Strengthening Claims-based Interpretations and Uses of Local and Large-scale Science Assessment Scores (SCILLSS)

A Principled Approach to Designing Three-dimensional Science Assessment Tasks

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Introduction

States, districts, schools, and classrooms are grappling with how to maximize student achievement in science within the context of the recent shift toward the Next Generation Science Standards (NGSS). The NGSS are research-based standards born out of the National Research Council's (NRC) A Framework for K-12 Science Education (*Framework*; NRC, 2012)—a report calling for a re-envisioning of science education that reflects the science, engineering, and technology needs of the 21st century, and engages K-12 students as scientists and engineers in the classroom. The NGSS are meant to support the vision of the *Framework* by defining the three-dimensional performance expectations, or standards, that describe what students will need to effectively solve problems in response to real-world science phenomenon and to build a cohesive understanding of science over time. The three dimensions of learning as defined in the *Framework* include, 1) crosscutting concepts (CCCs) (i.e., concepts that span across science domains and help students explore connections across the four domains of science, such as "cause and effect"); 2) science and engineering practices (SEPs) (i.e., the practices of investigating the natural world (for science) and designing and building systems (for engineering)); and 3) disciplinary core ideas (DCIs) (i.e., key ideas that build on each other and are grouped into four domains: Physical Science, Life Science, Earth and Space Science, and Engineering). These dimensions are not meant to exist in isolation, but rather are designed to be integrated both in instruction and assessment. The NRC notes that "integrating the three dimensions in a coherent way is challenging" and "the development of standards, curriculum, instruction, and assessment that successfully integrates the three dimensions is an area ripe for research and innovation" (NRC, 2012, pp. 217-218). Now that the NGSS have been created to address the *Framework's* vision, innovative solutions for the other aspects of science education (e.g., curriculum, instruction, and assessment) are needed. The new, three-dimensional science standards pose unique challenges to summative and local assessment and demand new ways of measuring science learning to ensure students are being assessed on complex science thinking, not just superficial knowledge.

The Strengthening Claims-based Interpretations and Uses of Large-scale Science Assessment Scores (SCILLSS) project brings together a collaborative of three states—Nebraska, Montana, and Wyoming—with a team of researchers and a panel of experts to bridge the gap between national-level shifts in the expectations for science education, and state-, district-, school- and classroom-level interpretation and implementation. Funded through a four year (April 2017 to December 2020) Enhanced Assessment Grant from the US Department of Education, SCILLSS aims to (a) strengthen the knowledge base among state and local educators for using principled-design approaches to design and evaluate quality science assessments (both local and summative) that generate meaningful and useful scores, and (b) establish a means for connecting statewide summative assessment results with classroom assessments and student work samples in a complementary system.

SCILLSS is designed to benefit states by establishing a comprehensive assessment approach along with replicable and scalable principled-design processes and tools that state and local educators can use to clarify and strengthen the connection between statewide summative science assessments, local assessments, and classroom instruction, enabling all stakeholders to derive maximum meaning and utility from assessment scores.

Purpose

The purpose of this paper is to provide the SCILLSS participating states and external stakeholders, such as state education agencies, assessment vendors, and other organizations, with an overview of the SCILLSS five-phase principled-design model that was used to develop a set of replicable tools which can be scaled to address the unique characteristics and contexts of states' assessment systems, with a particular focus on establishing coherence among state on-demand summative assessments, or assessments developed and administered at a time mandated by the state, and classroom-embedded assessments, or assessments developed by the state or district and administered at a time determined by the district/school that fits the instructional sequence in the classroom.

This five-phase model facilitates the identification of the science construct—or the complex of knowledge, skills, or other attributes that should be assessed—and ensures that the construct is appropriately reflected throughout the development of the processes and tools for the project including, but not limited to, the claims, measurement targets, elaborated dimensions, integrated dimension maps, design patterns, task templates, and tasks.

It is important to emphasize that the processes and tools resulting from this work will not encompass every aspect of the assessment system. Neither the overall design of the assessment (e.g., the number and types of tasks) nor the scoring system(s) are addressed at this stage of the work. Nor will the SCILLSS resources result in pieces of an assessment system (e.g., claims, performance level descriptors, design patterns, tasks) that can be used directly in a state's system. Rather, the goal is to produce principled-design and development processes, along with a set of design artifacts and other resources, that can support our state partners in defining in detail the science construct(s) targeted for measurement based on the principles of the *Framework*.

SCILLSS Iterative Five-phase Principled-Design Model

Principled-design is a disciplined approach aimed at designing assessment systems while keeping in mind the inferences end users wish to make based on test scores. If assessment information (i.e., subscores, total scores, etc.) is expected to have value and usefulness for educators, then early in the design phase assessment developers must have a clear sense of how the test scores will be used to support inferences about teaching and learning. Principled-design is an approach to constructing assessments that ensures the evidence, and interpretations of evidence from the assessment, align with and support the intended claims, purposes, and uses of the assessment.

