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The purpose of this primer is to encourage K-12 educators to use consistent and clear prompts structured around the crosscutting concepts to provide a common scientific language that students and teachers use as they engage in the formative assessment process.

USING CROSSCUTTING CONCEPTS TO PROMPT STUDENT RESPONSES

CCSSO Science SCASS Committee on Classroom Assessment

May 1, 2018

THE COUNCIL OF CHIEF STATE SCHOOL OFFICERS

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The Primer was developed by a team of state science leaders to support educators in understanding and developing formative assessment prompts aligned to three-dimensional student science performances. The prompts are connected to lesson components and instructional strategies are consistent with state standards and current research for science education.

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Purposes and Uses of the Primer

- *Support educators in developing formative assessment experiences that utilize crosscutting concepts to prompt student three-dimensional performances (audience is educators).*
- *Inform educators of what is meant by student science performances and the attributes of formative assessment.*
- *Provide examples of how 3-D student performances, aligned to state standards, can be situated within lesson components.*
- *Provide sample prompts and responses for each of the crosscutting concepts in sample student performances.*
- *As a rationale for using the crosscutting concepts to prompt student responses.*
- *As a tool to develop a series of briefs to share the premise of the Primer with teachers.*

CONTENTS

CONTEXT | THREE DIMENSIONS OF SCIENCE TEACHING AND LEARNING

Three Dimensions of Science Education

A Framework for K-12 Science Education (*Framework*), (NRC, 2012) and the *Next Generation Science Standards* (NGSS) (NGSS Lead States, 2013) present significant innovations for how students engage in science learning and, hence, how instruction should also change. The *Framework's* innovation of using three dimensions has led to significant changes in how standards and instruction are designed. The three dimensions of science education described in the *Framework* are science and engineering practices (SEPs), crosscutting concepts (CCCs), and disciplinary core ideas (DCIs). Science teaching should engage students in performances of science and engineering at the intersection of these three dimensions.

Science and Engineering Practices (SEPs)

The *Framework* presents a clear vision for using science and engineering practices as ways and means for engaging students in authentic applications of science and engineering. These practices present a structure for scaffolding scientific investigations and engineering design to ensure students are able to scientifically gather information and data, reason with that information and data, and communicate their reasoning to others.

The science and engineering practices are

1. Asking questions (science) and defining problems (engineering)
2. Developing models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Constructing explanations (science) and designing solutions (engineering)
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

Students use these practices to make sense of science phenomena, design solutions to problems to ultimately develop greater understanding of the natural world and determine how solutions to problems are engineered.

Crosscutting Concepts (CCCs)

Crosscutting concepts are the second dimension of the new vision for science education. This dimension provides cognitive structures upon which teachers and students can organize and unify the ideas of the science disciplines. The crosscutting concepts are useful tools for students to use in defining the systems of phenomena, seeking cause and effect relationships, and determining patterns that contribute to evidence-supporting practices.

The crosscutting concepts are

1. Patterns
2. Cause and effect
3. Scale, proportion, and quantity
4. Systems and system models
5. Energy and matter
6. Structure and function
7. Stability and change

The premise of crosscutting concepts is not new to K-12 science standards. During the past 20 years, the idea has appeared in several premier resources intended to help guide state science standards development. [See *National Science Education Standards (NRC, 1996)*, *Benchmarks for Science Literacy* (AAAS, 1993), and the *2009 NAEP Science Framework* (NAGB, 2008).]

Disciplinary Core Ideas (DCIs)

The third dimension of the vision includes the disciplinary core ideas. The core ideas in this dimension come from the American Association for the Advancement of Science (AAAS, 1993) *Benchmarks for Science Literacy* and the National Science Education Standards (NRC, 1996); however, now they are organized into larger ideas that progress across grade-bands. The reduction in the number and the shift in grain size of these ideas provides a significant advancement in science standards. Another significant innovation in the new vision is the way disciplinary core ideas are used by students. The ideas are used as evidence in scientific arguments and to support explanations. In the past, standards focused on students knowing core ideas; the new vision is for students to *use* core ideas to support science performances. Moving from students knowing *what* and *that* to understanding *how* and *why* science phenomena occur is central to the new vision.

The vision of the *Framework* is for students to use all three dimensions as tools to engage in student science performances for the purpose of making sense of phenomena and solving problems.

1 | USING CROSSCUTTING CONCEPTS TO ENGAGE STUDENTS

Crosscutting concepts are an important dimension in the *Framework*, *NGSS*, and state science standards aligned to the vision for science teaching and learning described in the *Framework*. This dimension provides a scaffold upon which teachers and students can organize the cognitive structures for unifying the science disciplines. What *is* new about the crosscutting concepts in the *Framework* is how they are featured as one of the three dimensions as required expectations for student performance.

Crosscutting Concepts Described in the Framework

1) ***Patterns*** – Observed patterns of forms and events guide organization and classification. Patterns prompt questions about the factors that influence cause and effect relationships. Patterns are useful as evidence to support explanations and arguments.

2) ***Cause and Effect*** – Mechanism and explanation. Events have causes, sometimes simple, sometimes multifaceted and complex. A major activity of science is investigating and explaining causal relationships and the mechanisms by which they are mediated. Such mechanisms can then be tested across given contexts and used to predict and explain events in new contexts.

3) ***Scale, Proportion, and Quantity*** – In considering phenomena, it is critical to recognize what is relevant at different measures of size, time, and energy and to recognize how changes in scale, proportion, or quantity affect a system's structure or performance.

4) ***Systems and System Models*** – Defining the system under study—specifying its boundaries and making explicit a model of that system—provides tools for understanding and testing ideas that are applicable throughout science and engineering.

5) ***Energy and Matter*** – Flows, cycles, and conservation. Tracking fluxes of energy and matter into, out of, and within systems helps one understand the system's possibilities and limitations.

6) ***Structure and Function*** – An object's structure and shape determine many of its properties and functions. The structures, shapes, and substructures of living organisms determine how the organism functions to meet its needs within an environment.

7) ***Stability and Change*** – For natural and built systems alike, conditions of stability and rates of change provide the focus for understanding how the system operates and the causes of changes in systems.

Crosscutting concepts are essential tools for teaching and learning science because students can understand the natural world by using crosscutting concepts to make sense of phenomena across the science disciplines. As students move from one core idea to another core idea within a class or across grade-levels, they can continually utilize the crosscutting concepts as consistent cognitive constructs for engaging in sense-making when presented with novel, natural phenomena. Natural phenomena are observable events that occur in the universe and we can use our science knowledge to explain or predict phenomena (i.e., water condensing on a glass, strong winds preceding a rainstorm, a copper penny turning green, snakes shedding their skin) (Achieve, 2016).

Rationale for Using Crosscutting Concepts to Prompt Student Responses

The crosscutting concepts provide a consistent language for teachers to communicate with students. When teachers' prompts are structured with the crosscutting concepts, the focus of student thinking can be directed to key aspects of the phenomenon, the system being investigated, and/or patterns that may be used as evidence to support explanations or arguments for the causes of a phenomenon.

Examples of possible teachers' questions that utilize the crosscutting concepts to focus students' thinking on making sense of phenomena include

- How do the components of a *system change* when more *energy* is added to the *system*?
- Why does adding heat energy to the *system cause* the observed *changes in the system*?
- How does the *proportion* of salt in the solution *affect* the movement of water into or out of cells of the carrot?
- How do the *patterns* in the data we collected help provide evidence that a mathematical relationship exists between the mass of a moving object and the energy that object transfers?

Teachers are responsible for helping students develop a structure to make sense of phenomena. Using crosscutting concepts to focus student thinking creates a productive way to help students focus their thinking on specific aspects of a phenomenon (e.g., proportion of salt in water, scale of thickness of crust compared to diameter of Earth, flow of energy into or out of the system of a chemical reaction). The crosscutting concepts become powerful when used as familiar touchstones of language initially by the teacher to prompt science performances and then by students to reason with and communicate their reasoning for the causes of phenomena.

Understanding student thinking requires a variety of different strategies to make thinking visible. The structure of prompts can have significant impact on the degree to which student thinking is developed and made visible to inform current or future instruction. The structure of the prompt(s) can focus students' attention on responding in multiple ways that help acquire evidence required to support an explanation and/or argument for why or how a phenomenon occurs. The prompt should provide a clear expectation for students to respond with evidence for the cause(s) of the phenomenon.

When teachers prompt students with **crosscutting sentence stems**, they should always be followed with the expectation that students support their responses with evidence. It is important to use the crosscutting concepts to support reasoning structures for students to use in responding to teacher prompts. Examples include

- The *cause* of _____________ was _____________.
  Evidence to support my explanation for the causes of the phenomenon is ____________.
- The *changes* in the *system* were caused by increasing the flow of *energy* into the *system* from _____________.
  Evidence to support my explanation is _________________.
- The phenomenon of _____________ is *caused* by _____________.
  Evidence to support this explanation (claim) is ______________.
- The *proportion* of hydrogen ions in the solution *causes* a *change* in the rate of _____________ change in the chemical reaction.
  Evidence to support the explanation is how _____________ *changes* the rate that _____________ *changes*.

Additional examples of crosscutting concept prompts for assessment may be found here:

http://learndbir.org/resources/CrosscuttingConceptsPrompts-160822.pdf (Penuel and Van Horne, 2018. When students understand the expectation is to communicate the cause and effect relationships of phenomena and provide evidence to support their reasoning, they are more likely to communicate effectively. Explicit emphasis on clear expectations for student performances in the science classroom should never be underestimated.

When teachers utilize consistent language of crosscutting concepts to prompt students, the result is students using crosscutting concepts to accurately communicate their own reasoning (see Figure 1.1). Students use the language the teacher accurately and consistently uses (Moulding & Bybee, 2017).

How can the crosscutting concepts be organized by the function they play in reasoning?

Organizing the seven crosscutting concepts into 1) Causality, 2) Systems, and 3) Patterns supports conceptual understanding for teachers and students. As students explore phenomena, they are seeking **patterns** to support explanations for the **causes** of changes in **systems** in terms of matter, energy, stability, scale, and proportion.

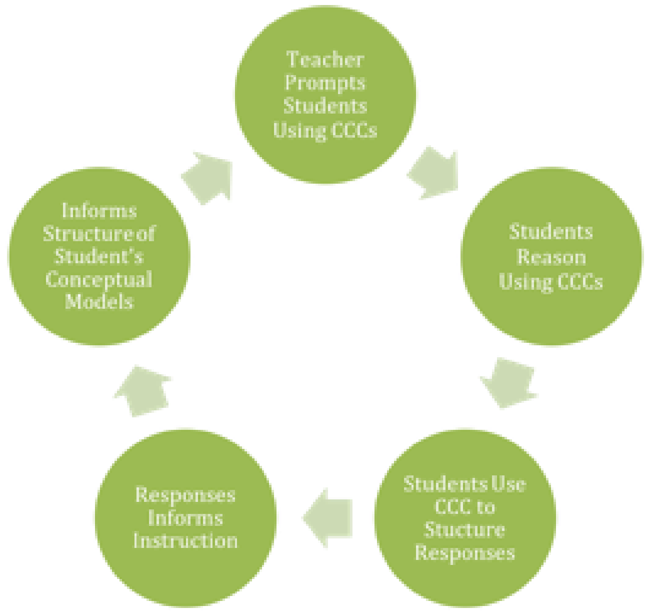


Figure 1.1: Teacher Prompts Using Crosscutting Concepts Lead to Student Responses Using Crosscutting Concepts (Moulding & Bybee, 2017)

The role of crosscutting concepts in teaching and learning

Using causality, systems, and patterns is an effective way to organize the crosscutting concepts in a way that helps both teachers and students to more effectively make sense of phenomena (see Figure 1.2). Crosscutting concepts can be used to structure questions specific to causality, systems, and patterns that prompt students to make sense of phenomena. Below, sample prompts are shared that focus on causality, systems, and patterns that allow students to make sense of the following phenomenon, *"Water appears on the outside of a glass of iced tea."*

Causality

Looking for **causality** is essential to science. Students should have an explicit understanding that constructing explanations of the causes of phenomena are at the center of understanding the natural world and in solving engineering problems. Hence, science learning should center on students engaging in science and engineering practices that focus on making sense of the cause(s) of phenomena and/or the cause of one engineering design solution working better than another. If students can explain the causes using evidence, then they can better demonstrate their understanding of the world around them and provide explanations of how or why one engineered solution is better than another. Cause and effect as well as structure and function relationships should be used to initiate student reasoning.

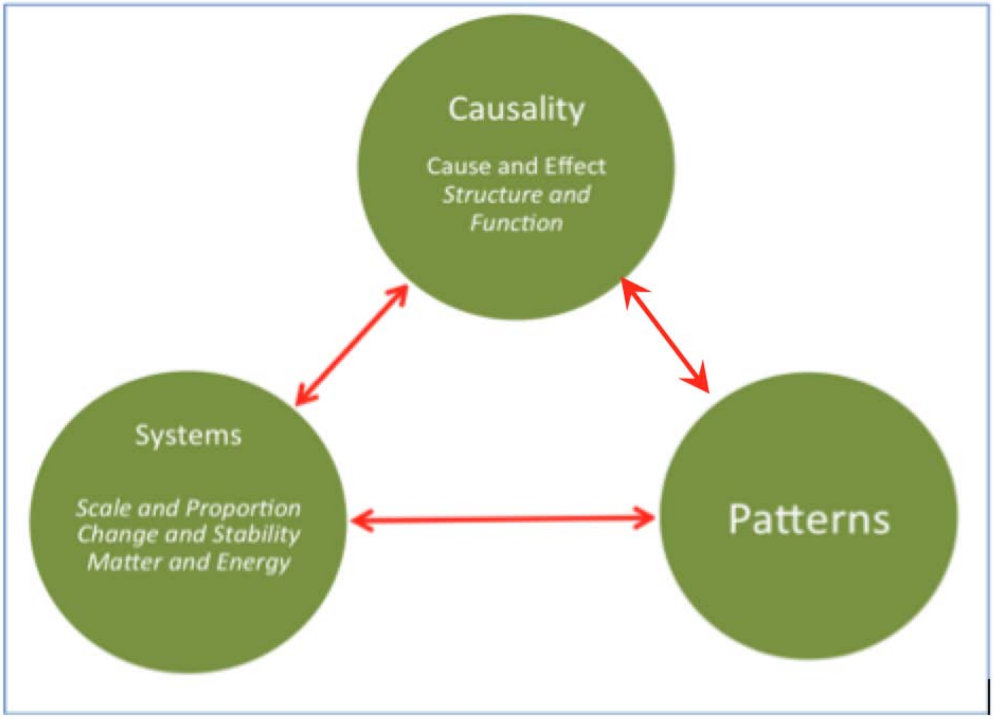


Figure 1.2: Organizing the Crosscutting Concepts by Function (Moulding et al., 2015)

Sample questions using *causality* to prompt students' reasoning about the phenomenon of water condensing on a glass of iced tea follow:

- *What causes the water to appear on the outside of the glass of iced tea?*
- *What causes more water to appear on some days than others?*
- *How are the causes of water appearing on the glass related to clouds forming in the sky?*
- *How does the structure of the water molecules function to form drops on the glass of iced tea?*

The teacher might prompt students with a question such as, "*What causes the water to form on the glass?*" and the student might respond with, "*Energy is flowing from the water particles in the air to the cold glass causing the water to change from a gas to a liquid that collects on the glass.*"

Systems

Defining and using the concept of **systems** provides a way for students to logically analyze the boundaries of the phenomenon and describe the interactions occurring within the **system,** the relationship of the **system** being investigated to surrounding **systems,** and the causes of changes in the **system.** To investigate the cause of this phenomenon, students need a clear understanding of the **system** and interactions among components in this **system**.

