of such relationships among different quantities is a key step in forming mathematical models that interpret scientific data." (p. 90)

The crosscutting concept of Scale, Proportion, and Quantity figures prominently in the practices of "Using Mathematics and Computational Thinking" and in "Analyzing and Interpreting Data." This concept addresses taking measurements of structures and phenomena, and these fundamental observations are usually obtained, analyzed, and interpreted quantitatively. This crosscutting concept also figures prominently in the practice of "Developing and Using Models." Scale and proportion are often best understood using models. For example, the relative scales of objects in the solar system or of the components of an atom are difficult to comprehend mathematically (because the numbers involved are either so large or so small), but visual or conceptual models make them much more understandable (e.g., if the solar system were the size of a penny, the Milky Way galaxy would be the size of Texas).

NGSS Crosscutting Concepts*

Section 2: Crosscutting Concepts Matrix

1. Patterns – Observed patterns in nature guide organization and classification and prompt questions about relationships and causes underlying them.

K-2 Crosscutting Statements	3-5 Crosscutting Statements	6-8 Crosscutting Statements	9-12 Crosscutting Statements
▪ Patterns in the natural and human designed world can be observed, used to describe phenomena, and used as evidence.	▪ Similarities and differences in patterns can be used to sort, classify, communicate and analyze simple rates of change for natural phenomena and designed products. ▪ Patterns of change can be used to make predictions. ▪ Patterns can be used as evidence to support an explanation.	▪ Macroscopic patterns are related to the nature of microscopic and atomic-level structure. ▪ Patterns in rates of change and other numerical relationships can provide information about natural and human designed systems. ▪ Patterns can be used to identify cause and effect relationships. ▪ Graphs, charts, and images can be used to identify patterns in data.	▪ Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena. ▪ Classifications or explanations used at one scale may fail or need revision when information from smaller or larger scales is introduced; thus requiring improved investigations and experiments. ▪ Patterns of performance of designed systems can be analyzed and interpreted to reengineer and improve the system. ▪ Mathematical representations are needed to identify some patterns. ▪ Empirical evidence is needed to identify patterns.

2. Cause and Effect: Mechanism and Prediction – Events have causes, sometimes simple, sometimes multifaceted. Deciphering causal relationships, and the mechanisms by which they are mediated, is a major activity of science and engineering.

K-2 Crosscutting Statements	3-5 Crosscutting Statements	6-8 Crosscutting Statements	9-12 Crosscutting Statements
▪ Events have causes that generate observable patterns. ▪ Simple tests can be designed to gather evidence to support or refute student ideas about causes.	▪ Cause and effect relationships are routinely identified, tested, and used to explain change. ▪ Events that occur together with regularity might or might not be a cause and effect relationship.	▪ Relationships can be classified as causal or correlational, and correlation does not necessarily imply causation. ▪ Cause and effect relationships may be used to predict phenomena in natural or designed systems. ▪ Phenomena may have more than one cause, and some cause and effect relationships in systems can only be described using probability.	▪ Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. ▪ 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. ▪ Systems can be designed to cause a desired effect. ▪ Changes in systems may have various causes that may not have equal effects.