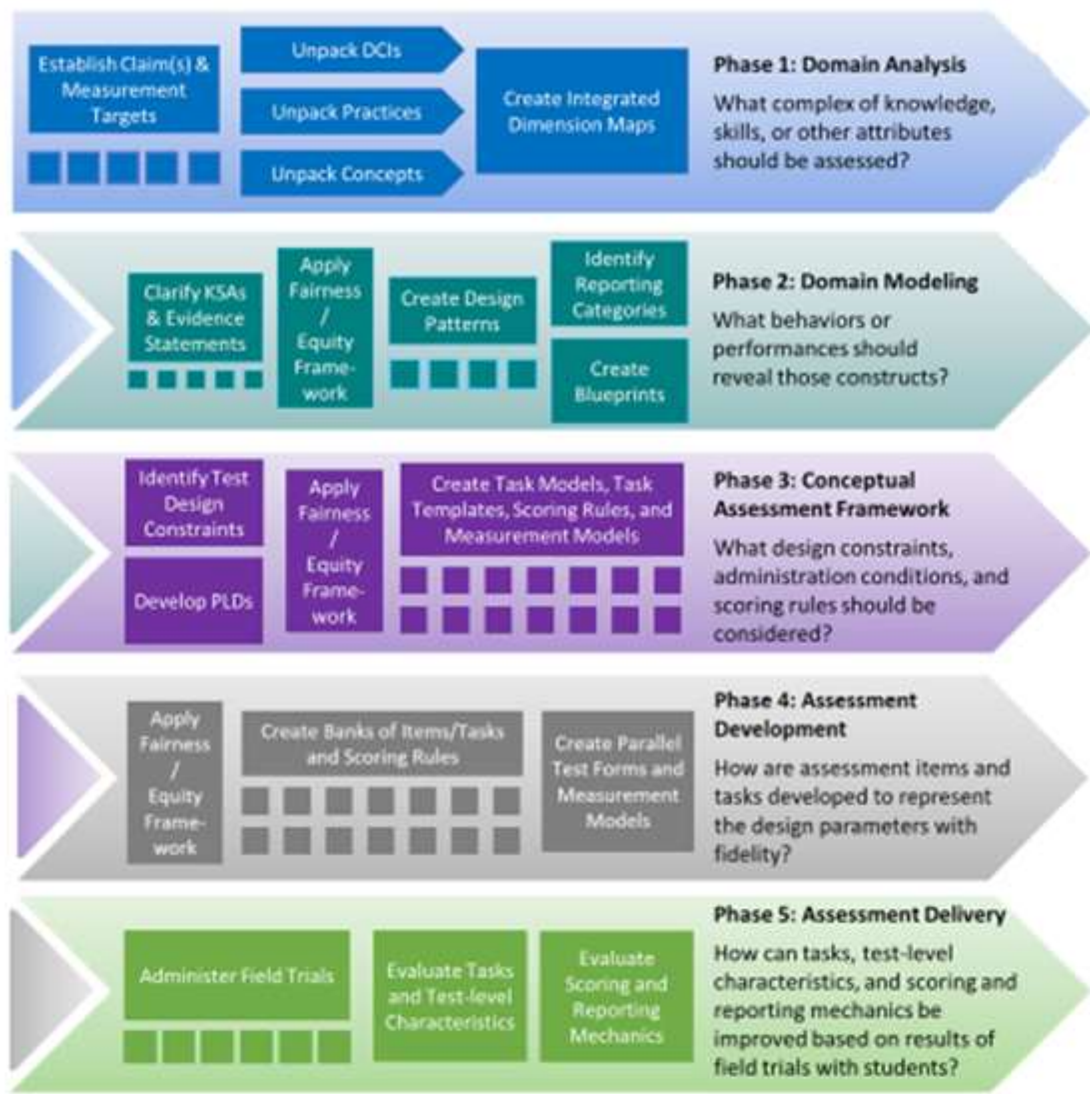
A popular type of principled-design is referred to as **Evidence-Centered Design (ECD)**. ECD is a framework that prompts developers to think about not just the assessment's claims and their warrants, but also about how the assessment is designed (Mislevy & Haertel, 2006). ECD is based on Messick's (1994) questions:

1. What constructs of knowledge, skills, or other attributes should be assessed?
2. What behaviors or performances should reveal those constructs?
3. What tasks or situations should elicit those behaviors?

To implement ECD as part of a principled-design approach, SCILLSS partners will consider these questions in relation to one another. The purpose of considering the relationships among these questions is to build an evidentiary argument that supports inferences about what students know, can do, or have accomplished more generally based on what we observe them say, do, or make in a few particular instances (Mislevy et al., 2003). This view of assessment as argument is a cornerstone of test **validity** (Kane, 1992, 2006; Messick, 1989)—that is, the degree to which the assessment accurately measures what it is intended to measure in support of the intended interpretive uses, and **reliability**—the degree to which the assessment yields consistent results.

The state partners in the SCILLSS project will use an iterative five-phase principled-design process (see Exhibit 1) to design assessments that align closely to the three-dimensional science standards derived from the NGSS and principles of the *Framework*. This principled assessment design method (Mislevy & Haertel, 2006) is useful for translating academic content (e.g., the disciplines' core ideas, crosscutting concepts, and scientific practices) into assessment tasks by using tools like design patterns and task templates. The design patterns and task templates, in turn, help identify the constructs and prerequisite knowledge, skills and abilities needed by students to perform successfully on the assessment tasks that, ultimately, will comprise the states' science assessment.