Sample questions using *systems* to prompt students' reasoning about the phenomenon of water condensing on a glass of iced tea include

- *How is energy flowing and matter changing in the system?*
- *What causes the matter to move into and/or out of the system?*
- *How can you use a model to show how energy is flowing into or out of the system?*
- *At what point in time will the system become more stable?*

The teacher might prompt students with a question such as, *"How does the proportion of water vapor (gas) in the air affect the rate that water condenses on the glass?"* and the student might respond with, "*The greater the proportion of water vapor in the air, the greater the rate water condenses on the outside of the glass."*

When instruction supports students using the crosscutting concepts of scale, proportion, and quantity, or stability and change, students are able to make sense of the interactions within and among systems.

Patterns

Students are good at observing and recognizing **patterns** (e.g., in data, in phenomena, in systems, frequency of observed changes, seasonal **patterns** of change). When instruction makes the crosscutting concept of patterns explicit, students become skilled at using **patterns** as evidence in science performances (e.g., using **patterns** as evidence for the cause of a phenomenon being investigated, supporting assertions, explanations, and/or scientific arguments). Students have successfully used **patterns** as evidence when they can accurately identify a **pattern** and use this **pattern** as evidence to support an explanation of the causes of the phenomenon. Often, phenomena are observable **patterns** occurring in nature (e.g., clouds often form near mountain tops, trees are smaller at higher elevations).

Sample questions using *patterns* to prompt students' reasoning about the phenomenon of water condensing on a glass of iced tea include

- *What patterns in the rate of condensing of water were observed?*
- *How does the pattern of where water first condenses on the glass relate to why water condenses on the glass?*
- *Why do patterns exist between humidity and the amount of water condensing on the glass?*

The teacher might prompt students with a question such as, *"What patterns exist between the amount of the water forming on the glass and the weather?"* and the student might respond with, "*When the weather is humid, the rate of the water condensing on the glass increases; this pattern is evidence that the water comes from water vapor in the air."*

When instruction supports students in using the crosscutting concept of patterns for evidence to support explanations, students are better able to make sense of the conditions necessary for the phenomenon to occur.

Coupling Crosscutting Concepts

Crosscutting concepts are powerful ways to focus students' attention on key aspects of science phenomena. One way to enhance the use of crosscutting concepts is to use them in pairs or series to focus students' attention of the causal relationships in phenomena. Examples include

- How did energy into the *system cause changes* in the *system* overall?
- How does the *proportion* of salt in the solution *affect* the transfer of water across the cell membrane?
- Why can some geological *changes* only be observed on a time *scale* of millions of years?
- Why does a *pattern* exist in the *changes* in numbers of some native species of birds and some invasive species of birds, but not all native species of birds?
- What *patterns* were observed in the composition of dye solutions that were *stable* compared to the dye solutions that were *unstable* when each was exposed to sunlight?
- How does *changing* the concentration of lead in the water *affect* the *proportion* of fish in the population that die?

Coupling practices with *crosscutting concepts* tends to move the teacher's prompt to the category of a student performance expectation. Examples include

- Construct an explanation for how the flow of energy into the system described by the water cycle *causes* water to *change* state.
- Develop a model to show how *matter* cycles and *energy* flows during the processes of photosynthesis and cellular respiration.
- Analyze data of the motion of falling objects to find *patterns* in the rate of *change* to find a mathematical relationship to predict the motion of other objects.

2 | STUDENT SCIENCE PERFORMANCES

Student science performances are a way to describe how students engage in the practices using crosscutting concepts and core ideas to make sense of the causes of phenomena. These performances should be described within lesson plans or assessment prompts. Formative assessment is one way to focus learning by providing descriptions of the attributes of proficient student performances across the practices, crosscutting concepts, and core ideas.

2a. Importance of Using Phenomena to Engage Students

Science phenomena are observable events that occur in the universe and that we can use our science knowledge to explain or predict. The goal of building knowledge in science is to develop conceptual understanding based on evidence to explain and predict phenomena. Engineering involves designing solutions to problems that arise from phenomena and using explanations of phenomena to design solutions. In this way, phenomena are the context for the work of both scientists and engineers (Achieve, 2016).

Despite their centrality in science and engineering, phenomena have traditionally been a missing piece in science education, which too often has focused on teaching general concepts and ideas that students have not experienced applying to real world contexts. Focusing students' learning on constructing explanations for the causes of phenomena supports their abilities to use science and engineering concepts and ideas. This approach enables students to know "Why do I need to learn this?" before they know what "this" is. Phenomena provide a context for learning and serve as a context for understanding the importance of learning science ideas to apply to the world in which students live.

It is important that **ALL** students are supported in working with science phenomena that are engaging and meaningful to them. Students bring different knowledge, backgrounds, and interests to a specific phenomenon. Educators should consider students' perspectives when choosing phenomena and prepare to support students' engagement in different ways. While starting with one phenomenon in the classroom, it is always a best practice to have all students identify related phenomena from their lives and communities to expand the phenomenon under consideration.

For example, when teaching toward the Kindergarten Performance Expectation K-PS3-1 about how sunlight warms the surface of the Earth, a teacher could notice that students don't have experience with hot sand and instead engage the group in observations of hot concrete or asphalt on the school playground. When necessary, teachers can engage the class in shared experiences with a relevant phenomenon (i.e., watching a video, virtual field trip, field study, discourse, investigations, engineering design solutions).

Centering science teaching and learning on phenomena students are motivated to investigate shifts the focus on learning from simply learning about a topic or fact to figuring out why or how something happens. For example, instead of simply learning about the topics of photosynthesis and mitosis, students are engaged in building evidence-based explanations for the causes and mechanisms for how trees grow and accumulate matter. Explaining phenomena and designing solutions to problems allows students to build generalizable ideas in the context of applying ideas and concepts to understanding phenomena in the real world. This approach to learning leads to deeper and more transferable knowledge.

2b. Gather, Reason, and Communicate Science Performance Sequence

Student science performances consist of students engaging in science at the intersection of the three dimensions (i.e., science and engineering practices, core ideas, crosscutting concepts) to make sense of phenomena (see Figure 2.1). Science performances are the "doing of science." When students engage in science and engineering practices, they use core ideas and crosscutting concepts to support the science performance. A useful way to organize the performances is through the sequence of 1) gathering information; 2) reasoning with the information; and 3) communicating the reasoning (see figure 4). Each of the three components of the Gather, Reason, Communicate (GRC) sequence provides opportunities for students to engage in science performances and for teachers to use crosscutting concepts as prompts to make students' thinking visible and assess learning (Moulding et al., 2015).

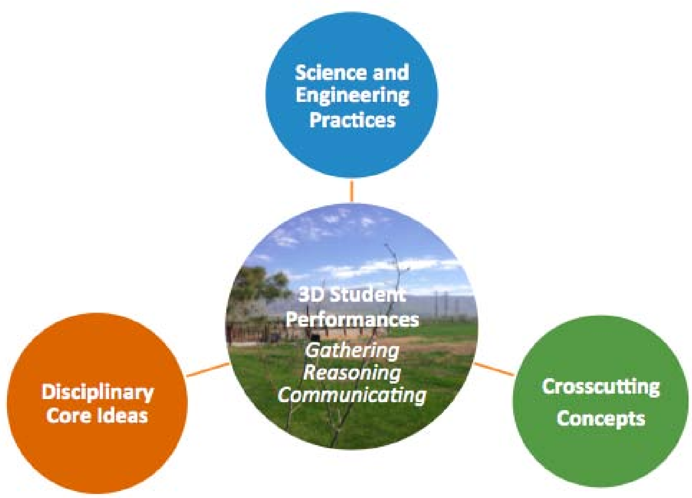


Figure 2.1: Three Dimensions of Student Science Performances (Moulding & Bybee, 2017)

Gathering performances generally engage students in obtaining information from text, other people, models, and/or investigations. Often the practices associated with gathering (see Figure 2.2) also require students to reason to determine if the information is valid and/or from a reliable source. Students' observations and measurements during investigations are part of the gathering component of the performance. When students use models such as charts or tables to organize information, they are in the gathering portion of the performance. Another way for students to use models for gathering includes using models such as the relative position of the Earth, moon, and sun to gather evidence for the observed phases of the moon. The gathering performances provide a natural integration with the receptive modalities (i.e., reading, listening, writing, speaking (interviewing)) of language arts. Careful observations and attention to detail become critical components of gathering through investigations. Nature walks and experiences outdoors provide students with opportunities to hone observation skills and knowledge of gathering.

Focusing students on the patterns they observe in nature and/or causes of the phenomenon they see provides a structure for prompting students to gather evidence that is relevant to the cause of phenomena. When students are gathering information from texts, models, and/or investigations, it is important to focus students on the boundaries of the system they are studying and/or how the interactions among the components of the system affect the function of the system. When students plan and carry out investigations, the purposes should be clearly related to gathering data and/or information for the causes of changes in systems, the relationship of the structure and function of systems, and/or how the scale, proportion, or quantity of the components of the system affect the way the system operates. Prompting students with crosscutting concepts focuses their thinking on the cause of the phenomenon being investigated.

Reasoning performances generally engage students in connecting phenomena to causes. Some reasoning performances focus on evaluating and analyzing information, but the central reasoning performances focus on connecting observations, core ideas, and/or crosscutting concepts to explanations and/or arguments for the causes of phenomena. The reasoning performances focused on analyzing information and/or data generally engage students in using mathematical tools to find patterns in the data. Most reasoning performances should center on students developing the relationship of evidence to explanations and argument. Arguments should engage students in evaluating the strength of how and/or why the evidence supports or refutes an explanation. The reasoning performances provide opportunities to use the crosscutting concepts with prompts such as, "How do the observed patterns provide evidence of the causes of changes in the system?" or "How do changes in the structure of the system affect the way the system operates?"

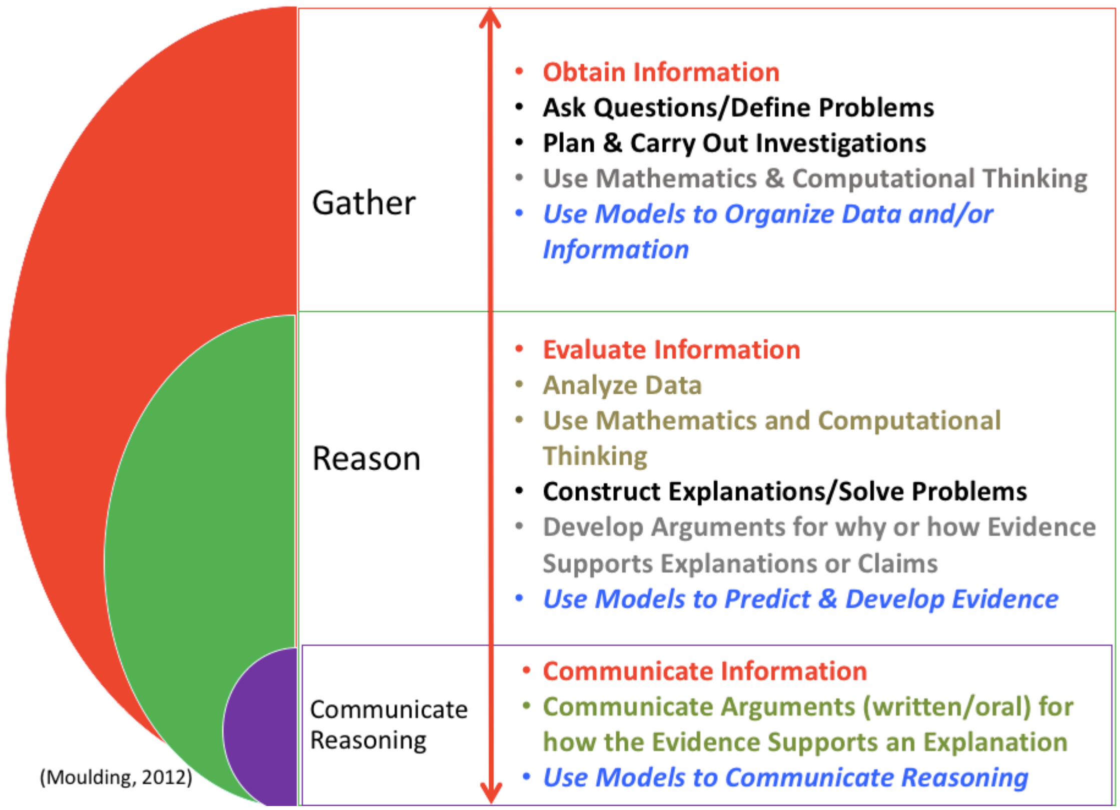
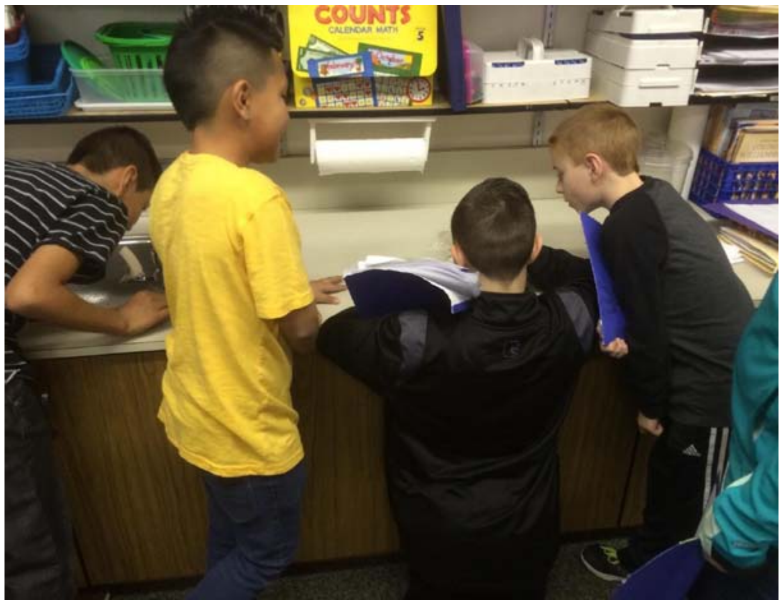


Figure 2.2: Gather, Reason, Communicate Sequence (Moulding et al., 2015)

Communicating performances includes writing, speaking, using models, and presenting arguments to communicate reasoning. The key to effective communication in science is using evidence to support explanations and arguing why or how the evidence supports the explanation. For example, students might use models of the Earth, moon, and sun to communicate the causes of the observed patterns in the moon phases or solar and lunar eclipses; but more importantly by communicating their thinking, students have the opportunity to reflect on their own reasoning for the causes of the phenomenon observed. Communicating performances are often underrated and yet critical in science teaching and learning. These performances provide opportunities to formalize students' reasoning and provide teachers with insights into student thinking. Prompting the communication performance with crosscutting concepts directs the students' presentation of their reasoning and provides the teacher with a clear focus for evaluating student learning (e.g., students provide a rationale for why the pattern is evidence for the causes of changes in the system, students provide a clear description of the structure function relationship among the components of the system, students show how the proportion of one component of the system affects how the system operates).

As students participate in science performances and develop conceptual models, it is important for them to try to represent their own ideas and models in meaningful ways (i.e., explanations, pictures, labels, 3-D representations, writing, mathematical formulas).

Prompting students with crosscutting concepts helps structure and focus their responses which helps the teacher better understand their thinking. In this way, the prompts become diagnostic and bring to light inaccuracies in student thinking so students can revise their models in light of new understandings. Often, students need to do this to integrate new core ideas or principles into their existing conceptual models (Moulding et al., 2015; Moulding & Bybee, 2017).



2c. Assessing Student Performances

Student learning can only be assessed when students make their thinking visible. This is most clearly done when students write, speak, act out their thinking, and/or develop models. Instructional sequences have multiple places where the teacher can assess students' science proficiency by prompting a specific performance. Crosscutting concepts can be used to focus the desired student's performance to specific aspects of the phenomenon.