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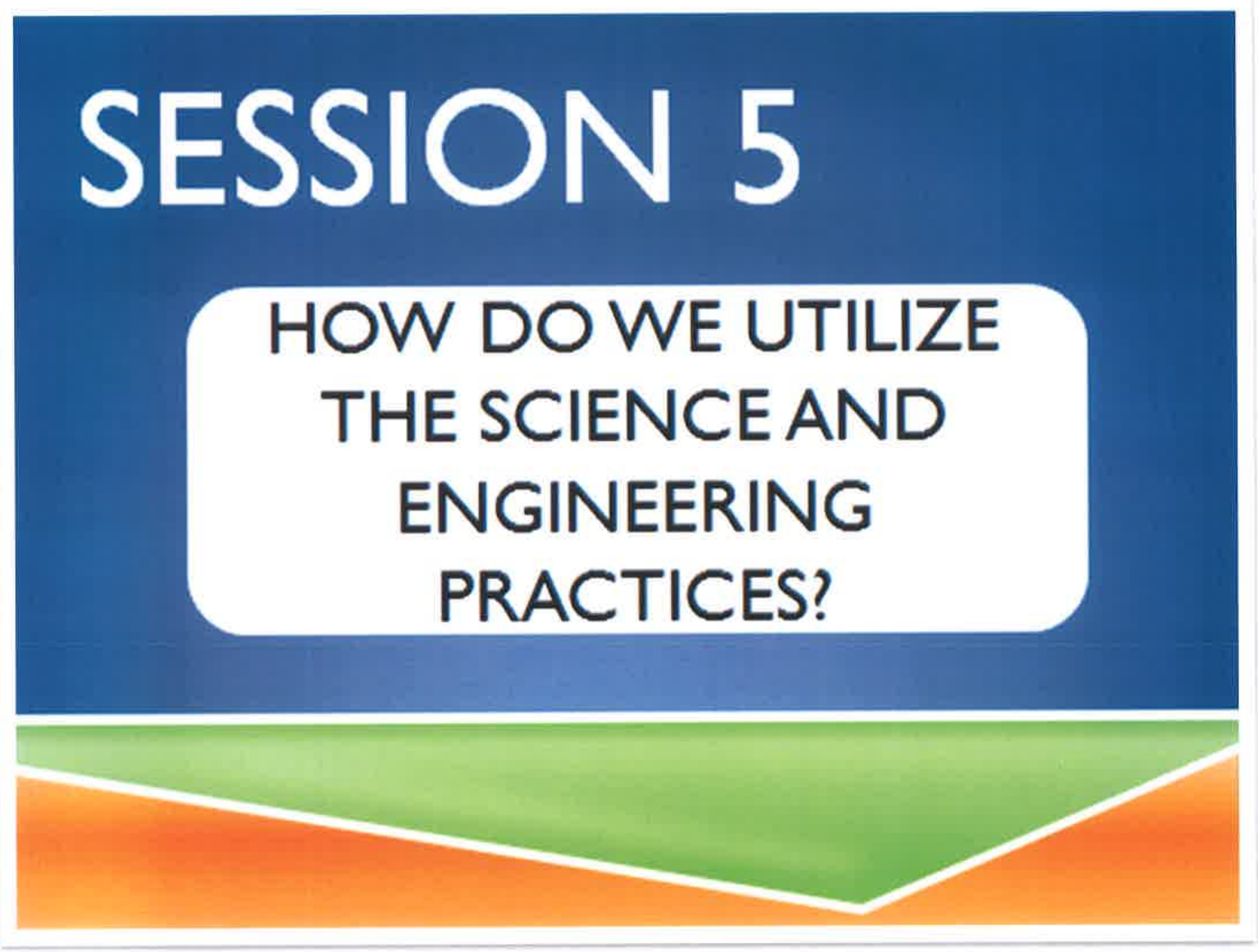
* Adapted from: National Research Council (2011). *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas.* Committee on a Conceptual Framework for New K-12 Science Education Standards. Board on Science Education, Division of Behavioral and Social Sciences and Education. Washington, DC: The National Academy Press. Chapter 4: Crosscutting Concepts.



SESSION 5

HOW DO WE UTILIZE THE SCIENCE AND ENGINEERING PRACTICES?

Three Dimensions of the *Framework for K-12 Science Education* being used to Develop the *Next Generation Science Standards* (NGSS)

Scientific and Engineering Practices

Asking Questions and Defining Problems

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

Engineering questions clarify problems to determine criteria for successful solutions and identify constraints to solve problems about the designed world.

Both scientists and engineers also ask questions to clarify the ideas of others.

Planning and Carrying Out Investigations

Scientists and engineers plan and carry out investigations in the field or laboratory, working collaboratively as well as individually. Their investigations are systematic and require clarifying what counts as data and identifying variables or parameters.

Engineering investigations identify the effectiveness, efficiency, and durability of designs under different conditions.

Analyzing and Interpreting Data

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

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

Developing and Using Models

A practice of both science and engineering is to use and construct models as helpful tools for representing ideas and explanations. These tools include diagrams, drawings, physical replicas, mathematical representations, analogies, and computer simulations.

Modeling tools are used to develop questions, predictions and explanations; analyze and identify flaws in systems; and communicate ideas. Models are used to build and revise scientific explanations and proposed engineered systems. Measurements and observations are used to revise models and designs.

Constructing Explanations and Designing Solutions

The products of science are explanations and the products of engineering are solutions.

The goal of science is the construction of theories that provide explanatory accounts of the world. A theory becomes accepted when it has multiple lines of empirical evidence and greater explanatory power of phenomena than previous theories.