Exhibit 1. Five-phase Iterative Principled-design Process



As displayed in Exhibit 1, SCILLSS partners are applying five ECD phases: 1) Domain Analysis, 2) Domain Modeling, 3) Conceptual Assessment Framework, 4) Assessment Development, and 5) Assessment Delivery. In the first phase, **Domain Analysis**, we set out to articulate what information is important in a particular domain of science (e.g., biology, physics or chemistry) and to specify to the degree possible how the knowledge, skills, and abilities in the domain are acquired—describing the links to curriculum and instruction, with an eye toward the implication this information has on the design of the overall assessment and the candidate assessment tasks. Thus, this phase of the assessment design work is focused on gathering substantive information about the domain to be assessed. The key aspects of the domain, once defined in the first phase, are then organized and structured in the second, **Domain Modeling**, phase. The domain modeling work is accomplished through the principled application of design patterns (i.e., formal representations that address the recurring design problems in a particular domain of science). In assessment, a design pattern is used as a schema or structure for conceptualizing the components of the assessment argument and is structured around the identification of the focal knowledge, skills, and abilities (fKSAs) to be assessed; the identification of the behaviors that provide evidence of the attainment of those fKSAs; and the features of the assessment items and tasks that elicit those behaviors. The third phase, **Conceptual Assessment Framework**, builds on the Domain Modeling layer by continuing to organize and structure domain content in terms of the assessment argument, but moving more toward the mechanical details required to develop and implement an operational assessment. In the fourth phase, **Assessment Development**, task template specifications are used to develop tasks and rubrics. The candidate tasks are then organized into parallel test forms and test administration instructions are specified. In the fifth phase, **Assessment Delivery**, "field" trials are administered to empirically evaluate the interactions of the students with the tasks and the test-level characteristics, as well as to evaluate the scoring and reporting mechanics.

In this paper, we clarify and elaborate on each phase of this design process. We define and articulate the elements, processes, and outcomes of SCILLSS' partners' work to organize and select the essential three-dimensional science content for the assessments at grades 5, 8, and 11. It is particularly important to note, that while this five-phase process suggests a sequential design model, we employed cyclical and iterative refinements to all elements of this process, as appropriate, to ensure alignment within and among design tools and templates.

Phase 1: Domain Analysis

During the first phase of the principled-design approach, we focus on the content relevant to the assessment. In the sections below, we describe each element of this phase of the work, including: (1) establishing the claims we want to make about students' performance; (2) identifying the measurement targets central to the assessment, including a thorough elaboration and unpacking of these measurement targets; and (3) creating the integrated dimension maps. We close this paper with a summary process and recommendations for carrying out the work of Domain Analysis for a state assessment program.

Claims

The first step is the development of the claims. At the policy level, a claim typically describes what it is educators and other stakeholder want to know and say about what students know and can do in a particular domain, in this case elementary and secondary school science. When developing a claim, it is important to consider the critical aspects of the discipline, as well as the nature of the scores that will be produced by the assessment that, in turn, provide evidence to support the claim(s) made about student performance.

For the SCILLSS project we developed, as an example, one overarching claim (e.g., *students demonstrate a sophisticated understanding of the core ideas and applications of practices and crosscutting concepts in the disciplines of science*). Included in this claim is the inference that students are able to integrate disciplinary core ideas and crosscutting concepts with scientific practices to investigate and explain how and why phenomena occur; they are able to design experiments and refine solutions to problems; they can connect knowledge across the disciplines of science to ask questions, and plan and carry out investigations; and they can analyze and interpret data to support an argument about one or more phenomena in a variety of contexts.

In this broad claim we are highlighting that the focus of the assessment is not simply the students' knowledge of science content, but the emphasis on how they use that knowledge while engaging in scientific practices and crosscutting concepts and ideas. This exemplar claim highlights the integrated nature of the aspects of the discipline, with the implication that the representative assessment tasks are designed to require students to address more than just disciplinary content when addressing the tasks. The assessment tasks and the subsequent scoring system, by design, provide evidence based on student performance to support the claim.

Measurement Targets

As demonstrated, the claim as generated was meant as an overarching claim for the assessment. It does not provide guidance for the development of specific tasks. Thus, *measurement targets* must be articulated to bridge the gap between the overarching claim and the design of the individual tasks. Measurement targets are narrative descriptions that integrate the DCIs, SEPs, and CCCs into a single statement representing what is to be assessed. While they are not meant to produce sub-scores, clearly specified measurement targets provide a way to deconstruct the domain into sets of related constructs. The measurement targets, therefore, should align with the prioritized academic content designed to frame the assessment.

To generate the measurement targets, SCILLSS content experts used the NGSS Example Bundles (https://www.nextgenscience.org/resources/bundling-ngss)—a group of performance expectations (PEs) or standards that have been combined to help educators organize instruction around various topics, often considered the "big ideas" for a particular grade level. The intent of a bundle is not to dictate curriculum or to say "how" the multi-dimensional PEs should be taught. Rather, a bundle is intended to match the scale of an instructional "unit," as it is commonly defined in many education settings. In addition, within the NGSS example PE bundles, a corresponding document identifies the underlying rationale and assumptions about the unifying relationships among the bundled PEs.