Regardless of the assessment type or purpose, the practices describe what the student is doing in the performance (e.g., developing a model, constructing an explanation, analyzing data). The crosscutting concepts within a performance can be used to focus students on specific aspects of the phenomenon (e.g., changes in systems, causes of changes, flow of energy into the system). When practices are coupled with crosscutting concepts, the performances strategically focus the actions of the student. A performance such as, "Develop models of the flow of energy into or out of the system," provides direction for the students' performance and can be used as the criteria to determine students' proficiency. In this performance, the criteria are stated within the performance – develop a model showing the flow of energy from one system to another. This makes the prompt an assessable performance.

Student science performances happen whenever students engage in making sense of phenomena; however, when the three-dimensions of the performance are used to direct the performance, the criteria of the performance are more clearly defined for both the student and teacher. Clearly defining the performance with the three dimensions allows the student to better reflect on his/her performance and the teacher to know the degree to which specific aspects of the performance are proficient.

During the teaching and learning process, assessing learning should be continuous; however, unless the students' thinking is made visible through performances in which the students communicate by speaking, modeling, acting out, or writing, the students' performance cannot be assessed. In any student science performance, there are always opportunities where the students' reflection on the reasoning they are using to make sense of phenomenon is assessable. Each of the dimensions should be included as criteria for the assessment.

3 | ATTRIBUTES OF FORMATIVE ASSESSMENT

Structuring student thinking with crosscutting concepts is useful since these concepts appear across all science disciplines. Crosscutting concepts can prompt rich student responses to provide evidence of student understanding for the formative assessment process.

Three-Dimensional Assessment Systems

The Framework for K-12 Science Education includes classroom assessment as part of the overall system of science assessments (National Research Council, 2014). The assessment pyramid (Figure 3.1) shows types and frequencies of a balanced assessment system, which fits within a larger context of teaching and learning. It emphasizes that ongoing formative feedback is the foundation of effective classroom instruction.

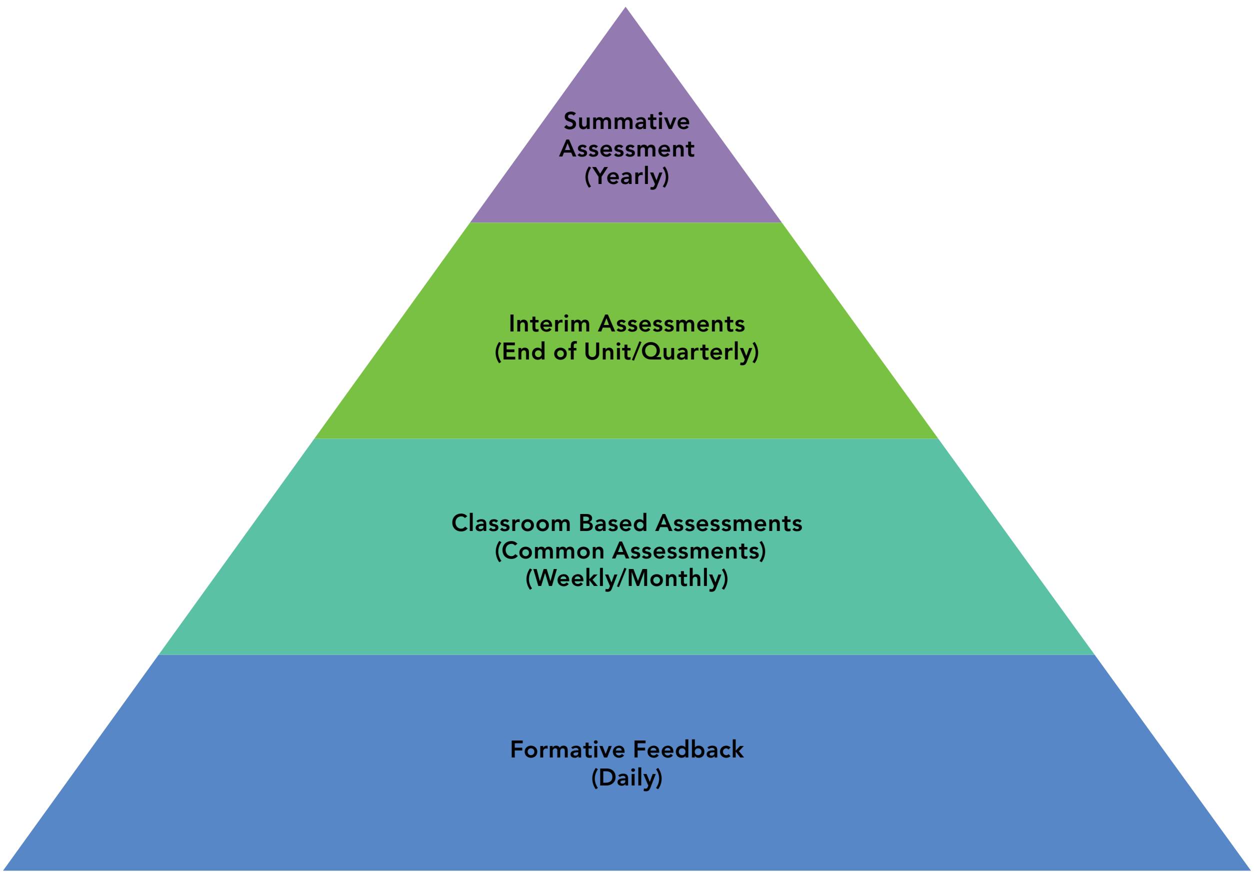


Figure 3.1: Balanced Assessment System Pyramid (NRC, 2014)

Classroom-based assessments can be summative or formative in nature. Formative assessment a) is administered during the course of instruction, b) has the purpose of identifying the strengths and limitations of students' work, c) assists teachers in planning upcoming instruction, and d) informs the learner and guides their own learning through self-assessment and reflection (Cizek, 2010). As part of a broader system of assessment for three-dimensional science standards, the formative assessment process should clarify intended learning for students, elicit evidence of student understanding, and have teachers and students interpret and act on evidence.

What is Formative Assessment?

The Formative Assessment for Students and Teachers (FAST) State Collaborative on Assessment and Student Standards (SCASS) group developed a definition of formative assessment as "a process used by teachers and students during instruction that provides feedback to adjust ongoing teaching and learning to improve students' achievement of intended instructional outcomes" (CCSSO, 2008). The CCSSO (CCSSO, 2013) FAST SCASS identified five attributes of effective formative assessment, including

- learning progressions that clearly articulate the subgoals of the ultimate learning goal;
- learning goals and criteria for success clearly identified and communicated to students;
- descriptive feedback provided to students with evidence-based feedback linked to the intended instructional outcomes and criteria for success;
- self- and peer-assessment; and
- collaboration that engages students and teachers as partners in learning.

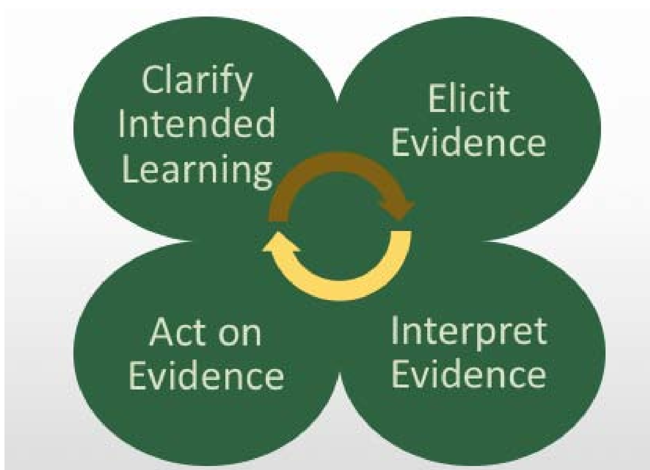


Figure 3.2 Four Steps of Formative Assessment

The National Advisory Panel of the Smarter Balanced Digital Library described formative assessment as "a deliberate process used by teachers and students during instruction that provides actionable feedback used to adjust ongoing teaching and learning strategies to improve students' attainment of curricular learning targets/goals". The formative assessment process as defined by the Smarter Balanced Digital Library includes the following steps (Figure 3.2):

- clarify intended learning;
- elicit evidence;
- interpret evidence; and
- act on evidence.

When clarifying the intended learning educators would develop learning goals and defining success criteria for the student. Educators would elicit evidence by interacting with students through questioning, observations, and reviewing student work and responses. Evidence would then be interpreted, looking for possible explanations for gaps, misconceptions, or procedural errors. Finally, educators and students would act using the information garnered from the process. Formative assessment is a deliberate, iterative process. Once educators and students have had a chance to interpret results of elicited evidence, what should happen next? The process informs necessary instructional responses and changes are enacted. (See http://stemteachingtools.org/PD/SessionA in Resources)

Generally, formative assessment

- is a process, not an event (Heritage, 2011);
- takes place as students are progressing through learning progressions with shared clear goals and success criteria;
- involves students in the process (Stiggins, 2009) through self- and peer-assessment;
- includes descriptive feedback to students with opportunities for self-assessment (Black & Wiliam, 1998); and
- allows educators to adjust instruction based on evidence of student understanding.

3a. Culturally Relevant Science Assessment

Why should we make formative assessment culturally relevant?

Equity as defined in the *Framework* should be a focus of any effort to improve learning outcomes for students. Achievement gaps in science persist and utilizing culturally relevant formative assessment strategies allows educators to address the learning needs of all students. Formative assessment is most effective when students are engaged in the context of science phenomena and attending to culturally inclusive strategies is an effective way to accomplish this goal.

How do we make formative assessment a culturally relevant endeavor?

The *Framework* describes how science instruction should build on students' interests and backgrounds through inclusive practices including recognition that learning is a cultural endeavor, discourse strategies to engage all students, experiences that build on interest and identity, and learning experiences that reflect students' cultural funds of knowledge. In the formative assessment process, it is crucial to recognize and value the many ideas that students have and the various cultural ways of knowing and making sense of the world. Figure 3.3 provides strategies for cultural responsiveness specific to the four steps of the formative assessment process.

3b. Students' Abilities to Reflect on Their Own Learning

The formative assessment process provides students with opportunities to reflect on their own learning. Actionable feedback from the teacher, peers, and self-assessment is an important component of learning. Students should be provided with opportunities and structures for reflecting on feedback from others to support the ongoing process for adjusting their own learning. A number of strategies have proven to be effective at facilitating student reflection including reflection journals, small group discussions, and written prompts.

Formative Assessment Process	Strategies for Cultural Responsiveness
Clarifying Intended Learning	• Start with a locally relevant phenomenon to engage students' interest and experiences. • Consider using place mapping to reflect community assets and leverage cultural funds of knowledge. • Use terms that are culturally neutral and that all students will understand.
Eliciting Evidence	• Consider how students from different cultural backgrounds might express an idea. • Provide all students with multiple methods and opportunities for demonstrating understanding. • Have students develop and revise models. • Recognize different ideas to signal to students that their ideas are valued.
Interpreting and Acting on Evidence	• Recognize the diverse ways students from different cultural backgrounds might express an idea. • Recognize that the ideas students share are valuable and can be built upon, rather than identifying them as incorrect or misconceptions. • Consider using an approach to identify themes in student thinking, such as Facets (Minstrel, 2000).
Involving Students Throughout the Process	• Use discourse as a formative assessment strategy. • Allow opportunities for students to share and refine their thinking with peers and engage in sense-making and peer feedback.

Figure 3.3: Formative Assessment Process and Cultural Responsiveness

3c. Measuring Three-Dimensional Learning

The *Framework* emphasizes the importance of classroom-level assessment, including formative assessment. To realize the vision of assessment consistent with the *Framework*, formative assessment must assess three-dimensional performances holistically and each of the three dimensions. Formative assessment provides evidence of what students are able to know and do and direction for adjusting teaching and learning in the Science and Engineering Practices, Disciplinary Core Ideas, and Crosscutting Concepts.

As students engage in the formative assessment process, language should reflect three-dimensional learning. Assessment should move away from using "depth of knowledge" words like "identify" and "describe" toward the language of the three dimensions, especially crosscutting concepts and practices. The language of the dimensions can frame the evidence of where students are in a progression of learning along the three dimensions. This evidence allows teachers to guide instruction and students to engage in thinking in more complex and sophisticated ways.

4 | CROSSCUTTING CONCEPTS AND STUDENT SCIENCE PERFORMANCES

Crosscutting concepts provide structure for students' reasoning about the causes of phenomena. Formative assessment prompts that use crosscutting concepts to structure questions can focus students' attention on key aspects of a phenomenon (e.g., flow and conservation of energy in the system, changes in the system, conditions for stability of a system) that help them make sense of the phenomenon.

Crosscutting concepts generally work together to provide clarity in making sense of phenomena (e.g., causes of changes in systems, proportion of solute in solution affects the movement of water across a membrane, flow of energy into the system, cycling of matter within the system). Focusing students on one aspect or a series of attributes of a phenomenon helps them seek evidence about the cause and/or changes in the phenomenon. The Earth sciences often focus on the causes of changes and/or stability of systems and/or structures. Focusing students on these key crosscutting concepts (in green) is a way to stimulate and organize their reasoning. For example, the formation of the Colorado Plateau resulted in layers of sandstone that *changed* over time. The *changes* lead to the various features of landforms and *structures* in the rocks (e.g., arches, hoodoos, canyons). Each of these features has a *cause* and the *changes* to *structures* are ongoing. Focusing students on the *causes of changes in the structure* of the Grand Canyon provides structure and focus for student reasoning.

4a. Patterns – Sample Prompts and Responses

Patterns are all around us, from the change in seasons to the stripes on a garter snake. Children begin recognizing patterns at an early age and utilize their observations of patterns to make meaning of the world, classify objects, and identify cause and effect relationships. The *Framework* describes this crosscutting concept as, "*Observed patterns of forms and events guide organization and classification, and they prompt questions about relationships and the factors that influence them.*" (p. 84).

Patterns can be used as powerful prompts to elicit student thinking. For example, in a lesson about animal behavior, patterns can be observed in flocking birds (see Appendix A). Students watch a series of videos of starlings flying in unison at dusk, a phenomenon called murmuration. Through a series of discussions and observations, students develop a model of the patterns of the starlings' animal behavior. Students utilize computer simulation models, video footage, nonfiction texts, and possibly observations in the field to validate their explanations. Identifying patterns helps scientists to identify phenomena and predict general outcomes. These patterns may start simplistic and build to become more complex throughout a school year and from grade to grade.

Sample prompts to initiate student's reasoning about patterns are usually connected to other crosscutting concepts when exploring phenomena. Examples of these prompts include

- What *caused* the *pattern* to *change*?
- How are *patterns* similar across multiple *systems*?
- Given enough time, will the *pattern* change or be *stable* over time?
- What are the *patterns* you observed between the *matter* and *energy* in the *system*?

In science, patterns are most often used as evidence to support reasoning. Coupling patterns with specific practices is important in prompting student performances. Examples include

- Analyze data to find *patterns* across multiple data sets.
- Construct an explanation supported by evidence of observable *patterns* in bird migration.
- Develop an argument for how and/or why the *patterns* in the data support the explanation of the *causes* of *changes* in the behavior of the flock.

The way teachers use prompts to direct students' learning has a significant effect on their responses, but more importantly on the structure of reasoning. It is important to use language that directs students to not only seek patterns, but also in using the patterns as evidence. Coupling crosscutting concepts and practices in meaningful ways is essential for quality assessment. Figure 4.1 provides sample prompts using patterns related to the lesson on birds' flocking behavior in Appendix A.