The goal of engineering design is to find a systematic solution to problems that is based on scientific knowledge and models of the material world. Each proposed solution results from a process of balancing competing criteria of desired functions, technical feasibility, cost, safety, aesthetics, and compliance with legal requirements. The optimal choice depends on how well the proposed solutions meet criteria and constraints.

Engaging in Argument from Evidence

Argumentation is the process by which explanations and solutions are reached.

In science and engineering, reasoning and argument based on evidence are essential to identifying the best explanation for a natural phenomenon or the best solution to a design problem. Scientists and engineers use argumentation to listen to, compare, and evaluate competing ideas and methods based on merits.

Scientists and engineers engage in argumentation when investigating a phenomenon, testing a design solution, resolving questions about measurements, building data models, and using evidence to identify strengths and weaknesses of claims.

Using Mathematics and Computational Thinking

In both science and engineering, mathematics and computation are fundamental tools for representing physical variables and their relationships. They are used for a range of tasks such as constructing simulations; statistically analyzing data; and recognizing, expressing, and applying quantitative relationships.

Mathematical and computational approaches enable scientists and engineers to predict the behavior of systems and test the validity of such predictions. Statistical methods are frequently used to identify significant patterns and establish correlational relationships.

Obtaining, Evaluating, and Communicating Information

Scientists and engineers must be able to communicate clearly and persuasively the ideas and methods they generate. Critiquing and communicating ideas individually and in groups is a critical professional activity.

Communicating information and ideas can be done in multiple ways: using tables, diagrams, graphs, models, and equations as well as orally, in writing, and through extended discussions. Scientists and engineers employ multiple sources to acquire information that is used to evaluate the merit and validity of claims, methods, and designs.

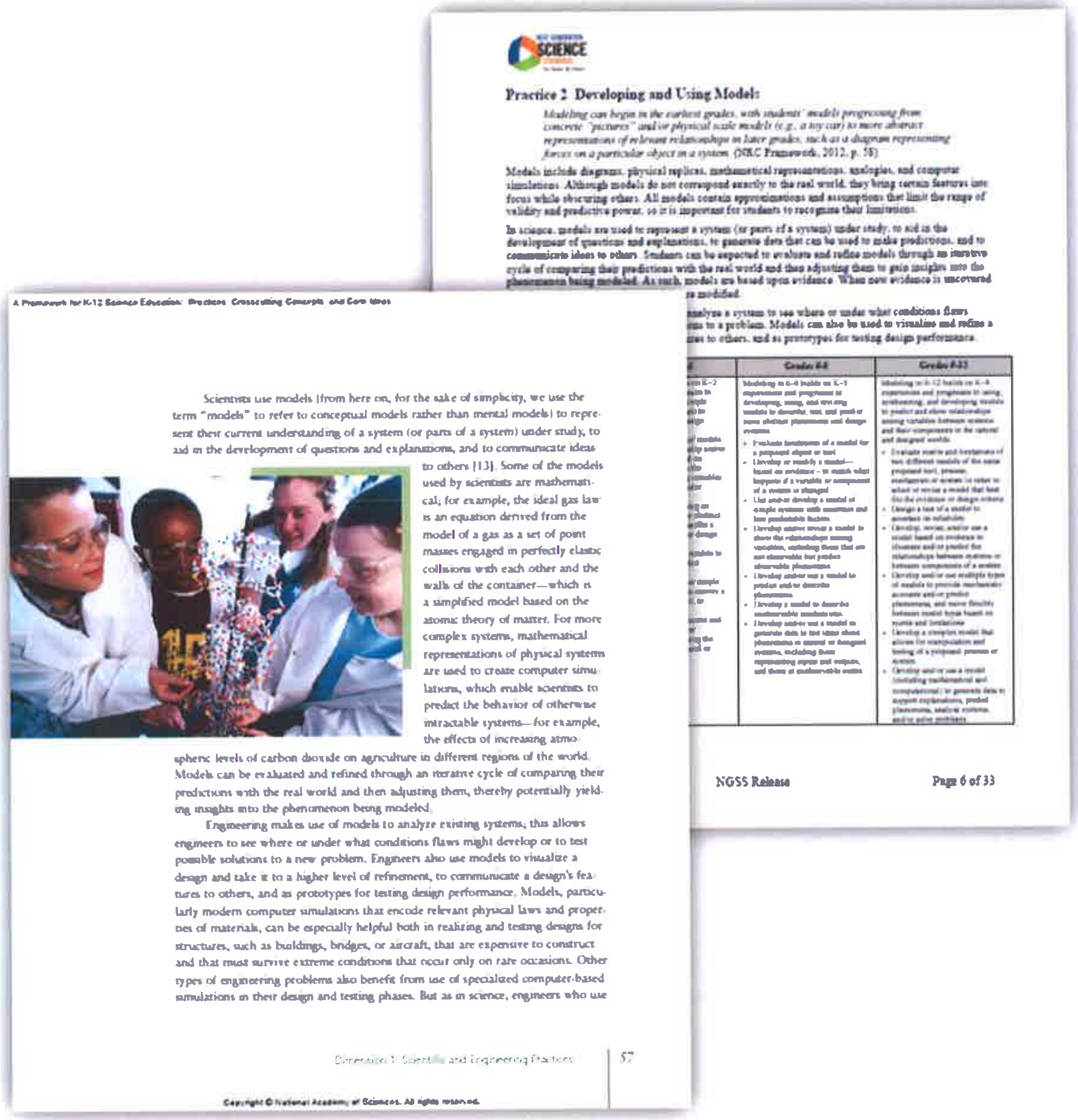
Developed by NSTA based on content from the *Framework for K-12 Science Education* and *May 2012 Public Draft of the NGSS*