Using this "bundling" approach for grades 5, 8, and 11, the measurement targets are designed to represent clusters of multi-dimensional PEs that students are expected to demonstrate by the end of an academic grade. The SCILLSS content experts designed the targets to connect instruction to assessment, provide a context for ensuring assessment results are meaningful and actionable at the classroom level, and to support the paradigm shift in performance expectations identified by the SCILLSS partners for science teaching and learning for all students. At grade 5, the measurement targets reflect bundles based on the topical arrangement of the NGSS; at grade 8, the measurement targets reflect the Course III Topics arrangement of the NGSS; and at grade 11, the measurement targets reflect the Course III Topics arrangement of NGSS.

An example of a measurement target from grade 5 is, "Students are able to investigate and interpret data to draw or support conclusions about the structure and properties of matter, including whether or not matter is conserved, and to identify materials and mixtures based upon their properties or results of a reaction." This measurement target combines the main ideas from several related grade 5 PEs (5-PS1-1, 5-PS1-2, 5-PS1-3, 5-PS1-4, 5-PS1-5). Thus, this measurement target integrates the DCIs, SEPs, and CCCs from these five PEs.

Once the measurement targets are determined for a grade level they should be reviewed as a set. SCILLSS partners reviewed the sets of measurement targets at grades 5, 8, and 11 to ensure that they provide coverage of the main constructs for the grade level such that including tasks that measure these targets provide evidence related to, and in support of, the overall claim. As such, each of the measurement targets were designed to reflect an integration of the DCIs, SEPs, and CCCs.

The larger claims and the related measurement targets provide information about what should be measured. They do not provide information about how to measure those targets. To determine the "how" of the ECD approach requires assessment designers to unpack or deconstruct the measurement targets with respect to the NGSS PEs.

Examples of three sets of measurement targets, one each at grades 5, 8, and 11, are provided in Appendix A.

Elaborating and Unpacking the Measurement Targets

Once the measurement targets are defined, they are further elaborated through a process called unpacking. In the unpacking process the PEs are listed that align to a measurement target. The DCIs, SEPs, and CCCs associated with these PEs are then also listed. Each of these dimensions are then "unpacked" to reveal the essential elements as related to the PE. Unpacking DCIs, SEPs, and CCCs entails thoughtful consideration of ideas, practices, and concepts in relation to students' grade level, or expected level of expertise (Harris et al. 2016, p.6).

To aid in the unpacking, SCILLSS partners used a template for each of the dimensions to provide further guidance on the interpretation of these dimensions and how they can be assessed. Exhibit 2 displays the fields included within each of these templates. For the DCI, the unpacking focused on further elaborating the content that is covered by the DCI and clarifying the expectations for what students should know and be able to do at the assessed grade level. For the SEP and CCC it is clarifying what it means to engage in this practice or crosscutting concept for students at the assessed grade level. Completing the templates included breaking down the knowledge, skills and abilities (KSAs) required of students into multi-dimensional maps of the content domain and the KSAs.

Exhibit 2. Fields of the Unpacking Template for the Performance Expectations

Fields of the unpacking template for the DCI	
Field	**Description**
Elaboration of the DCI	Lists the different parts of the DCI and their relationships to each other. Also provides clarifications (other than those listed below)
Proficiency Boundaries	Describes what is outside of the scope of (but is related to) the DCI. Considers the grade range of the DCI.
Prior Knowledge	Describes what knowledge students might need to address the DCI, but is not covered by the DCI. This may be knowledge that students would have acquired at an earlier grade level.
Student Challenges	Describes common errors that students might have or make related to the DCI.
Articulation of DCIs Across Grade Levels	Lists related DCIs at adjacent above and below grade levels to show how a DCI is vertically articulated across grades.
Fields of the unpacking template for the SEPs and CCCs	
Field	**Description**
Essential Knowledge and Skills	Describes what it means for students to engage in the SEP or with the CCC.
Evidence of a High Level of Performance	Defines behaviors that you would expect to see if a high-performance student was engaging with the SEP or CCC.
Prerequisite Knowledge and Skills	Describes what knowledge students might need to address the SEP or CCC but which is not covered by this component. This may be knowledge that students would have acquired at an earlier grade level.
Relationships to Other Practices	Describes other practices that students might typically exhibit while engaging with the SEP or CCC. Includes information on how to separate out performance on the different aspects.
Student Challenges	Describes common errors that students might have or make related to the SEP or CCC.
Common Core State Standards (CCSS) for Mathematics Connections	Lists CCSS in mathematics that address similar knowledge, skills, and abilities to those represented in the SEP or CCC.
Common Core State Standards for ELA/Literacy Connections	Lists CCSS in ELA/literacy that address similar knowledge, skills, and abilities to those represented in the SEP or CCC.