Phenomenon: Often near dusk, flocks of starlings can be seen flying in tight formation; the whole flock appears to fly in unison.	
Possible Prompts	**Possible Student Responses**
• What causes the *changes* in the *pattern* that results in the behavior of starling murmuration?	• The *causes* of birds flying in *patterns* is for increasing chances of survival. They are able to communicate among the birds in a flock to change the *pattern* in response to the environment.
• How does the *pattern* murmuration *change* when predators such as falcons approach?	• The birds continue to fly in *patterns,* but the *pattern* moves away from the approaching predator.
• Why is the *pattern* of starling murmuration **not** always observed when the birds are flying together?	• The *pattern* of murmuration is related to seasonal migration *patterns* and birds are not always migrating. Some species of birds do not exhibit this behavior at all.

Figure 4.1: Prompts for the Lesson, "Birds of a Feather Flock Together" in Appendix A Using Patterns to Initiate Student Responses

4b. Causality (Cause and Effect & Structure and Function) – Sample Prompts and Responses

Science phenomena have causes, even if those causes are not initially known to the students. Understanding causality is an important component of any student science performance. When teachers design prompts to elicit student reasoning, it is useful to include causality within the prompt. Teachers should explicitly plan ways to engage students in gathering evidence to support explanations for the causes of a phenomenon. Students' understanding of causality is the key to making sense of phenomena. Causality is the central crosscutting concept and should be integral to every student science performance. Using causality as a prompt should underlie most or all prompts. Causality prompts are most useful when used within a series of crosscutting concept prompts that engage students in reasoning.

Cause and Effect

The *Framework* describes "*cause and effect as events have causes, sometimes simple, sometimes multifaceted. A major activity of science is investigating and explaining causal relationships and the mechanisms by which they are mediated. Such mechanisms can then be tested across given contexts and used to predict and explain events in new contexts.*" (NRC, 2012. p. 84)

Structure and Function

The *Framework* describes "*structure and function as the way in which an object or living thing is shaped and its substructure determines many of its properties and functions.*" (NRC, 2012. p. 84)

Science instruction helps students develop habits of mind that lead them to regularly formulate questions about causal relationships for phenomena they may encounter (e.g., What caused the caterpillar to change into a butterfly? How does the tree respond as the seasons change? What causes water to always run downhill? What causes birds to fly in flocks?). Learning science is strongly related to students wondering about what causes something to happen. Instruction should make explicit that science is seeking cause and effect relationships, but more important is engaging students in wondering and seeking explanations for the causes of phenomena they encounter (Moulding et al., 2015).

Prompts that focus on the cause of a phenomenon are often initiated with "why" questions. Prompts that focus on the mechanisms for a phenomenon are often initiated with "how" questions. Examples of prompts using "why" and "how" questions to initiate students' reasoning about phenomena with possible student responses are provided in Figure 4.2 below:

Phenomenon: Often in the morning the grass is covered with water.	
Possible Prompts	**Possible Student Responses**
• Why does water change from a gas to a liquid on a cold morning resulting in dew appearing on grass? • How does the flow of energy out of the system affect the number of molecules of water changing from a gas into a liquid?	• *Not appropriate for elementary as stated (matter and energy in the 3-5 band does not expect explanations as stated in the Framework).* • *Middle School – On a cold morning the gas water particles slow down causing the water to change from a gas to a liquid.* • *The loss of energy (colder temperatures) causes more gas water particles to change into liquid water.* • *Water as a liquid has less energy than water as a gas. Matter with lower temperatures has less energy than matter at higher temperatures.* • *High School – As the temperature falls on a cold morning, energy is transferred from the system of water molecules to the surrounding system causing the gas water molecules to slow down and change (condense) into a liquid dew on the grass.* • *As more energy is removed, fewer molecules of water are able to stay in gas form and so more liquid water appears on the grass.* • *Energy is moving from one system to another and the total quantity of water molecules in the air and on the grass is the same.*
SEE APPENDIX C for more examples of prompts and student responses.	

Figure 4.2: Prompts Using "Why" and "How" to Initiate Student Responses

Formative Assessment within Lesson Structures

Formative assessment is best situated within well-planned instruction. Four lessons appear in Appendix A and feature embedded prompts using crosscutting concept prompts. Appendix C provides examples of expected responses from students to the teacher's crosscutting concept prompts.

In the example in Figure 4.3, students observe a straw inside a bottle. They notice that the section of the straw that is in the water looks larger than the section that it is above the water and the straw appears to be broken at the interface between water and air. The students are asked to plan and carry out an investigation to gather evidence to support a claim about how light interactions with matter explains the phenomena observed [A cause-effect relationship]. The success criteria set by the teacher for the lesson is that students will identify patterns in their observations by creating a data table that allows them to make a cause effect claim describing the interactions between light and matter [Assessment Component].

Students are prompted by a series of questions to think about their observations in ways that allow them to construct explanations based on the gathered evidence, core ideas, and patterns in observations. Figure 4.3 provides sample prompts using causality related to the lesson on refraction of light in Appendix A.

Phenomenon: A drinking straw appears to be bent and larger when it is placed in a bottle of water.	
Possible Prompts	**Possible Student Responses***
• What *causes* the straw to look different above and below the liquid?	• The *causes* of the straw looking different above and below the water are due to how light is refracted differently in air and water.
• Why does *changing* the density of the fluid *affect* how light moves through the liquid?	• When light interacts with matter it is changed causing it to change speed. The density increases the amount of matter the light interacts with and so how the matter effects the path of light depends on the density of the liquid it is traveling through.
• How are properties of light *affected* by its interaction with matter?	• The interaction of light with matter *causes* the velocity and wavelength of the light to *change,* but not its frequency. The *changes* in the light wave *cause* objects to bend.
• What *patterns* do you see that can be used as evidence that light behaves differently as it travels from one medium to another?	• The *change* in the appearance of the object is *caused* by differences in the densities of the liquids the light passes through; the *pattern* we see from the investigation is that the denser the liquid, the more the object appears to be bent.

Figure 4.3: Prompts for the Lesson, "Refraction of Light" in Appendix A Using Causality to Initiate Student Responses

When students share their explanations and arguments for the evidence supporting their explanations, they engage in peer review. This provides the learner with both peer- and self-assessment feedback to support reflections on their own learning.

4c. Systems (Scale and Proportion, Change and Stability, and Matter and Energy) – Sample Prompts and Responses

Scientists use systems to define the parameters of the phenomena they investigate. Therefore, aspects of science phenomena are investigated and observed through the lens of systems. In order for students to analyze the effects of change and control variables of an investigation, the parts of the system must be defined. When observing patterns, identifying the system components allows for the creation of explanations how and/or why the system functions in predictive ways.

Systems and System Models

Defining the system and/or systems being investigated is a useful strategy for focusing students' attention on the ways a phenomenon operates. The *Framework* describes the crosscutting concept of systems and system models as, "*Defining the system under study—specifying its boundaries and making explicit a model of that system—provides tools for understanding and testing ideas that are applicable throughout science and engineering.*" (NRC, 2012. p. 84)

Using the crosscutting concept of systems provides students with a way to focus on the interactions of the components of systems and the concepts that define the system. These concepts and/or attributes of systems include a) energy and matter, b) scale, proportion, and quantity, and c) change and stability.

Students' understanding of systems is critical to making sense of science phenomena. Describing a system in terms of change and stability provides us with insights into the causes of change. All things change given enough time; hence, systems are not stable over very long timeframes. The repeating pattern of cyclic change, such as the moon orbiting Earth, can also be seen as a stable situation, even though it is clearly not static. Such a system has constant attributes, such as the distance from Earth to the moon, the period of its orbit, and the pattern of phases seen over time; however, on a much longer time scale, these too will change as the moon moves slowly away from Earth, the orbit slows, and patterns change.

Systems should also be described in terms of matter and energy. The inputs, outputs, and cycling of matter and flow of energy inside a system are useful to understand the system. In systems, matter changes and cycles over time. Describing ways matter changes in a system provides insights into how the system operates. Determining the forces acting on matter and the ways energy changes matter provides students with an understanding of how systems operate.

Energy and Matter

Matter does not change unless energy is absorbed or released. Energy is conserved so it can be

accounted for in systems in terms of energy inputs, outputs, and flow within a system. Nearly any system can be understood by the nature of the matter and/or energy in the system and how energy and matter flow into, out of, and within the system. The *Framework* describes the crosscutting concepts of energy and matter as, "*Tracking changes in energy and matter into, out of, and within systems helps one understand the systems' possibilities and limitations.*" (NRC, 2012. p. 84)

The concepts of energy and matter can be described in terms of conservation in a given system — flow or transfer between and among systems, cycles, and interactions. Students can use common language around matter and energy to facilitate understanding across disciplines.

Students can examine, characterize, and model the transfers and interactions of energy and matter to make sense of many phenomena. Students should be able to track matter and energy into, out of, and within systems to understand that system's possibilities and limitations. Cycles are also useful for characterizing matter and energy. Students can often readily observe the movement of matter, such as in the water cycle, but need to apply their understanding of the transfer of energy in the system to explain natural phenomena, such as why puddles dry up after it rains. Energy and matter are the essential components of any system and important ways to help students develop models that are more useful in making sense of phenomena.

Scale, Proportion, and Quantity

Scale, proportion, and quantity are essential to describing and understanding the systems and processes that underpin phenomena. The *Framework* captures the importance of the crosscutting concepts of scale, proportion, and quantity as, *"In considering phenomena, it is critical to recognize what is relevant at different measures of size, time, and energy and to recognize how changes in scale, proportion, or quantity affect a system's structure or performance."* (NRC, 2012. p. 84)

Scale, proportion, and quantity can describe scales of time or physical magnitude. Students can apply these concepts to delineate, describe, and analyze a system through the practices of "Using Mathematics and Computational Thinking" and "Analyzing and Interpreting Data."

For students, figuring out a phenomenon can be a function of scale. With a phenomenon such as the reaction of baking soda and vinegar, as students move from elementary to high school their understanding of that phenomenon can progress from what is observable at a macroscopic level, to inferring changes that cannot be seen, to describing chemical reactions at the atomic and subatomic levels.

Models can help students make sense of systems that are too small or too large to observe directly, such as cell parts and planets in the solar system. The concept of proportion is essential to developing and using models that accurately represent the components of system.

Students should recognize the importance of differences in scales of time and size. These two concepts provide students a way to understand how changes at one scale may not impact a system that exists at another scale for both time and size. For example, when a few thousand people dump raw sewage into Lake Michigan, it does not affect the water quality due to the scale of the lake to the number of people, but when 10 million people dump sewage into Lake Michigan, it significantly affects the lake's ecosystems. But with a lake of a smaller scale, such as Lake Tahoe, a few thousand people dumping raw sewage into the lake affects the water quality, due to the smaller scale of the lake. Some changes to systems are significant at a small scale but not a large scale, and vice versa.

Stability and Change

Stability and change are key crosscutting concepts used to make sense of phenomena and design engineered systems. The *Framework* describes the crosscutting concept of stability and change as, *"For natural and built systems alike, conditions of stability and determinants of rates of change or evolution of a system are critical elements of study."* (NRC, 2012. p. 84)

Stability is a state in which a system or aspects of a system are unchanging or return to an original condition after a disturbance. Stability and change are understood over different time and size scales. Students can apply these concepts to investigate both natural and engineered systems.

Students use the concepts of change and stability in tandem with many other crosscutting concepts to understand phenomena. Stability and change refer to functions of a system and even changing systems can be stable, as in dynamic equilibrium. Matter and energy within a system can change over time in consistent patterns, creating stability. Stability and change can be examined over different time and space scales; systems that are stable over hundreds of years may not be stable over millions of years. Stability is often conditional, changing conditions affects stability.

Change and stability are essential to engineering. Some systems are designed to favor stability over time, such as buildings and bridges. Other systems are designed to promote change, such as designing a device to prevent pollution from reaching the ocean.

The Oysters Lesson in Appendix A provides examples of prompting students with crosscutting concepts related to systems to engage in exploring the impact of oysters on an ecosystem. In the lesson, students watch a video of two tanks of cloudy water from Chesapeake Bay and observe changes that occur in the two tanks over time. After two hours, the tank with oysters becomes clear and the other tank remains cloudy. Throughout a series of investigations, students create and revise models of the systems and develop an explanation for the causes of changes in the system in each tank. Figure 4.4 provides examples of prompts using crosscutting concepts related to systems from the Oyster Lesson for use in classroom discussion and/or writing tasks.

The student responses in Figure 4.3 are typical only for students who have been engaged in science instruction with teachers who regularly and consistently prompt students with crosscutting concepts and expect students to respond using crosscutting concepts. When teachers use science language frequently, consistently, and accurately, students respond with the same language with amazing proficiency. The crosscutting concepts provide a structure for science discussions that helps focus student learning on key aspects of phenomena (Moulding & Bybee, 2017).

As part of the formative assessment process, teachers and students can interpret evidence based on the changes in the matter and energy in systems these prompts elicit. The prompts are designed to help make student thinking visible and can help inform instruction and help teachers address students' learning needs by adjusting instructional emphasis and/or strategies.

Phenomenon: When oysters are added to a tank that has cloudy sediment-filled water, the water in the tank becomes clearer than a tank without oysters.	
Possible Prompts	**Possible Student Responses**
• How do differences in the components of each tank *cause changes* in the two *systems*?	• *The only difference between the two systems is the oysters are in one tank, but not the other.* • *The system with oysters changes by becoming clearer, but the tank without oysters does not appear to change.*
• How does the *matter* move between the components of each *system*?	• *Water and sediment are matter and the sediment stays in the oysters and the water moves through the oysters. The oysters are part of the system but are a system themselves.* • *Sediment stays in the oyster's' body system, but water moves out of the oyster's' body system.* • *In the tank without the oysters, the proportion of water and sediment does not change.*
• What *changes* in the *system* would you predict to be observable after *one minute, one hour, two days*?	• *The proportion of gunk causing cloudiness in the system will decrease over time because the oysters are causing a change in the system.* • *The system will change more after one day than after one minute.* • *The quantity of sediment removed after one day is greater than after one hour.*
• How does the number *(quantity)* of oysters in the tank *affect* the rate of *change* in the *system*?	• *Putting more oysters in the system will cause a faster change in the tank.* • *The system will not change without oysters in the tank; perhaps the tank will not clear up at all.*

• How does your model show changes in the system that are difficult to see directly?	• *We can't see inside of the oysters, but our model shows the oyster as a living system and the sediment stays inside of the oyster system.* • *Our model shows changes that are too slow or too small to see directly.*
• How does your model demonstrate how oysters change the number of particles of matter in the water?	• *Our model shows changes in the quantity of particles in the water.* • *Our model shows that oysters decrease the quantity of particles in the water.*
• How long will it take for the oysters to cause a change in the water quality (clarity?) of the Chesapeake Bay ecosystem?	• *The changes to the system will take a long time because the scale of the Chesapeake Bay is much larger than the aquarium. You know more water and more sediment, but hopefully there will be more oysters too.* • *Perhaps it is the proportion of oysters to water and sediment in the two systems that is different, so it will take a long time for change to occur. But the oysters will help cause the change in the system.*

Figure 4.4: Prompts for the Lesson "Oysters" in Appendix A Using Systems to Initiate Student Responses

5 | DEVELOPING THREE-DIMENSIONAL ASSESSMENT ITEMS

Natural and engineered phenomena provide a useful context for developing assessments that provide evidence of students' knowledge and skills to engage in three-dimensional science performances. Selecting useful phenomena to use in assessing students' knowledge and abilities specific to a standard (performance expectation (PE) and/or lesson performance) requires an understanding of the attributes of the standard you are assessing. We recommend that each of the dimensions of a standard be analyzed to determine the evidence students must provide for you to know they meet each dimension of the standard. The foundation boxes in the NGSS and similar state standards documents provide clear intent for each dimension of a PE and are a useful tool for determining the attributes to assess.