Finding the Scientific and Engineering Practices

Practice	Evidence
Asking Question and Defining Problems	
Planning and Carrying Out Investigations	
Analyzing and Interpreting Data	
Developing and Using Models	
Constructing Explanations and Designing Solutions	
Engaging in Argument from Evidence	
Using Mathematics and Computational Thinking	
Obtaining, Evaluation, and Communicating Information	

Unpacking the Practices

Using the excerpt copy of the *Framework* and the *NGSS Appendix F*, determine what is intended by the science and engineering practice of "Developing and Using Models." Read and make notes. Underline the most important ideas you find. Write questions or thoughts in the margins. Read "between the lines" to see what understandings are implicit.



Practice 2 Developing and Using Models

Modeling can begin in the earliest grades, with students' models progressing from concrete "pictures" and/or physical scale models (e.g., a toy car) to more abstract representations of relevant relationships in later grades, such as a diagram representing forces on a particular object in a system. (NRC Framework, 2012, p. 58)

Models include diagrams, physical replicas, mathematical representations, analogies, and computer simulations. Although models do not correspond exactly to the real world, they bring certain features into focus while obscuring others. All models contain approximations and assumptions that limit the range of validity and predictive power, so it is important for students to recognize their limitations.

In science, models are used to represent a system (or parts of a system) under study, to aid in the development of questions and explanations, to generate data that can be used to make predictions, and to communicate ideas to others. Students can be expected to evaluate and refine models through an iterative cycle of comparing their predictions with the real world and then adjusting them to gain insights into the phenomena being modeled. As such, models are based upon evidence. When new evidence is uncovered

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ons to a problem. Models can also be used to visualize and refine a

res to others, and as prototypes for testing design performance.

Grades 6-8	Grades 9-12
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.	Modeling in 9–12 builds on K–8 experiences and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed worlds.

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A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas

Scientists use models (from here on, for the sake of simplicity, we use the term "models" to refer to conceptual models rather than mental models) to represent their current understanding of a system (or parts of a system) under study, to aid in the development of questions and explanations, and to communicate ideas to others [13]. Some of the models used by scientists are mathematical; for example, the ideal gas law is an equation derived from the model of a gas as a set of point masses engaged in perfectly elastic collisions with each other and the walls of the container—which is a simplified model based on the atomic theory of matter. For more complex systems, mathematical representations of physical systems are used to create computer simulations, which enable scientists to predict the behavior of otherwise intractable systems—for example, the effects of increasing atmospheric levels of carbon dioxide on agriculture in different regions of the world. Models can be evaluated and refined through an iterative cycle of comparing their predictions with the real world and then adjusting them, thereby potentially yielding insights into the phenomenon being modeled.