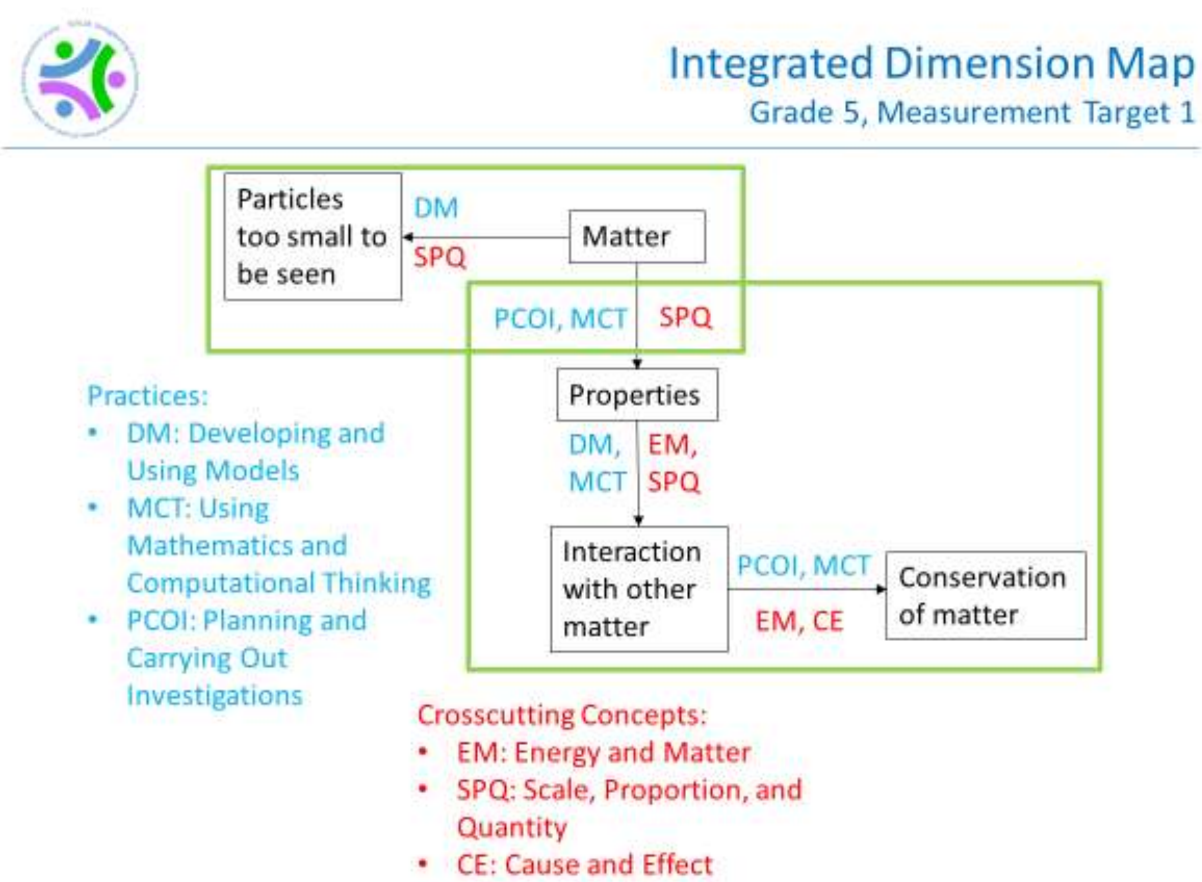
Examples of the elaborated dimensions for three measurement targets, one for each dimension at grades 5, 8, and 11, are provided in Appendix B.

Integrated Dimension Maps

Integrated dimension maps are visual representations of the measurement target that describe the essential DCI relationships and link them to aspects of the targeted CCCs and SEPs (or to closely related CCCs and SEPs as identified by the unpacking process). Each map represents the "terrain" of the measurement target; it illustrates how the three dimensions are intended to work together to visualize student proficiency with a measurement target, and they show the possible ways for combining aspects of the three dimensions. SCILLSS partners developed three integrated dimension maps, one each for grades 5, 8, and 11.

Each map covers one measurement target. The development of the map starts with specifying the different aspects of the content and how they are related to each other. For example, in the grade 5 measurement target, "Students are able to investigate and interpret data to draw or support conclusions about the structure and properties of matter, including whether or not matter is conserved, and to identify materials and mixtures based upon their properties or results of a reaction," the content includes the idea of "matter" as made up of “particles too small to be seen” that is has "properties" and that it "interacts with other matter" in a way that there is "conservation of matter" (see Exhibit 3). Once the content is included, the practices and crosscutting concepts are incorporated to show where the integration between the three dimensions is strongest. Sets of content, practices, and crosscutting concepts are then grouped together (shown as green boxes in Exhibit 3) to demonstrate where it might make sense to develop tasks. This map can then be used by task developers to highlight what content can be covered by a task, and which other dimensions can be elicited in the task.

Exhibit 3. Example Grade 5 Integrated Dimension Map, Bundle 1



Examples of three integrated dimension maps, one each at grades 5, 8, and 11, are provided in Appendix C.