Developing formal and informal formative assessments are best done within the context of a lesson. It is imperative to identify the specific three-dimensional performances within the lesson you wish to assess and then clarify exactly the attributes of the students' performances you are willing to accept as meeting the criteria of proficient. Students' proficiency with engaging in doing specific practices and in using core ideas and/or crosscutting concepts accurately to support those practices requires careful analysis of the standard's performance expectations. Appendix A provides examples of ways to approach lesson development that use "Lesson Performances" as well as "Performance Expectations" from the standards to describe expectations beyond the lesson. Additionally, the lessons describe observable student performances in the "Science Essentials" written as couplets of practices and crosscutting concepts. Typically, the assessment aspect of the lesson exists within the communicate portion of a lesson. In this portion of the lesson, students make reasoning visible by using models, writing, and/or speaking.

Assessing three-dimensional learning provides a useful opportunity for educators to view how students engage in science performances. Students use core ideas and crosscutting concepts to engage in one or more science and engineering practices. These performances are not different from the performances students are doing in response to instruction and should be integrated within each lesson.

Three-dimensional assessment items are easiest to develop from clearly written three-dimensional performance expectations. The PEs in the NGSS are a good example of the structure for these statements of student performances. The performance expectation (PE) statements typically begin with a science and engineering practice (SEP) followed by the crosscutting concept (CCC) and the disciplinary core idea (DCI). The order of the crosscutting concept and core idea frequently change, but the practice should always lead the statement. The typical verbs used in past standards such as identify, describe, explain, and analyze have been replaced by the science and engineering practices.

Often the core idea is replaced with the phenomenon in the lesson performances and students use the DCI as evidence to support an explanation. For example, in a unit of instruction aligned to the NGSS Standard MS-PS1-5, both the Performance Expectation(s) and the Lesson Performance Expectation(s) should be assessed. Developing assessment items for each within a lesson may follow a sequence similar to the one in Figure 5.1.

In this performance, students construct an explanation for the causes of changes in the mass during a chemical reaction. Students' understanding that matter is conserved contributes to their understanding that decreasing the mass in the beaker means the matter must go someplace. The crosscutting concept in the PE is matter – matter is conserved; however, their understanding of systems and change/stability contributes to making sense of the phenomenon. The crosscutting concepts in the LP are a) matter is conserved, b) systems, and c) cause and effect. The crosscutting concepts are used to prompt students in the questions for both performances. Each prompt for a performance includes each of the three dimensions. Student performances should be the action of the practice and the knowledge of how to use the core idea and crosscutting concept to support the practice.

Developing assessments for three-dimensional performance expectations requires assessing each dimension as well as the performance of the three-dimensional performance expectation. In Figure 5.1, the focus of the assessment is primarily on the three-dimensions and then on the crosscutting concepts of matter and systems. This was made simpler by the fact that the core idea and crosscutting concepts are the same – matter is conserved.

Standard Performance Expectation (PE)	MS-PS1-5. Develop and use a model to describe how the total number of atoms does not change in a chemical reaction and thus mass is conserved. *(SEP – Models and CCC – Conservation of Matter)*
Lesson Performances (LP)	Construct an explanation for the causes of the mass of a sample of baking soda and vinegar decreasing when mixed in a beaker.
Phenomenon: When baking soda and vinegar are mixed in a beaker on a scale, the mixture bubbles and weighs less than before mixing.	
Assess LP in the Communication Performance	Teacher Prompt: Construct an explanation supported by evidence for the causes of changes in mass when baking soda and vinegar are mixed.
Student Communication	Possible Student Response: Matter is conserved so the change in mass is due to a gas leaving the system of the beaker, baking soda, and vinegar. The gas has mass and leaves the system, goes into the air, and is not measured. This causes the mass to be less.
Assess PE in the Communication Performance	Teacher Prompt: Use the model provided to show the changes in matter from one system (beaker and reactants) to another (surrounding) during the chemical reaction between baking soda and vinegar in a beaker sitting on an electronic scale.

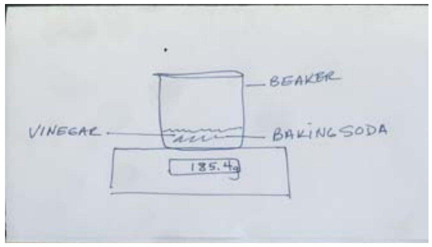
Prompt: Use the existing model before the reaction to show the changes among the systems after the reaction.	 Before Reaction After Reaction
Assess LP in Lesson	What causes the measured mass on the electronic scale to change as the substances react?
Student Response	In the reaction, gas is given off and is no longer part of the mass of the original system, but part of the air now. This causes the beaker to have less matter and air to have more mass.
DCIs students use to support explanations for cause of changes in system.	• In a chemical process, the atoms that make up the original substances are regrouped into different molecules, and these new substances have different properties from those of the reactants. • The total number of each type of atom is conserved and thus the mass does not change.

Figure 5.1: Sample Sequence for an Assessment

Context for Assessments

This primer has focused on the importance of the crosscutting concepts, but each dimension is included when the crosscutting concepts are used to prompt students with questions or state performance expectations. Prompting with crosscutting concepts has the advantage of focusing the practice to a specific aspect of the phenomenon. For example, a prompt such as, "What causes changes in a pond ecosystem in the late summer?" focuses students on the idea of changes in a system, but the context of the pond and the core ideas of how ecosystems interact are essential for students' science understanding. Good assessments for this context require students to make their understanding visible of how ecosystems operate, how matter and energy enter and leave the ecosystem, and the interactions of both the living and nonliving components of the ecosystem.

Assessing students' understanding of ecosystems requires gathering evidence of student knowledge of matter, energy, photosynthesis, predator/prey relationships, and the carbon cycle. Fortunately, these understandings accumulate over the course of a student's K-12 science education. Students bring to the assessment all of the knowledge and experiences collected over the course of their lives, in and out of school, to respond to the prompt. This means that the context of the cluster of tasks is important for both engaging as well as prompting students to respond. Phenomena used for both instruction and assessment engages students when it is interesting and familiar. It is important the prompts use consistent language, the language of the crosscutting concepts. Does this approach give an advantage to students from classrooms and school systems where teachers consistently and accurately use the crosscutting concepts to prompt students? Yes!

Summary

The purpose for an assessment should be considered for all types of assessments and developed to meet purposes for which it is intended. Assessment should reflect classroom instruction across all types of assessment and for all purposes of assessment. An important aspect of classroom instruction is use of formative assessment tasks. Summative assessments should use crosscutting concepts to prompt students in ways that are consistent with the use of crosscutting concepts in formative assessment. Whether the purpose of the assessment is for formative assessment or summative assessment in the classroom, district, or state level, using crosscutting concepts is an effective way to prompt students' responses. We encourage the consistent and accurate use of crosscutting concepts to prompt student responses across all types of assessment.

6 | SUMMARY

When students consistently and accurately engage in using the crosscutting concepts in the science classroom they develop the skills and knowledge needed to make sense of science phenomena and engineering challenges beyond the classroom. Classroom instruction that establishes an explicit expectation for students to consistently use crosscutting concepts structures students' science reasoning, which provides an effective tool for learning. This document provides an overview for how using crosscutting concept prompts can effectively engage students in variations of the science and engineering practices and core ideas. By using this prompt structure, students gain sense-making strategies they can practice and reflect on throughout instruction. As students move from grade to grade and topic to topic, the crosscutting concepts will continue to help them structure their reasoning and support an equitable opportunity for all students to engage in science learning.

The nature of science instruction in the *Framework* places an emphasis on the performance of students with regard to the explanation of natural phenomena and the solving of engineering problems. This shift allows students to engage as a scientist or engineer in the questions at hand and allows opportunities for teachers to guide students as they grow in their ability to perform as scientists, engineers, and citizens. The student science performances provide teachers with ample and structured opportunities to assess the degree to which individual students are performing with regard to the use of disciplinary core ideas, crosscutting concepts, and science and engineering practices. This primer provides guidance on structuring prompts for accessing real time information about how students are performing across the three dimensions of science and engineering described in the *Framework*. As teachers formatively assess student learning, the emphasis is on how to adapt future teaching and learning for all students.

7 | RESOURCES

Culturally Relevant Science Assessment

Strategies for Clarifying Intended Learning

- Dr. Megan Bang has a number of resources around cultural funds of knowledge and learning as a cultural accomplishment: https://education.uw.edu/people/faculty/mbang3
- STEM Teaching Tool #28 provides considerations for selecting a phenomenon, including connecting to everyday and family experiences: Qualities of a Good Anchor Phenomenon for a Coherent Sequence of Science Lessons
- Phenomena for NGSS website: http://www.ngssphenomena.com/whyusephenomena/

Strategies for Eliciting Evidence

- STEM Teaching Tool #25: How can formative assessment support culturally responsive argumentation in a classroom community?
- Tools for Ambitious Science Teaching provides guidance on making thinking visible: Face-to-Face Tools: Making Changes in Student Thinking Visible Over Time

Strategies for Interpreting Evidence, Acting on Evidence, Involving Students in the Process, and Providing Feedback to Students

- Inquiry Project from TERC Talk Strategies: https://inquiryproject.terc.edu/prof_dev/library.cfm.html
- STEM Teaching Tool #35 and the associated Student Talk Flow Chart: How Can I Foster Curiosity and Learning in my Classroom? Through Talk!
- Facets approach to analyzing student work, see STEM Teaching Tool #37: Beyond "misconceptions": How to recognize and build on Facets of student thinking
- Connecting to students' indigenous ways of knowing, see STEM Teaching Tool #10: Teaching STEM In Ways that Respect and Build Upon Indigenous Peoples' Rights and STEM Teaching Tool #11: Implementing Meaningful STEM Education with Indigenous Students & Families
- STEM Teaching Tool #16: Research Brief: The Informal Formative Assessment Cycle as a Model for Teacher Practice
- STEM Teaching Tool #18: How teachers can develop formative assessments that fit a three-dimensional view of science learning

Strategies for Encouraging Classroom Discourse

- Ready, Set, Science! Chapter 5 NRC Report: https://www.nap.edu/download/11882
- Ambitious Science Teaching – Discourse Primer: http://ambitiousscienceteaching.org/wp-content/uploads/2014/09/Discourse-Primer.pdf

Guidance for Classroom Instruction and Assessment

Strategies for Classroom Assessment Specific to the Framework and NGSS

- Seeing Students Learn Science: Integrating Assessment and Instruction in the Classroom. National Academies of Sciences, Engineering, and Medicine. 2017. Washington, DC: The National Academies Press: https://doi.org/10.17226/23548
- Developing Assessments for the Next Generation Science Standards. National Research Council. 2014. Washington, DC: The National Academies Press: https://doi.org/10.17226/18409
- Constructing Assessment Tasks that Blend Disciplinary Core Ideas, Crosscutting Concepts, and Science Practices for Classroom Formative Applications Christopher J. Harris | Joseph S. Krajcik | James W. Pellegrino | Kevin W. McElhaney: https://www.sri.com/sites/default/files/publications/constructing_assessment_tasks_2016.pdf

Strategies for Classroom Instruction Using Crosscutting Concepts to Prompt Student Responses

- Going 3-D Lessons aligned to the Next Generation Science Standards and state standards consistent with the Framework for K-12 Science Education: https://sites.google.com/okcps.org/going3d-grclessons/home
- A Vision and Plan for Science Teaching and Learning - An Educator's Guide to A Framework for K-12 Science Standards, Next Generation Science Standards, and State Science Standards. 2015. Essential Teaching and Learning, Salt Lake City, UT: http://pestl.org/sciencebook.html
- Stem Teaching Tool #28: Qualities of a Good Anchor Phenomenon for a Coherent Sequence of Science Lessons
- Using Phenomena in NGSS-Designed Lessons and Units: http://www.nextgenscience.org/sites/default/files/Using%20Phenomena%20in%20NGSS.pdf

Guidance and Tools for Formative Assessment Professional Development

- ACESSE Resource A: Introduction to Formative Assessment to Support Equitable 3D Instruction: http://stemteachingtools.org/PD/SessionA
- ACESSE Resource B - How to Assess Three-Dimensional Learning in Your Classroom: http://stemteachingtools.org/pd/sessionb

8 | REFERENCES

AAAS. (1993). *Benchmarks for science literacy.* New York: Oxford University Press.

Achieve. (2016). *Using phenomena in NGSS-designed lessons and units.* Retrived from https://www.nextgenscience.org/sites/default/files/Using%20Phenomena%20in%20NGSS.pdf

Black, P.J., & Wiliam, D. (1998). Inside the black box: Raising standards through classroom assessment. *Phi Delta Kappan*, *80*, 139-48.

Cizek, G.J. 2010. An introduction to formative assessment: History, characteristics, and challenges. In H.L. Andrade & G.J. Cizek (Eds.), *Handbook of formative assessment.* New York, NY: Routledge.

Council of Chief State School Officers. (2008). *Attributes of effective formative assessment.* A work product coordinated and led by Sarah McManus, North Carolina Department of Public Instruction, for the Formative Assessment for Teachers and Students (FAST) State Collaborative on Assessment and Student Standards (SCASS) of the Council of Chief State School Officers. Washington, DC: Author.

Council of Chief State School Officers. (2013). *Using the formative assessment rubrics, reflection and observation tools to support professional reflection on practice.* Commissioned by the Formative Assessment for Teachers and Students (FAST) State Collaborative on Assessment and Student Standards (SCASS) of the Council of Chief State School Officers (CCSSO). Washington, DC: Author.

Heritage, M. (2011). Formative assessment: An enabler of learning. *Better: Evidence-based education*, Spring 2011. Retrieved April 17, 2018, from https://www.csai-online.org/sites/default/files/resources/4666/FA_Enabler_of_Learning.pdf.

Minstrell, J. (2000). Student thinking and related assessment: Creating a facet-based learning environment. In Committee on the Evaluation of National and State Assessments of Educational Progress. N.S. Raju, J.W. Pellegrino, M.W. Bertenthal, K.J. Mitchell, and L.R. Jones (Eds.), Grading the nation's report card: Research from the evaluation of NAEP (pp. 44-73). Commission on Behavioral and Social Sciences and Education. Washington, DC: National Academy Press.

Moulding, B., Bybee, R., and Paulson, N. (2015). *Vision and plan for science teaching and learning.* Salt Lake City, UT: Essential Teaching and Learning PD, LLC.

Moulding, B., and Bybee, R., (2017). *Teaching science is phenomenal.* Ogden, UT: ELM Tree Publishing.

National Assessment Governing Board. (2008). *Science framework for the 2015 national assessment of educational progress.* WestEd and CCSSO. Washington, DC: U.S. Government Printing Office

National Research Council. (1996). *National science education standards.* National Committee for Science Education Standards and Assessment. Washington, DC: National Academy Press.

National Research Council. (2012). *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 Academies Press.

National Research Council. (2014). *Developing assessments for the next generation science standards*. Washington, DC: The National Academies Press.

National Research Council. (2015). *Guide to implementing the next generation science standards.* Committee on Guidance on Implementing the Next Generation Science Standards. Board on Science Education, Division of Behavioral and Social Sciences and Education. Washington, DC: The National Academies Press.

Penuel, W.R. and Van Horne, K. (2018). *Prompts for integrating crosscutting concepts into assessment and instruction.* Retrieved from stemteachingtools.org/brief/41

Popham, W.J. (2008). *Transformative assessment*. Alexandria, VA: Association for Supervision and Curriculum Development. Retrieved April 19, 2018, from http://www.ascd.org/publications/books/108018.aspx.

Stiggins, D. and DuFour, R. (2009). Maximizing the power of formative assessments. *Phi Delta Kappan*, *90*, 640-644.

9 | APPENDIX A – LESSONS

1. Oysters: Restoration Treasure (5-LS2-1/5-ESS3-1/3-5 ETS1-2)
2. Refraction of Light (HS-PS4-1)
3. Birds of a Feather Flock Together (HS-LS2-8)
4. Charge! (3-PS2-3)

These sample lessons are in different formats. "Oysters: A Restoration Treasure" is a 5E + Gathering, Reasoning, Communicating (GRC) model where formative assessment is embedded. "Refraction of Light" is a formal formative assessment model, and "Birds of a Feather" and "Charge!" are GRC models with formative assessment embedded.