Engineering makes use of models to analyze existing systems; this allows engineers to see where or under what conditions flaws might develop or to test possible solutions to a new problem. Engineers also use models to visualize a design and take it to a higher level of refinement, to communicate a design's features to others, and as prototypes for testing design performance. Models, particularly modern computer simulations that encode relevant physical laws and properties of materials, can be especially helpful both in realizing and testing designs for structures, such as buildings, bridges, or aircraft, that are expensive to construct and that must survive extreme conditions that occur only on rare occasions. Other types of engineering problems also benefit from use of specialized computer-based simulations in their design and testing phases. But as in science, engineers who use

Dimension 1: Scientific and Engineering Practices 57

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PROGRESSION

Students at any grade level should be able to ask questions of each other about the texts they read, the features of the phenomena they observe, and the conclusions they draw from their models or scientific investigations. For engineering, they should ask questions to define the problem to be solved and to elicit ideas that lead to the constraints and specifications for its solution. As they progress across the grades, their questions should become more relevant, focused, and sophisticated. Facilitating such evolution will require a classroom culture that respects and values good questions, that offers students opportunities to refine their questions and questioning strategies, and that incorporates the teaching of effective questioning strategies across all grade levels. As a result, students will become increasingly proficient at posing questions that request relevant empirical evidence; that seek to refine a model, an explanation, or an engineering problem; or that challenge the premise of an argument or the suitability of a design.

Practice 2 Developing and Using Models

Scientists construct mental and conceptual models of phenomena. Mental models are internal, personal, idiosyncratic, incomplete, unstable, and essentially functional. They serve the purpose of being a tool for thinking with, making predictions, and making sense of experience. Conceptual models, the focus of this section, are, in contrast, explicit representations that are in some ways analogous to the phenomena they represent. Conceptual models allow scientists and engineers to better visualize and understand a phenomenon under investigation or develop a possible solution to a design problem. Used in science and engineering as either structural, functional, or behavioral analogs, albeit simplified, conceptual models include diagrams, physical replicas, mathematical representations, analogies, and computer simulations. Although they do not correspond exactly to the more complicated entity being modeled, they do bring certain features into focus while minimizing or obscuring others. Because all models contain approximations and assumptions that limit the range of validity of their application and the precision of their predictive power, it is important to recognize their limitations.

Conceptual models are in some senses the external articulation of the mental models that scientists hold and are strongly interrelated with mental models. Building an understanding of models and their role in science helps students to construct and revise mental models of phenomena. Better mental models, in turn, lead to a deeper understanding of science and enhanced scientific reasoning.

Scientists use models (from here on, for the sake of simplicity, we use the term "models" to refer to conceptual models rather than mental models) to represent their current understanding of a system (or parts of a system) under study, to aid in the development of questions and explanations, and to communicate ideas to others [13]. Some of the models used by scientists are mathematical; for example, the ideal gas law is an equation derived from the model of a gas as a set of point masses engaged in perfectly elastic collisions with each other and the walls of the container—which is a simplified model based on the atomic theory of matter. For more complex systems, mathematical representations of physical systems are used to create computer simulations, which enable scientists to predict the behavior of otherwise intractable systems—for example, the effects of increasing atmospheric levels of carbon dioxide on agriculture in different regions of the world. Models can be evaluated and refined through an iterative cycle of comparing their predictions with the real world and then adjusting them, thereby potentially yielding insights into the phenomenon being modeled.

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GOALS

By grade 12, students should be able to

- Construct drawings or diagrams as representations of events or systems—for example, draw a picture of an insect with labeled features, represent what happens to the water in a puddle as it is warmed by the sun, or represent a simple physical model of a real-world object and use it as the basis of an explanation or to make predictions about how the system will behave in specified circumstances.
- Represent and explain phenomena with multiple types of models—for example, represent molecules with 3-D models or with bond diagrams—and move flexibly between model types when different ones are most useful for different purposes.
- Discuss the limitations and precision of a model as the representation of a system, process, or design and suggest ways in which the model might be improved to better fit available evidence or better reflect a design's specifications. Refine a model in light of empirical evidence or criticism to improve its quality and explanatory power.
- Use (provided) computer simulations or simulations developed with simple simulation tools as a tool for understanding and investigating aspects of a system, particularly those not readily visible to the naked eye.
- Make and use a model to test a design, or aspects of a design, and to compare the effectiveness of different design solutions.

PROGRESSION

Modeling can begin in the earliest grades, with students' models progressing from concrete "pictures" and/or physical scale models (e.g., a toy car) to more abstract representations of relevant relationships in later grades, such as a diagram representing forces on a particular object in a system. Students should be asked to use diagrams, maps, and other abstract models as tools that enable them to elaborate on their own ideas or findings and present them to others [15]. Young students should be encouraged to devise pictorial and simple graphical representations of the findings of their investigations and to use these models in developing their explanations of what occurred.