Phase 2: Domain Modeling

The second phase of this five-phase design process, **Domain Modeling**, consists of systematic structures for organizing the content identified in domain analysis in terms of an assessment argument. The underlying technical details—statistical models, rubrics, or task materials—are not the focus of this phase of the work. Rather, the aim here is to lay out the argument that connects the observations of students’ actions (performance on the tasks) to inferences about what they know or can do in science. This takes the form of a narrative providing descriptions of the proficiencies (i.e., the knowledge, skills and abilities) of interest, the methods for observing those proficiencies, and the ways of arranging situations in which students can provide evidence of their proficiencies. In the earlier domain analysis phase, subject matter experts and instructional designers contribute to the work. In the domain modeling phase, the assessment designer plays a more prominent role. Here the assessment designer collaborates with the domain experts to organize information about the domain and about the purpose of the assessment into terms and structures that form assessment arguments (Mislevy & Riconscente, 2006).

In what follows we define and articulate the elements, process, and outcomes of the SCILLSS’ partners’ work during phase 2 to organize and structure the key aspects of the domain through the use of design patterns, which help developers represent the domain content in terms of the overall assessment argument. An assessment *design pattern* helps the domain experts and assessment designers fill in the pieces of an assessment argument. The design patterns derived from this process are the main tools for moving from conceptualization to development, assisting developers in clearly articulating each design component. Designs patterns are used to guide assessment designers or developers in the decisions they make when developing task outlines.

In the sections below, we describe each element of this phase, focusing on the development of the design pattern, and the application of a Fairness/Equity Framework. We close this paper with a summary process and recommendations for carrying out the work of domain modeling within a principled-design approach to assessment design and development.

Design Patterns

During the second phase of the principled-design model a narrative description of the assessment argument structure is produced to guide item development. Assessment developers will need to consider the following questions during this phase:

- What knowledge, skills or abilities (KSAs) should be assessed (i.e., the student model)?
- What behaviors or performances should reveal those knowledge, skills, and abilities (the evidence model)?
- What items, situations, or stimuli should elicit those behaviors and performances (the task model)?

At this stage, information related to these three questions is organized into a document called a *design pattern*. The fields of the *design pattern* (see

Exhibit 4) organize the information collected at the domain analysis stage to structure the assessment argument. In the assessment argument the student model represents the claims that we want to make about the student, the evidence model states the evidence needed to make those claims, and the task model provides information on how a task should be structured to allow for the production of that evidence.

Exhibit 4. Fields of a Design Pattern and How They Relate to the Assessment Argument

Design Pattern Field	Description	Assessment Argument Component
Rationale	Describes the overall purpose of the design pattern	
Focal Knowledge, Skills, and Abilities (fKSAs)	The primary knowledge/skills/abilities targeted by the design pattern	Student Model
Additional Knowledge, Skills, and Abilities (aKSAs)	Other knowledge/skills/abilities that may be required by tasks designed to measure the fKSAs	Student Model
Potential Observations	Aspects of the work product that would reflect on students' fKSAs. Often serve as the basis for rubric development	Evidence Model
Potential Work Products	What it is the student will produce after interacting with the tasks	Task Model
Characteristic Features	Aspects of the assessment situation that are needed to evoke the desired evidence	Task Model
Variable Features	Aspects of the assessment situation that may be varied (often to shift the difficulty or the focus of the task)	Task Model

(adapted from Mislevy & Riconscente, 2006)

Knowledge, Skills, and Abilities (KSAs)

The KSAs refer to the proficiencies to be targeted by the assessment task (Harris et al., 2006, Mislevy & Haertel, 2006, Mislevy & Riconscente, 2006). These statements describe what we want to measure, or what constructs the tasks should elicit from the students. The KSAs are broken up into two categories, focal and additional. The fKSAs are those constructs that are central to the assessment.

The additional KSAs (aKSAs) are related constructs that may be required of the student. For example, to measure students' ability to apply algebraic formulas to solve math problems, two fKSAs may be used: one for the ability to construct an equation to represent a problem and the other for the ability to solve an algebraic equation. An aKSA would be the students' ability to read. Reading ability may not necessarily be something intended for measurement, but, nevertheless, it has an impact on how well students can comprehend the problem. While in this case the aKSA is something to account for either in the item design or the scoring but is not intended for direct measurement, in another case the aKSA might highlight a skill that is worth measuring. For example, there could be science tasks that require students to create a graph or other representation of data. This is something that the task designer may want to measure about the student in some of the tasks that are developed.

In this project the fKSAs are drawn from the integrated dimension map and the elaborations. The dimension map is used to highlight the ways in which the measurement target can be broken up, and this break-down can be used to decide which fKSAs to create. For each design pattern there is at least one fKSA per box in the integrated dimension map, but collectively there may be multiple fKSAs. When deciding how many fKSAs to include, the degree to which there is one task that could be used to measure that fKSA should be considered. If the fKSA is too large to be measured by one task (the task may have multiple parts), then multiple fKSAs should be considered.

It is also important to note that the fKSAs should represent an integration of the DCIs, SEPs, and CCCs. The multi-component tasks to be developed from this design pattern should highlight the integration of these three aspects, and the fKSAs should reflect this integration of the dimensions as well. For example, one fKSA developed for the fifth grade is: "Students are able to create a model that describes matter as made of particles too small to be seen." This fKSA includes the concept that there are particles that are too small to be seen, the practice of modeling, and the crosscutting concept of matter.