Using the crosscutting concept of systems is an effective way for students to make visible their understanding of the processes, relationships, and interactions of phenomena. In this lesson about water systems with and without oysters, students can observe changes that occur in the two systems over time. Students identify the components of the system, describe the input and outputs of matter that are causing changes in the systems, and revise the models to deepen their understanding of how systems operate.

<table>
<tr><td colspan="2">Oysters: A Restoration Treasure is a 5E + Gathering, Reasoning, Communicating (GRC) model with formative assessment embedded.</td></tr>
<tr><td colspan="2">Student Science Performance</td></tr>
<tr><td>Grade 5</td><td rowspan="2">Title
Oysters: A Restoration Treasure</td></tr>
<tr><td>Topic – Oysters: Matter and Systems</td></tr>
<tr><td colspan="2">Performance Expectation (NGSS) and/or State Standards:

5-LS2-1. Develop a model of a system to describe the movement of matter among plants, animals, decomposers, and the environment. (systems) [Clarification Statement: Emphasis is on the idea that matter that is not food (air, water, decomposed materials in soil) is changed by plants into matter that is food. Examples of systems could include organisms, ecosystems, and Earth.] [Assessment Boundary: Assessment does not include molecular explanations.]

3-5-ETS1-2. (secondary to 5-LS2-1). Generate and compare multiple possible solutions to a problem based on how well each solution is likely to meet the criteria and constraints of the problem and the changing needs of people and society.

5-ESS3-1. (secondary to 5-LS2-1). Obtain and combine information about ways individual communities use science ideas to protect the Earth's resources and environment. (systems)</td></tr>
<tr><td colspan="2">Lesson Performance Expectations (These are additional student performances that occur during the lesson):

• Construct and communicate an explanation for how oysters affect changes in the cycling of matter through systems at multiple scales.
• Develop a model to describe the movement of matter (particles and water) by oysters in a tank system.
• Develop an argument for how and/or why evidence supports an explanation for the effect of oysters on an ecosystem.</td></tr>
</table>

Engaging

The goal of this phase is to capture the students' attention and interest and help students focused on the causes of the phenomenon - the clearing of the tank.

Students are engaged in making sense of phenomenon using their own conceptual models and core ideas.

Create opportunities to informally determine misconceptions expressed by the students.

Formative assessment steps:

Clarify Intended Learning – understanding phenomenon, developing model, constructing argument/explanation.

What are criteria for proficiency in developing models and constructing arguments/explanations?

Elicit Evidence – through prompts for writing/discussion and through evidence generated in reasoning/communicating phases (e.g., labeled model). Have students discuss why the tank with the oysters is different.

Interpret Evidence – look for naive or alternative conceptions within model, writing, discussion.

The oysters make the particles disappear. The focus needs to be on why. At this point predictions are being made as to what happens to the particles.

What types of responses might you expect from students?

Act on Evidence – at this point in the lesson, it is not necessary to correct naive or alternative conceptions. However, keep these in mind as students return to the model in the next phase of the lesson.

Student Science Performances

Phenomenon: When oysters are added to a tank that has cloudy sediment-filled water, the water in the tank becomes clearer than a tank without oysters.

Gathering

1. Students obtain information for the ***causes of changes*** in the aquarium systems shown below by observing the pictures.

Two Tanks Filled with the Same Water but One has Oysters In It

Photo source: http://twistedsifter.com/2014/10/two-tanks-filled-with-same-water-one-has-oysters/

2. Students investigate similarities and differences of the models of the systems in the two tanks to develop questions about the causes of differences in the changes in each of the tanks over time.

(Prompts for Writing or Discussion: Describe the changes in the left tank. Describe the changes in the right tank. Describe the observable cycling of matter in the tanks. What questions do you have about the tanks?)

3. Students obtain information about the interactions of the components of each of the two systems (tanks).

(Teacher Hint: Students can obtain information from a lecture or reading. Describe to students that the tanks started with identical water with particles of matter from the bay or river. The only difference between the tanks was the inclusion of live oysters in the tank on the right. These are the results after two hours.)

Reasoning

4. Students use models (e.g., narrative, drawing, diagrams, labels) to describe the interactions among the components of each of two systems (left tank and right tank).

(Prompts for Writing or Discussion: What are the components of the left tank system? What are the components of the right tank system? How are the components of each system interacting? How is the matter cycling in the tank system?)

5. Students construct an explanation for the causes of differences in the changes in two systems based on observations.

(Prompts for Writing or Discussion: What happens to the particles of matter in the right tank system? What are the changes in the matter in the right tank system?)

	Communicating 6. Students develop a model of the two systems to illustrate their explanations for the differences between the tanks. *(Teacher Hint: Prompts for Writing or Discussion: How do the components of the system interact? What happens to the particles of matter in the right tank system? What are the changes in the matter in the right tank system? What role do the oysters play in the right tank system?)*
Explore The exploration performances provide concrete experiences to extend students' current understanding and demonstrate their abilities to make sense of science phenomenon. **Clarify Intended Learning** – students are adding to their understanding of the phenomenon, further developing the model, and constructing argument/ explanation. The oysters are feeding on the material in the tank which makes it clear. Movement of matter in an ecosystem. **Elicit Evidence** – through prompts for writing/discussion and through evidence generated in reasoning/communicating phases (e.g. labeled model) **Interpret Evidence** – look for naive or alternative conceptions within model, writing, discussion *What types of responses might you expect from students?* **Act on Evidence** – at this point in the lesson, students should be adjusting their previous models. Students work together to make revisions; teacher can use evidence to guide students. *How will you engage and guide students in the revisions of their models and explanations?*	***Gathering*** 1. Students obtain information about oysters interacting in a system by watching a video on oyster filtration: [https://www.youtube.com/watch?v=saAy7GfLq4w.](https://www.youtube.com/watch?v=saAy7GfLq4w) 2. Students use a model (T Chart) to organize and compare information about the similarities and differences between the changes in the two tank systems. *(Prompts for Writing or Discussion: Describe the left tank. Describe the right tank. What is similar? What is different? Complete a Venn Diagram for the two tanks. Describe the matter that you observe. How do the tanks change over time?)* ***Reasoning*** 3. Students develop a model (e.g., narrative, draw and label) for the components of each of the two systems (left tank and right tank). *(Prompts for Writing or Discussion: What is a system? What are the components of the left tank system? What are the components of the right tank system?)* 4. Students construct an explanation for the differences between the tanks, based on their observations, the scenario that the teacher shared, and their descriptions of the systems. *(Prompts for Writing or Discussion: What happens to the particles of matter in the right tank system? What changes are happening to the matter in the right tank system?)* ***Communicating*** 5. Students revise their previous model to illustrate their explanations for the differences between the two tank systems. *(Prompts for Writing or Discussion: How do the oysters affect the tank system? How are the components of the system interacting? What happened to the particles of matter in the right tank system? What evidence do you have that the oysters are causing changes in the system?)*

Explaining	*Gathering*
Students engage in three-dimensional performances to make sense of the phenomena featured in the engage and explore phase. The teacher directs students' attention to key aspects of the prior phases and first asks students for their explanations. Both the teacher and student formatively assess the learning progress. **Clarify Intended Learning** – students are finalizing their understanding of the phenomena, and finalizing the model, argument, and explanation. **Elicit Evidence** – through prompts for writing/discussion and through evidence generated in reasoning/communicating phases (e.g., labeled model) **Interpret Evidence** – look for naive or alternative conceptions within model, writing, discussion *What types of responses might you expect from students?* **Act on Evidence** – at this point in the lesson, students should be finalizing their previous models. Students work together to make revisions. The teacher can use evidence to guide students. *How will you engage and guide students in the revisions of their models and explanations?*	1. Students obtain information by watching a video about how oysters change water clarity: https://www.youtube.com/watch?v=VTuBbuUro4g. 2. Students obtain information by watching dye moving through an oyster to obtain information about the causes of changes to a small system through filtration by oysters. *(Teacher Hint:* http://ww2.mdsg.umd.edu/interactive_lessons/oysters/oysfilt.htm (first video) *The Maryland Sea Grant video may need to be downloaded from Safari to run properly.)* ***Reasoning*** 3. Students revise their previous explanations based on new evidence from the videos for the causes of differences in the changes to the two systems. Class Discussion Questions to Initiate Class Discussion: *Q: How do the oysters cause changes in the water in the tank?* *Q: How does the movement of matter through the system within the oysters cause changes to the tank system?* *Q: What happens to the particles of matter cycling in the right tank system?* *Q: How is the time the system is operating related to the changes in the system?* *Q: How does the internal body system of the oysters cause changes in the quantity of particles in the ecosystems where they live?* *Q: How is the model of the system related to the way oysters affect the Chesapeake Bay ecosystem?* ***Communicating*** 4. Students revise their previous model of the system to illustrate their explanations for the causes of differences between the tank systems. *(Prompts for Writing or Discussion: Based on student observations of the tank system use questions to prompt student responses. Examples of questions could include:* *Q: How do the different components of the system interact?* *Q: How does your model demonstrate changes in the system caused by oysters removing particles of matter from water?* *Q: How does your model show changes to the system that are difficult to observe directly in the Chesapeake Bay ecosystem?* *Q: Why does your model not accurately represent the scale of time needed for oysters to filter water in the bay?*

Elaborating Students are involved in learning experiences that extend, expand, and enrich the concepts and abilities developed in the prior phases. The intent is to facilitate the transfer of concepts and abilities to related, but new situations. In the elaboration phase, the teacher challenges students with a new phenomenon and encourages interactions among students and with other sources such as written material, databases, simulations, and web-based searches. ***Applying Models help to Solve a Problem*** **Clarify Intended Learning** – students are extending their understanding of the phenomena to a natural situation to solve or analyze a solution for improving water quality. **Elicit Evidence** – through prompts for writing/discussion and through evidence generated in reasoning/ communicating models (i.e., written, oral, or multimedia presentation) **Interpret Evidence** – look for naive or alternative conceptions within model, writing, discussion *What types of responses might you expect from students?* **Act on Evidence** – at this point in the lesson, students should be finalizing their previous models. Students work together to make revisions. The teacher can use evidence to guide students. *How will you engage and guide students in the revisions of their models and explanations?*	***Phenomenon: Water quality of the Chesapeake Bay has changed since humans began living near the Bay.*** ***Gathering*** 1. Students obtain information (video) for how changes to the oysters' habitat can restore components of a system. *(Teacher Hint: Use Video of the Oyster Reef Restoration Project found at* https://www.youtube.com/watch?v=4QsGqNZNUOw&feature=youtu.be.) 2. Students define the problem by determining the criteria and constraints and engineering a solution to the problem in the oyster reef ecosystem restoration in the St. Lucie Estuary. 3. Students obtain information by researching reliable sources (e.g., PBS Newsletter Oysters Reclaim Ancient Reefs in the Chesapeake) for how an ecosystem with poor water quality (e.g., Magothy River, Chesapeake Bay, locally relevant waterway) has changed over time. ***Reasoning*** 4. Students compare models of the components of the tank that cause changes to the system over time and compare to the components of a natural waterway system. 5. Students use the tank model as evidence to construct an argument about the effect of oysters on an ecosystem. 6. Students predict changes to a water system where oysters are removed or die off. *(Prompts for Writing or Discussion: What might a natural waterway look like without human intervention? How is the St. Lucie Estuary system different from the tank system? How can humans increase the impact of oysters? How would one monitor the system for improvement? Does the size of a system make a difference when using oysters to filter water?)* ***Communicating*** 7. Students generate a viable solution to improve water quality in a given waterway system and share recommendations for restoration in that area (through written, oral, or multimedia presentation). *(Prompts for Writing or Discussion: Describe the system you are going to restore. What role do oysters play in restoring water quality in an ecosystem? How long do you think it will take to improve the water quality in your ecosystem?)*

Evaluation Throughout the lesson, students receive feedback on the adequacy of their explanations and abilities. Informal, formative evaluations have been occurring from the initial phase of the instructional sequence. At end of the lesson, information from assessment becomes more formal. In the evaluate phase, the teacher should involve students in experiences that are understandable and consistent with those of prior phases and congruent with the explanations from prior phases. Note that these descriptions of proficiency can be referenced throughout the lesson as benchmarks for formative assessment. **Clarify Intended Learning** – students explain the lesson phenomena using a model and written argument **Elicit Evidence** – through model and written argument **Interpret Evidence** – look for evidence of student work below proficiency **Act on Evidence** – at this point in the lesson, determine how you will address student work that is below proficiency *Will you reteach with the full class/large group? Will you pull out individual or small groups of students?*	**Assessment of Student Learning** ***Evaluation Phase Prompt One*** 1. Students develop a model of an oyster/tank system to describe the movement of matter in the system among plants, animals, decomposers, and the environment. ***Evaluation Phase Prompt Two*** 2. Students use evidence from the tank models, videos, and other resources to construct an explanation for how communities can make changes to improve water quality of a natural waterway's ecosystems. *Description of Student Proficiency for these two prompts may be found in the lesson's appendix.*
SEP, CCC, & DCI Featured in Lesson	**Science Essentials**
Science Practices Construct an Explanation Develop and use models	Compare multiple explanations of the same science phenomenon. Explain science phenomenon using evidence. Share explanations with others. Relate useful models for simple phenomenon. Use representations to reflect on mechanism of how things work. Share science findings in writing and graphic presentation to others.
Crosscutting Concepts Systems and System Models	Explain the inputs and outputs of matter, energy, and forces in system. Explain why a specific order of events is necessary to cause some phenomenon to occur. Develop explanations for the role of various parts of systems. Track the cycling of matter in systems to make sense of changes in systems. Use models to show changes in systems.

Disciplinary Core Ideas	
Ecosystems Matter	The food of almost any kind of animal can be traced back to plants. Organisms are related in food webs in which some animals eat plants for food and other animals eat the animals that eat plants. Some organisms, such as fungi and bacteria, break down dead organisms (both plants or their parts and animals) and therefore operate as "decomposers." Decomposition eventually restores (recycles) some materials back to the soil. Organisms can survive only in environments in which their particular needs are met. A healthy ecosystem is one in which multiple species of different types are each able to meet their needs in a relatively stable web of life. Newly introduced species can damage the balance of an ecosystem. (5-LS2-1) Matter cycles between the air and soil and among plants, animals, and microbes as these organisms live and die. Organisms obtain gases, and water, from the environment and release waste matter (gas, liquid, or solid) back into the environment. (5-LS2-1)

Lesson Appendix
Lesson Assessment Rubric

Description of Proficiency for Evaluation Phase Prompt One

	Above Proficiency	*Proficient*	*Below Proficiency*
Model of the tank includes the relevant components of water, particles, and oysters (or no oysters)	*The tanks are cloudy due to sediment and pollutants. The tank without oysters will stay cloudy and may settle to the bottom of the tank over long periods of time. The tank with oysters is filtered and cleared faster. The oysters feed off of the sediment which clears the water.*	*Model includes and identifies system components* • *Oysters* • *Sediment (e.g., soil/ sand, tiny animals and plants, pollutants* • *Water*	*Model may omit a component of the model.*
Model of the tank demonstrates the relationships between the components of the tank systems	*Relationship between oysters and sediment is expressed using an advanced ecological understanding (e.g., position in food webs, use of abiotic components).*	*Relationships include* • *Oysters filter sediment for food* • *Water and sediment move through oyster* • *Sediment remains in oyster as an energy source*	*Relationship between oysters and sediment contains a naive concept or the connection between oysters and the sediment is not accurately explained.*
Model of the tank demonstrates the connections of the tank model to science concepts (natural waterways)	*Model goes beyond the waterways mentioned in class and makes connections to other natural waterways.*	*Students use model to describe* • *Cycling of matter in system* • *How changing a component of the model changes the system*	*Model fails to demonstrate the connection of the tank to a natural waterway.*

Prompt 2.