More sophisticated types of models should increasingly be used across the grades, both in instruction and curriculum materials, as students progress through their science education. The quality of a student-developed model will be highly dependent on prior knowledge and skill and also on the student's understanding of the system being modeled, so students should be expected to refine their models as their understanding develops. Curricula will need to stress the role of models explicitly and provide students with modeling tools (e.g., Model-It, agent-based modeling such as NetLogo, spreadsheet models), so that students come to value this core practice and develop a level of facility in constructing and applying appropriate models.

Practice 3

Planning and Carrying Out Investigations

Scientists and engineers investigate and observe the world with essentially two goals: (1) to systematically describe the world and (2) to develop and test theories and explanations of how the world works. In the first, careful observation and description often lead to identification of features that need to be explained or questions that need to be explored.

The second goal requires investigations to test explanatory models of the world and their predictions and whether the inferences suggested by these models are supported by data. Planning and designing such investigations require the ability to design experimental or observational inquiries that are appropriate to answering the question being asked or testing a hypothesis that has been formed. This process begins by identifying the relevant variables and considering how they might be observed, measured, and controlled (constrained by the experimental design to take particular values).

Planning for controls is an important part of the design of an investigation. In laboratory experiments, it is critical to decide which variables are to be treated as results or outputs and thus left to vary at will and which are to be treated as input conditions and hence controlled. In many cases, particularly in the case of field observations, such planning involves deciding what can be controlled and how to collect different samples of data under different conditions, even though not all conditions are under the direct control of the investigator.

Decisions must also be made about what measurements should be taken, the level of accuracy required, and the kinds of instrumentation best suited to making such measurements. As in other forms of inquiry, the key issue is one of precision—the goal is to measure the variable as accurately as possible and reduce sources of error. The investigator must therefore decide what constitutes

NGSS Science and Engineering Practices* (March 2013 Draft)

Science and Engineering Practices	K–2 Condensed Practices	3–5 Condensed Practices	6–8 Condensed Practices	9–12 Condensed Practices
Developing and Using Models A practice of both science and engineering is to use and construct models as helpful tools for representing ideas and explanations. These tools include diagrams, drawings, physical replicas, mathematical representations, analogies, and computer simulations. Modeling tools are used to develop questions, predictions and explanations; analyze and identify flaws in systems; and communicate ideas. Models are used to build and revise scientific explanations and proposed engineered systems. Measurements and observations are used to revise models and designs.	Modeling in K–2 builds on prior experiences and progresses to include using and developing models (i.e., diagram, drawing, physical replica, diorama, dramatization, or storyboard) that represent concrete events or design solutions.	Modeling in 3–5 builds on K–2 experiences and progresses to building and revising simple models and using models to represent events and design solutions.	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.	Modeling in 9–12 builds on K–8 experiences and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed world(s).
	• Distinguish between a model and the actual object, process, and/or events the model represents. • Compare models to identify common features and differences.	• Identify limitations of models.	• Evaluate limitations of a model for a proposed object or tool.	• Evaluate merits and limitations of two different models of the same proposed tool, process, mechanism, or system in order to select or revise a model that best fits the evidence or design criteria. • Design a test of a model to ascertain its reliability.
	• Develop and/or use a model to represent amounts, relationships, relative scales (bigger, smaller), and/or patterns in the natural and designed world(s).	• Collaboratively develop and/or revise a model based on evidence that shows the relationships among variables for frequent and regular occurring events. • Develop a model using an analogy, example, or abstract representation to describe a scientific principle or design solution. • Develop and/or use models to describe and/or predict phenomena.	• Develop or modify a model—based on evidence – to match what happens if a variable or component of a system is changed. • Use and/or develop a model of simple systems with uncertain and less predictable factors. • Develop and/or revise a model to show the relationships among variables, including those that are not observable but predict observable phenomena. • Develop and/or use a model to predict and/or describe phenomena. • Develop a model to describe unobservable mechanisms.	• Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system. • Develop and/or use multiple types of models to provide mechanistic accounts and/or predict phenomena, and move flexibly between model types based on merits and limitations.

	• Develop a simple model based on evidence to represent a proposed object or tool.	• Develop a diagram or simple physical prototype to convey a proposed object, tool, or process. • Use a model to test cause and effect relationships or interactions concerning the functioning of a natural or designed system.	• Develop and/or use a model to generate data to test ideas about phenomena in natural or designed systems, including those representing inputs and outputs, and those at unobservable scales.	• Develop a complex model that allows for manipulation and testing of a proposed process or system. • Develop and/or use a model (including mathematical and computational) to generate data to support explanations, predict phenomena, analyze systems, and/or solve problems.