Potential Observations and Potential Work Products

For the evidence model we need to make several scoring considerations: the first is how the responses to each part of a task are going to be scored and the second is how these scores on different parts of a task are going to aggregate or sum to an overall score. At the *domain modeling* stage, the focus is on the first consideration—developing the criteria for scoring each part of a task to aid in determining how the different parts of the task will be collectively scored. The summary score method, or the second consideration, is left until later when the overall structure of the entire assessment is fully developed.

The first step in developing the criteria is to determine what it is the students might be producing. These are the potential work products, and may be specifications such as an explanation, or a model, or an identification. Once those are considered then the potential observations serve to highlight which aspects of these work products require the development of a rubric. For example, if a work product is the development of an explanatory model of a phenomenon, the potential observations could focus on the accuracy of the overall model, the degree to which the model represents a particular phenomenon, the appropriateness of the symbols used in the model, or the degree to which the model supports an explanation.

When developing the work products and the observations, it is important to consider how the evidence specified would reflect on the fKSAs. For example, while it may be that some tasks require students to identify the type of phenomena occurring, this may not be enough to state that the student is engaging with the three-dimensional nature of the fKSA. Therefore, the work product may include an identification of the phenomena along with an explanation. The potential observation may be the degree to which the explanation matches the identification. In this case, the potential observation is not about the correctness of the identification, but more about how well the student can support that identification.

Characteristic and Variable Features

Aspects of the task are defined in the characteristic and variable feature fields. The characteristic features are aspects of a task that must be present in any task that would measure the fKSAs. This could be as straightforward as stating that each task must contain a scenario involving a real-world phenomenon or it could include constraints for the task. For example, in a modeling task one characteristic feature might be that students have to develop a model, while another feature might put the constraint that the model included in the task have no more than two variables.

Variable features are aspects of the tasks that the designer must take into account in the design of the tasks. By varying these features, the difficulty of the task and/or the focus of the task will also vary. Some of the variable features may be related to the aKSAs. So, one of the decisions that needs to be made is whether or not a particular aKSA is required of students taking the assessment. Other variable features may be related to the cognitive complexity of the models students use which, in turn, can affect the difficulty of the task. The list of variable features focuses the assessment designers on the decisions they need to make, and provides support to them when highlighting how those decisions affect the way students will interact with the tasks.

Examples of the design patterns for three measurement targets, one each at grades 5, 8, and 11, are provided in Appendix D.

Fairness/Equity Framework

Accessibility is a key element in every phase of assessment system development and implementation. Central to the goals of an innovative assessment system is understanding how the provision of meaningful, research-based accessibility strategies and accommodations result in the accurate demonstration of broad representations of knowledge, and thus support valid inferences for all students.

According to AERA, APA, and NCME (2014, pp. 6-7), tests should be designed to facilitate and minimize construct-irrelevant barriers for all test takers in the target population. Universal Design for Learning (UDL) seeks to make educational materials and assessments as accessible as possible to the widest variety of students while seeking to minimize separate-but-equal situations.

UDL provides flexibility in the ways information is presented, in the ways students respond or demonstrate knowledge and skills, and in the ways students are engaged (Higher Education Opportunity Act, 2008). Applying the principles of UDL to assessment development provides guidance in creating assessment materials that reduce barriers, optimize levels of challenge, and minimize the need for additional accommodations for students, including students with disabilities and students who are limited English proficient, while maintaining high achievement expectations for all students. In addition to assisting teachers in planning lessons/units of study, utilizing the UDL Guidelines also helps them create or select classroom assessments that are accessible and that appropriately demonstrate student learning. Embedding the principles of UDL in the development and implementation of assessments addresses an important component of an inclusive system of assessments. As stated by Thurlow, Lazarus, Christensen, and Shyyan (2016, p. 7), “Accessible assessments are used to allow all students to show their knowledge and skills on the same challenging content.”

Understanding the characteristics of the students taking the assessment is one of the first steps in the application of UDL principles to inform the design of each item and to minimize the need for adaptations and accommodations for students to access the measured construct. Through the application of a principled-design approach to assessment development, UDL principles are carefully incorporated into the assessment item design including operational items, field test items, and test bank items. The UDL approach focuses the development of items for all students on construct-relevant content (the knowledge, skills, and abilities intended to be measured), minimizing the impact of construct-irrelevant skills (e.g., print size, lack of assistive technology device, inability to engage with the items), and considering appropriate accessibility options.

By incorporating the guidelines of UDL as described by the National Center on Universal Design for Learning (http://www.udlcenter.org), the SCILLSS partners considered how students’ abilities and characteristics can influence the representation of content, response to content, and engagement during learning, and addressed multiple means of representation (the “what” of learning), expression (the “how” of learning), and engagement (the “why” of learning) in the development of performance tasks/items. UDL Guidelines are utilized throughout the design process, specifically during phases 2, 3, and 4.