Students use evidence from their tank models, videos, and other resources to construct an explanation for how communities can improve the water quality of a natural waterway.

Description of Proficiency for Evaluation Phase Prompt Two

	Above Proficiency	*Proficient*	*Below Proficiency*
Claim	*The claim goes beyond improving water quality of natural waterways and extends to other water bodies and sources.*	*Make a claim about how communities can improve the water quality of a natural waterway (e.g., Communities can introduce oysters to polluted waterways, communities can increase oyster populations through controlling harvesting or creating nurseries).*	*Model fails to illustrate how the introduction of oysters or increasing the oyster population improves water quality in nature.*
Identify and describe evidence	*The evidence identified and described goes beyond those discovered during the lesson.*	*Describe evidence (from lesson or other sources)*	*Inaccurate or incomplete evidence is provided to support the claim.*
Evaluate and critique evidence	*The evidence supports the claim with possible additional applications*	*Describe how evidence supports claim*	*Limited evidence to support the claim.*
Reasoning/synthesis	*Evidence supports claim and other possible outcomes explored.*	*Connect evidence to support claim through scientific reasoning*	*The evidence fails to support the claim.*

Refraction of Light models a lesson with formative assessment embedded throughout the lesson.

Student Science Performance

Grade High School	**Title**
Physical Science	Refraction of Light

Performance Expectation (NGSS) and/or State Standards:

NGSS: HS-PS4-1: Use mathematical representations to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling in various media. *[Clarification Statement: Examples of data could include electromagnetic radiation traveling in a vacuum and glass, sound waves traveling through air and water, and seismic waves traveling through the Earth.] [Assessment Boundary: Assessment is limited to algebraic relationships and describing those relationships qualitatively.]*

Georgia: **SPS9.** Obtain, evaluate, and communicate information to explain the properties of waves.

Lesson Performance Expectation:

- Plan and carry out an investigation to gather evidence to support a claim about the cause effect relationship of light interactions with matter.

Success Criteria

Create a data table that allows them to identify patterns in their observations to make a cause effect claim describing the interactions between light and matter.

Disciplinary Core Ideas

The wavelength and frequency of a wave are related to one another by the speed of travel of the wave, which depends on the type of wave and the medium through which it is passing. *[K-12 Framework for Science Education, p. 132]*

When a wave meets the surface between two different materials or conditions (e.g., air to water), part of the wave is reflected at that surface and another part continues on, but at a different speed. The change of speed of the wave when passing from one medium to another can cause the wave to change direction or refract. *[K-12 Framework for Science Education, p. 132]*

Student Science Performances

Phenomenon: A drinking straw appears to be bent and larger when it is placed in a bottle of water.

Stage - Clarify Intended Learning Outcomes

1. Students investigate the cause-effect relationships in the way that light behaves as it travels from one medium to another.
2. Students plan and carry out an investigation to obtain information about how interaction of light traveling through matter from one medium to another causes changes in the appearance of the light and communicate these findings to the group via oral presentations, written reports, and creating models.

Guiding Questions

Q: How are the properties of light affected by the interaction with various substances?

Q: How can patterns be used as evidence to support an explanation for how light changes as it travels from one medium to another?

(Teacher Hint: Share learning outcome and success criteria with students.)

Stage Elicit Evidence of Learning

3. Students look for ***patterns*** in the behavior of light by observing a straw inside containers with different density liquids.

Guiding Questions

Q: What ***causes*** the straw to look different above and below the surface of the liquid?

Q: How is the transfer of light energy ***affected*** by moving to another medium of different densities?

Student's products may include

4. Students construct tables to organize data collected to show patterns of change in the appearance of the objects viewed through the liquids.
5. Students write short descriptions of the phenomena they observed that includes claims relating c***ause effect*** behavior of light properties in relation to experimental conditions (e.g., the speed of light changed when it traveled from air to alcohol).

(Teacher Hint: Ask the students these or other appropriate guiding questions to elicit evidence of student understanding of the core idea (refraction of light), crosscutting concepts (cause and effect, interaction of matter and energy), and practice (planning an investigation). These questions can be answered through multiple instructional modalities (e.g., written work, student conversations, whole group discussions.)

Stage – Interpret Evidence

Student Evidence of Proficiency	Other Possible Responses	Act on Evidence
Data Tables • Contain description of mediums tested, observations of phenomena in each medium, density (index of refraction) of the medium. • Students are able to use the table to recognize patterns in order to make a cause-effect claim on the interaction between light and matter.	• Mediums are misidentified • Table is not organized in a logical way (e.g., values from larger to smaller)	• If students are able to use the table to recognize patterns in order to make a cause-effect claim on the interaction between light and matter, then they are able to begin developing a mathematical model to predict the index of refraction of any liquid. • If students' data is not effectively organized, encourage students to compare their table with classmates. • Encourage students to compare their data table with classmates and then identify which representation allows them to most easily identify possible patterns.

Stage – Interpret Evidence

Student Evidence of Proficiency	Other Possible Responses	Act on Evidence
Student Claims • When the density (index of refraction) increases, the bending of the straw is larger. • As light interacts with denser mediums it slows down. • Denser liquids have a larger index of refraction because the break in the straw is larger.	• Denser liquids cause the break in the straw to appear larger (partially complete, the student doesn't include index of refraction). • Density of liquids does not cause a change in the appearance of the straw. • Denser liquids cause the break in the straw to appear smaller. • The index of refraction has no effect on the appearance of the straw.	• Encourage students to connect the break in the straw with the relationship between index of refraction and density. • Ask students to provide evidence that supports their claim.

(Teacher Hint: Engage students in peer review of their claims by having them share their evidence (data tables) and claims. Students could post their claims on the wall and then engage in classroom discourse or verbally share with a partner or small group to get feedback (this allows for both peer- and self-assessment). Use the Act on Evidence column of the table to interpret the data to make instructional decisions and provide actionable feedback to move students forward along the progression of learning toward the performance expectations.)

Stage – Reflection on and Extension of Learning

(Teacher Hint: Ask students to revisit the student performance expectations and success criteria to determine their progress toward the lesson outcome. Students should generate a written reflection and place it in their notebook or a google form.

The following guiding questions are designed to set the stage for the next student learning performance and the next formative assessment cycle. Students should be prompted to extend their understanding of the phenomena to move them toward meeting the performance expectation.)

Guiding Questions

From prior experiences, we know that the energy of an object changes due to the energy transfer (e.g., slows down if encounters a medium with high friction) as it moves between mediums with different properties.

How can you use this pattern to construct a claim on how the speed of light behaves as light travels between different mediums?

Science Essentials

Science Practices

Planning and carrying out investigations
Using mathematics and computational thinking
Analyzing and interpreting data
Constructing explanations
Engaging in argumentation from evidence

Crosscutting Concepts

Cause and effect
Modeling

Core Ideas

The speed of travel of the wave depends on the medium through which it is passing.
The index of refraction of a medium is proportional to the density of the medium.
The wavelength and frequency of a wave are related to one another by the speed of travel of the wave.

Patterns can be used as powerful prompts to elicit student thinking. In this lesson about animal behavior and patterns observed in flocking birds, students watch a series of videos of starlings flying in unison at dusk, a phenomenon called murmuration. Then, through a series of discussions and observations, students develop a model of the patterns of the starlings' animal behavior. To communicate the understanding of the phenomenon, students may utilize computer simulation models, video footage, nonfiction texts, and possibly observations from the field to validate their explanations.

The Birds of a Feather Lesson models a Gather, Reason and Communicate lesson with the formative assessment stages embedded in the left-hand column.	
Science Performance	
Grade HS	**Title** ***Birds of a Feather Flock Together***
Topic – Animal Behavior	
Performance Expectation (NGSS): **HS-LS2-8.** Evaluate the evidence for the role of group behavior on individual and species' chances to survive and reproduce. *[Clarification Statement: Emphasis is on (1) distinguishing between group and individual behavior, (2) identifying evidence supporting the outcomes of group behavior, and (3) developing logical and reasonable arguments based on evidence. Examples of group behaviors could include flocking, schooling, herding, and cooperative behaviors such as hunting, migrating, and swarming.]*	
Lesson Performance Expectations: • Ask questions about the causes of ***patterns*** in animal flocking behavior. • Use models (computer simulations) to develop evidence for the ***causes*** of flocking behavior. • Develop an explanation for the ***causes of changes in patterns*** of flocking behavior within a ***system*** of animals. **Formative Assessment Stages:** *Clarified Intended Learning, Elicit Evidence, Interpret Evidence, and Act on Evidence*	
This column is intended to address possible student learning targets for assessment.	**Lesson Performance Expectation** (Lesson Outcome) Plan and carry out an investigation to gather evidence to support a claim about the ***causes of patterns*** of flocking behavior of animals. **Success Criteria** Create a model that allows students to identify and explain the ***patterns*** and the role of group behavior on individual and species' chances to survive.

Stage: Clarify Intended Learning

Students ask questions about the causes of animals engaging in murmuration flight behavior patterns.

Stage: Elicit Evidence

Students develop initial models of observational patterns to develop evidence for the causes of flocking behavior.

Stage: Interpret Evidence

Students develop an initial explanation of the causes and changes in the animal system.

Stage: Act on Evidence

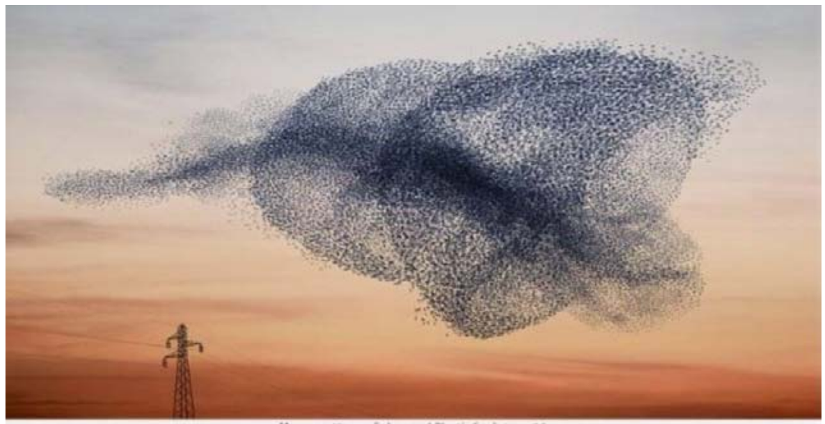
Students communicate an explanation to their peers of the causes and changes in the animal system, and perhaps refine initial models.

Student Science Performance

Phenomenon: Often near dusk, flocks of starlings can be seen flying in tight formations; the whole flock appears to fly in unison.

Gathering

1. Students obtain information about the ***patterns*** of animal behavior by watching the video that exhibits a flocking behavior called murmuration.



Murmurations - *Ephemeral Plastic Sculptures #4*

Watch the Video
Flight of the Starlings National Geographic video

2. Students formulate questions about the ***causes of patterns*** in the flight of birds and how/why many species of birds exhibit flocking behavior of murmuration.

(Teacher Hint: Engage students in developing questions to find ***causes of the pattern****. Describe the movement of the starling bird flock. What do you notice? Describe the movements observed from the flock. How are the birds responding to the movement of the rest of the flock? How do they do it so incredibly quickly? What questions do you have about the movement of the flock?)*

3. Students develop and use a model to record observations of starling murmuration and analyze this data to find ***patterns*** related to the ***causes*** of this behavior.

(Teacher Hint: Engage students in discourse using prompts such as: How does the number of birds ***affect*** *the murmuration within a flock of starlings? What* ***causes the pattern*** *of flight to change? How do birds keep from bumping into one another? Do the starlings have consistent flight* ***patterns****? Or are there external influences that* ***affect the patterns*** *we see? Students utilize computer simulation models, video footage, and possibly observations in the field to validate explanations. Amazing Starling Flocks are Flying Avalanches – Starling Physics:* https://www.wired.com/2010/06/starling-physics/*)*

(Teacher Hint: Students observe information about the ***patterns*** *of animal behavior called murmuration in other species, (flocking, swarming, herding, shoaling). Students utilize computer simulation models or actual video footage to validate explanation.)*

<table>
<tr><th>Stage: Clarify Intended Learning</th><th>Reasoning</th></tr>
<tr><td>
Students use evidence to construct explanations about the causes of animals engaging in murmuration flight behavior patterns.
Stage: Elicit Evidence
Students use models (computer simulations or field observations) to further develop evidence for the causes of patterns of flocking behavior.
Stage: Interpret Evidence
Students develop an explanation of the causes and changes in the animal system.
Stage: Act on Evidence
Students communicate their revised explanations of the causes and changes of patterns of flocking behavior.
</td><td>
4. Students construct an explanation supported by evidence for the causes of changes in behavioral patterns of animals within an interacting system of a flock.
Prompts to Initiate a Class Discussion:
Q: What causes the changes in the pattern that results in the behavior of starling murmuration?
Q: Based on the observations and initial modeling, explain why the pattern of starling murmuration is not always observed when the birds are flying together?
Q: How does this model support the concept of patterns?
(Teacher Hint: Boids computer modeling may be used to assist students in tracking and understanding bird flocking behavior patterns of birds: https://cs.stanford.edu/people/eroberts/courses/soco/projects/2008-09/modeling-natural-systems/boids.html. How does the simulation Boids Work? A Flocking Simulation https://www.youtube.com/watch?v=QbUPfMXXQIY). Alternative to using a computer simulation is engaging in field observations.)
(Teacher Hint: Murmurations by starlings may occur in different seasons depending on geographic location.)
5. Students obtain additional information to extend their learning about patterns of murmuration by reading the nonfiction text Explaining Bird Flocks: https://www.audubon.org/magazine/march-april-2009/explaining-bird-flocks .
Prompts to Initiate a Class Discussion:
Q: When have you noticed this type of pattern in other animals' behavior?
Q: How is flocking behavior related to the seasonal changes?
Q: What role does patterns play in animal behavior?
Q: What would be the impact if these types of animal behavior patterns ceased to exist?
Q: How are the seasons related to flocking behavior?
6. Students revise their models to show the causes of patterns in starling flocking behavior.
</td></tr>
</table>

Stage: Clarify Intended Learning *Students use their revised models to communicate the causes of the changes in the patterns of flocking behavior.* ***Stage: Elicit Evidence*** *Students use models (computer simulations) to develop evidence for the causes of patterns of flocking behavior.* ***Stage: Interpret Evidence*** *Students develop an explanation of the causes and changes in the animal system.* ***Stage: Act on Evidence*** *Students communicate an explanation of the causes and changes in the animal system.* ***Stage: Reflection on and Extension of Learning*** *Students should be prompted to extend their understanding of the causes and changes in patterns of flocking behavior to other animal grouping behaviors (e.g., swarming, herding, shoaling).*	***Communicating*** 7. Students use their models to communicate their explanation for flight ***patterns*** and relate the behavior to individual and group survival. 8. Students communicate their explanation developed from the evidence supporting the ***causes of patterns of*** grouping/flocking/herding behavior of multiple species of animals that help protect them to survive. *(Teacher Hint: This lesson could also be extended to the study of genetics and its relationship to behavior. Student investigation may include the awareness of individual space and awareness of neighbor's behavior with the presence of a predator causing the* ***system to change****.)*
	Science Essentials *(Student Performance Expectations from Appendix C, D, E (Moulding, et al., 2015))*
Science Practices	Make observations that generate evidence.
Obtain Information Ask Questions Develop and Use Models Construct an Explanation	Generate questions based on observations. Use representations to develop explanations of science phenomena. Use representations to predict cause and effect. Explain science phenomena using evidence.
Crosscutting Concepts	Explain why a specific order of events is necessary to cause the phenomena to occur.
Cause and Effect Systems Patterns	Describe interactions of specific parts of the system. Identify the causes of observed patterns.
Disciplinary Core Ideas	Group behavior has evolved because membership can increase the chances of survival for individuals.
Animal Behavior	

*Using the **cause and effect** crosscutting concept as a formative prompt can elicit student thinking and facilitate instructional decisions. In this lesson, students use static electricity to understand **causal** connections between the electric force and amount of charge. Students also understand the **effect** that the distance between charged objects has on the electric force.*

This third-grade lesson component uses the Gathering, Reasoning, and Communicating (GRC) format to engage students in an investigation of static electricity. Crosscutting Concepts are used to formatively assess students understanding of the phenomenon by prompting student responses. Students identify patterns to use as evidence for a cause and effect relationship between force and distance.	
Science Performance	
Grade – 3rd	**Title**
Topic – Force and Interactions	***Charge!***
Performance Expectation: (NGSS) **3-PS2-3.** Ask questions to determine cause and effect relationships of electric or magnetic interactions between two objects not in contact with each other. [Clarification Statement: Examples of an electric force could include the force on hair from an electrically charged balloon and the electrical forces between a charged rod and pieces of paper; examples of a magnetic force could include the force between two permanent magnets, the force between an electromagnet and steel paperclips, and the force exerted by one magnet versus the force exerted by two magnets. Examples of cause and effect relationships could include how the distance between objects affects strength of the force and how the orientation of magnets affects the direction of the magnetic force.] [Assessment Boundary: Assessment is limited to forces produced by objects that can be manipulated by students, and electrical interactions are limited to static electricity.]	
Lesson Performance Expectations • Ask questions about the cause and effect relationship of charged objects not in contact. • Plan and carry out an investigation based on generated questions that produce data on the effect of electrically charged objects on various objects that are not in contact with each other. • Analyze data collected on the effects on how charged objects interact with other objects and compare and contrast results with other groups in order to identify patterns within the data. • Construct explanations for the cause and effect relationship of interactions between charged objects not in contact with each other. **Formative Assessment Stages:** *Clarified Intended Learning, Elicit Evidence, Interpret evidence, Act on Evidence* **Success Criteria:** Use data collected from an investigation to support the explanation about a cause and effect relationship with distance between objects affecting the strength of a force.	

Student Science Performance

Phenomenon: A child's hair stands up when he/she gets near a balloon at a birthday party.

Gathering

1. Students explore (investigate) the phenomenon by rubbing a balloon on clothing and placing it near their hair ***causing*** their hair to stand on end.
2. Students develop questions about the ***causes*** of the observed phenomenon of static electricity and discuss similar phenomena they have experienced (e.g., rubbing shoes on carpet, comb in hair, jumping on trampoline).

(Teacher Hint: A short discussion should occur here and post questions to investigate on the board or chart paper to use in later discussions about questions that help students investigate the phenomenon.)

3. Students plan and carry out an investigation using balloons and other materials (e.g., paper dots, dental floss, empty pop cans) to gather data on the ***effect*** of electrically charged objects acting from a distance.

*(Teacher Hint: Encourage students to represent data in a graphical display that reveals **patterns** (e.g., identify types of objects that are most electrically charged, the number of paper dots picked up). Students may generate questions about the amount of charge (the more you rub the balloon, the closer the balloon is to the paper dots), or the amount (weight or number) a charge can pick up.*

4. Students plan and carry out an experiment to measure how the distance between two electrically charged objects ***affects*** the forces between the two objects.
5. Students use models (charts and tables) to record measurement of the ***effects*** of distance on the forces between electrically charged objects.

*(Teacher Hint: Students may have heard the words static electricity before but may have little understanding of the underlying science concepts. Emphasis is on the **cause and effect** relationship among objects interacting at varying distances, not on the buildup and transfer of electrons.)*

Reasoning

6. Students construct an explanation supported by evidence describing what ***causes*** the force between the balloon and object to become stronger or weaker.

Class Discussion

Questions to initiate class discussion:

Q: How can you ***cause*** the balloon pick up more paper dots?

Q: Why does moving the balloons further from the paper dots ***cause a change*** in the force between the balloon and paper?

Q: What is the relationship between force and distance in the investigation?

Q: What ***patterns*** in the data support your explanation for the forces between the balloon and paper?

Q: Which of your questions about static electric charge were the most useful for planning the investigation of the ***cause and effect*** relationship between distance and electric force.

*(Teacher Hint: The class discussion should focus on questions that provide students with an understanding of the **causes** of the phenomenon and common understanding of the DCIs and CCCs to construct an explanation. Provide students with opportunities to revisit the questions posted in the initial discussions from the gathering phase of the lesson. Which of the initial questions were useful in planning this investigation? Students' outcome of this lesson is simply that some forces act at a distance and the greater the distance the smaller the force of attraction or repulsion.)*

Communicating

7. Students revise their explanation supported by evidence describing ***cause and effect*** relationships between charged objects not in contact with each other.
8. Students are able to refine and extend questions generated at the beginning of the lesson about ***effects*** of distance on the force of attraction.

Assessment of Student Learning

Formative Assessment Stage: *Interpret Evidence*

Student Evidence of Proficiency	Other Possible Responses	Act on Evidence
• Data tables contain information about the test (e.g., distance of charged object, observation of interactions). • Students interpret data to find patterns about how objects not in contact with each other are able to interact. • Students explain that force acts over a distance. • Students are able to make a claim about the cause and effect relationship between distance and the strength of the force.	• Students have difficulty in collecting data. • Students are having difficulty observing the pattern of force with distance.	• Review investigation procedures and techniques (e.g., control amount of charge) to observe how students are collecting data accurately and appropriately. • Review as a class to analyze data and make inferences about patterns regarding how the force decreases with distance.

Formative Assessment Stage: *Reflections and extension of learning*

Refine questions generated and allow time for investigations.

Revisit the concept with magnets to determine similar patterns of forces acting over a distance.

Science Essentials	
Science Practices	Pose questions that are testable.
Ask Questions Plan and Carry out an Investigation Analyze Data Construct an Explanation	Formulate testable hypotheses and pose questions in science that seek evidence relevant to the question. Make careful observations that generate evidence. Work collaboratively in science investigations. Compare data to make sense of and explain phenomena. Explain science observations using evidence.
Crosscutting Concepts	Describe the conditions necessary for the phenomena to occur.
Cause and Effect Patterns	Use evidence to support explanations for the causes of phenomena. Use patterns as evidence to support science explanations. Use graphs and charts to investigate and analyze patterns in data.
Disciplinary Core Ideas	PS2.B: Types of Interactions · Electric, and magnetic forces between a pair of objects do not require that the objects be in contact. The sizes of the forces in each situation depend on the properties of the objects and their distances apart and, for forces between two magnets, on their orientation relative to each other.
Forces	Objects with a static electric charge act on one another even at a distance. The electric force between two objects decreases as the distance between the objects increases.

APPENDIX B
DEVELOPING THREE-DIMENSIONAL ASSESSMENT ITEMS

The purpose of this tool is to organize performance expectations within bundles in order to identify, explain, and analyze student learning. Crosscutting concepts are an effective tool with both formative and summative assessments. Below is a tool for use in developing formative and/or summative assessment items and/or clusters of items.

- Formative assessment can narrow achievement gaps by generating information that can guide instruction for all students.
- Formative assessments can be designed to be accessible to culturally and linguistically diverse students in ways summative assessments cannot—to allow students to respond in a variety of ways (e.g., in their native language or with the support of other students).
- Effective formative assessments can be situated in compelling, relevant contexts that are more accessible (http://stemteachingtools.org/brief/18).

Formative Assessment Process Template

<table>
<tr><td colspan="4">Assessing Three-Dimensional Performance Expectations

Tool for Organizing Bundles for Item Clusters</td></tr>
<tr><td colspan="4">Phenomenon: 1) Description of the phenomenon, 2) the specific causes of the phenomenon, 3) the evidence that supports an explanation of the causes of the phenomenon, and 4) the system in which the phenomenon occurs. Start with a locally relevant phenomenon to engage student interest and experience.

(Teacher Hint: You may wish to indicate the sources of the evidence (e.g., core idea, law, observational data, patterns).</td></tr>
<tr><td colspan="4">Insert PE Bundle:</td></tr>
<tr><td>Practices List from PE</td><td colspan="2">DCI List from PE</td><td>CCC list from PE</td></tr>
<tr><td></td><td colspan="2"></td><td></td></tr>
<tr><td colspan="4">Teacher Hint: Clearly defining the evidence of student learning, prior to developing formative assessment tasks. You may wish to use the exercise below in this process.</td></tr>
<tr><td>Assessments designed to merge the three-dimensions could contain the following evidence of student learning:</td><td colspan="3">Describe possible experiences that would provide evidence of student learning.</td></tr>
<tr><td>Assessments designed to merge DCI and CCC</td><td colspan="3"></td></tr>
<tr><td>Assessments designed to merge DCI and Practice</td><td colspan="3"></td></tr>
<tr><td>Non-PE

Practices to Support Performance</td><td colspan="3"></td></tr>
<tr><td>Non-PE

DCIs and CCC

Integral to Making Sense of Phenomenon</td><td></td><td colspan="2"></td></tr>
</table>

Clarify Intended Learning (Learning Goals)

[insert framing language to introduce the phenomenon and lesson performance (expectation/outcome/learning target) and how learning goals and success criteria will be shared]

Success Criteria

[Insert Success Criteria that communicates intended learning in terms that are culturally neutral and that all students will understand].

Elicit Evidence of Learning

[Insert what students and teacher will be doing to demonstrate where students are in their progress toward the intended learning. Consider multiple methods for demonstrating understanding (e.g., developing and refining a model, generating and analyzing data, engaging in both spoken and written explanations and argumentation)]

Teacher Questions to Prompt Student Responses
[Insert series of questions using crosscutting concepts to elicit evidence of student learning.]

Possible Method/ Product	**Student Experiences/Products May Include:** [Insert student products (e.g., students construct tables to organize data collected)].
Additional Possible Method/Product(s)	

Interpret and Act on Evidence

Student Evidence of Proficiency	Other Possible Responses	Act on Evidence
[Insert range of possible student responses, attending to the diverse ways students from different cultural backgrounds might express an idea. What are you looking for and what will more or less proficient performances look like?]	[Insert ideas students share that demonstrate developing understanding that can be built upon in designing instruction, rather than identifying them as incorrect or a misconception.]	[Insert next steps for instruction that will allow students to refine their understanding.]

Engaging Students in the Process

Teacher Notes

[Insert teacher's notes, such as "Engage students in peer review of their claims by having them share their evidence and claims. Students could post their claims on the wall and then engage in classroom discourse or verbally share with a partner or small group to get feedback" (*this allows for both peer- and self-assessment*)].

Use the "Act on Evidence" column of the table to interpret the data to make instructional decisions and provide actionable feedback to move students forward along the progression of learning toward the performance expectations.

Reflection on and Extension of Learning

Teacher Notes

[Insert teacher notes to support reflection and extension of learning.] Have students revisit the student performance expectation and success criteria to determine their progress toward the lesson outcome.

The following guiding questions are designed to set the stage for the next student learning performance and the next formative assessment cycle. Students should be prompted to extend their understanding of the phenomena to move them toward meeting the performance expectation.

Guiding Questions

[Insert questions to guide reflection.]

APPENDIX C
PHENOMENON - TEACHER PROMPTS - STUDENT RESPONSES USING CCC

Below are examples of Phenomenon - Teacher Prompts - Student Responses Across Causality, Systems, Patterns.

Examples using ***causality*** in prompts to initiate students' reasoning about phenomena with possible student responses are provided below.

Phenomenon: In the fall leaves change color and fall off most trees.	
Possible Prompts:	**Possible Student Responses***
• "Why do leaves ***change*** color in the Fall? • How do ***changes*** in the amount of daylight ***cause changes*** in the ***structure*** of leaves that leads to ***changes*** in color of the leaves?	• Elementary – *Changes in the seasons cause leaves to change color.* • Middle School – *Changes in the quantity of sunlight the leaves receive in the fall is different than in the summer and this causes the leaves to change color and fall off the trees.* • High School – *Seasonal changes in the quantity of sunlight the leaves receive causes chlorophyll production to slow down, then stop, and eventually the chlorophyll in the leaves is destroyed. The green color of leaves is caused by chlorophyll, so when it is gone the leaves take on the color of the other substances left in the leaf.*
Phenomenon: Often in the morning the grass is covered with water.	
Possible Prompts:	**Possible Student Responses***
• Why does water ***change*** from a gas to a liquid on a cold morning that results in dew appearing on the grass? • How does the flow of ***energy*** out of the ***system affect*** the number of molecules of water ***changing*** from a gas into a liquid?	• *Not appropriate for elementary as stated (matter and energy in the 3-5 band does not allow explanation as stated in the Framework).* • Middle School – *On a cold morning the gas water particles slow down causing the water to change from a gas to a liquid. The loss of energy (colder temperatures) causes more gas water particles to change into liquid. Water as a liquid has less energy than water as a gas. Matter with lower temperatures has less energy than matter at higher temperatures.* • High School – *As the temperature falls on a cold morning, energy is transferred from the system of water molecules to the surrounding system causing the gas water molecules to slow down and change (condense) into a liquid dew on the grass. As more energy is removed, fewer molecules of water are able to stay in gas form and so more liquid water appears on the grass. Energy is moving from one system to another and the total quantity of water molecules in the air and on the grass is the same.*
Phenomenon: Most South American iguanas live their entire lives on land, however, the Galapagos islands marine iguanas swim underwater to eat seaweed.	

• Why are some of the marine iguanas, anatomical ***structures*** different from iguanas living on the nearby South American continent? • How did populations of iguanas on islands ***change*** over time to have unique ***structures*** and behaviors for survival?	• Elementary – *Iguanas have* ***structures*** *that help them* ***function*** *in their environment (sea versus land).* • Middle School – *The* ***structures*** *of marine iguana* ***function*** *slightly differently to meet the needs of these organisms living in the ocean. Marine Iguanas'* ***structures have changed*** *over millions of years to be better adapted for the marine environment. Traits that are favorable for living in the intertidal zone are selected for an increase in the population.* • High School – *Slight differences in the genetic variation of the two populations and differences in living and nonliving components of the* ***ecosystem*** *lead to the natural selection of populations of individuals with different* ***structures****. Genetic traits that are favorable for living in an island* ***ecosystem*** *increase within a population of organisms living in an isolated environment. Given enough time, this may lead to some* ***changes*** *that result in differences in how* ***structures*** *in these organisms* ***function*** *to better meet the needs of the iguanas.*
Phenomenon: The design of the roofs on houses is different by region/location.	
• After observing the type of roofs in a particular region, how do the roof ***structures*** support the ***function*** of providing protection from environmental conditions? • After observing the typical building materials used in a region, how do the choices of materials support the ***function*** of minimizing energy costs? • Are there ***structural*** features of homes that appear to offer no ***functional*** value? • If you consider all these ***structural*** factors, what set of criteria could help you identify the ***functional*** requirements for a set of environmental conditions?	• Elementary – *The* ***structure*** *of the roof (shape)* ***causes*** *water or snow to run off more quickly and keep the interior of the house dry and/or the roof from collapsing.* • Middle School – *Human engineered* ***structures function*** *to meet the needs the people who designed them and the conditions of the location of the building. Where there is lots of snow the roofs have stronger materials.* • High School – *The roof structure is engineered specific to the climate at the building site. High snow depth may require steeper roofs. In areas with large snow fall, the roofs may have steeper pitch and be constructed with a greater slope. The criteria for engineering a roof are found in the local building codes and includes the weight limits for various roof slopes. The dimension of the lumber is another factor that affects the function of the roof or using different building material (metals, concrete) with greater properties to improve the structure to function to meet the needs of the conditions.*
** Student Responses may include naive ideas and/or concepts and inaccuracies that become resolved through the class discussion.*	

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