Reporting Categories and Test Blueprints

Once the *design pattern(s)* have been developed, they can be used to develop the reporting categories and the test blueprints. The collection of the *design patterns* highlights the critical aspects of the domain and provides meaningful groupings for the target constructs. By surveying these artifacts, a test developer can decide at what level they want to report on student performance. From there they can use the *design patterns* to create test blueprints. The reporting categories will be based on groupings of the *design patterns*. Once those are established the information in the *design patterns* can be used to determine how many tasks should be generated and what fKSAs should be covered by those tasks.

Once these decisions have been made, the test blueprint can be checked against the *design patterns* as a check of the coverage of the domain. The test blueprints can then be used to determine how many tasks will be developed and what each particular task will cover. This information will be used in phase 3 as the list of task models that are to be developed.

Phase 3: Conceptual Assessment Framework

While the first two phases of item and task development created artifacts at a general level which could be applied in many test development situations, the design work in phase 3 proceeds further by identifying the specifications and constraints that will govern the overall design of the assessment. This work ensures that design constraints relating to the assessment, such as the claims that will be made based on the assessment scores, as well as the nature of the assessment administration conditions, are incorporated into the overall design. It is at this stage that the information gathered in the earlier domain modeling phase is narrowed and focused to align with the purpose of the assessment.

The work at this phase begins by specifying the constraints of the assessment. Based on those constraints, design templates are generated. These templates serve as a guide for the development of the tasks and the scoring rules that will be included in the assessment. In the sections below, we describe each of the components of this phase. We close this paper with a summary process and recommendations for carrying out the work for establishing a conceptual assessment framework within a principled-design approach to assessment design and development.

Performance Level Descriptors and Delivery Parameters

Performance level descriptors (PLDs) are useful at this design stage because they can be used to define the student model and narrow the scope of the assessment. These PLDs rely on the fKSAs developed earlier in the domain modeling phase to serve as guides for statements describing what it is we want to know and say about the students. These statements not only define the purpose of the given assessment, they also lay out the boundaries of the KSAs that will be measured by the assessment.

In addition to constraining what it is that will be measured, outlining the assessment delivery parameters will constrain how these KSAs can be measured. When defining the delivery parameters, it is important to specify how the assessment will be delivered (e.g., via paper/pencil or as a computer-based test) and what item formats are allowable on the assessment (e.g., multiple choice items, constructed response items, technology-enhanced items using "hot spots" or drag-and-drop response options), as well as to identify scoring rules and constraints (e.g., is there a mix of multiple-choice and open-ended items on the assessment), and, from an administrative perspective, to determine how much time is allotted for the assessment.

Task Templates

Once the various constraints on the assessment design have been specified, a task template document will be developed. The task template document contains specifications related to the design of specific multi-component tasks. Similar to the design patterns described previously, the task templates organize the information around the student model, the evidence model, and the task model. The task templates use the information specified earlier in the design patterns to move closer to the development of a task, all the while providing guidance that allows for the design and development of various item/task types and multiple instances of those task types. The components of the task template are presented and described in Exhibit 5.

Exhibit 5. Overview of the Components of a Task Template

Task Template Component	Description
Student Model	A set of one or more variables in a psychometric model that reflect aspects of student capabilities (i.e., the KSAs)
Focal Knowledge, Skills, and Abilities	The primary knowledge/skills/abilities (KSAs) targeted by a particular task template
Task Model	Description of the environment in which examinees will say, do, or make something, to provide the data or evidence about what they know or can do as broadly conceived
Work Product Summary	Description of the responses or artifacts the students will produce that, subsequently, will be used in the evaluation (scoring) procedures
Example Phenomena	The possible types of phenomena that will be represented in the task
Task Model Variables	Variables for features of tasks (e.g., reading level, use of graphics, symbols, equations, etc.) that indicate the design decisions needed with regard to specific items or tasks
Notes on Task Model Variables	Unspecified aspects of the Task Model Variables that have not been previously specified
Measurement Model	Specifies the form in which the observable student responses depend on the student model variables
Evaluation Model	The process by which the work products are evaluated to create the observable variables or performance indicators

Student Model and fKSAs

The student model attempts to specify what it is the assessment is designed to measure. This is tied very closely to the PLDs because the student model is intended to characterize students' performance in terms of the proportion of the domain measured by the assessment. For a given task template, the student model may cover one or more fKSAs. These fKSAs, identified earlier in the design pattern stage, are listed in the fKSA field. The specification of the student model and fKSAs serve to narrow the scope of the task to be developed, and focus the task developer on the particular fKSAs that should be targeted in the task.

Task Model, Task Model Variables, Example Phenomenon, and Work Product Summary

In the task model field, the flow of the task is described. This includes what type of information is presented to the students and the order of this presentation. The task model variables then describe which elements of the task must remain fixed, which can vary, and the boundary information for distinguishing between the fixed and variable features of the task. One of these variables, the scenarios or phenomena used as context for the task, is identified and highlighted as a separate category. Doing so helps strengthen the requirement that some tasks ought to be situated in the context of a “real-world” phenomenon. The example phenomena provide guidance on appropriate scenarios to use and describe boundaries related to the phenomena. The work product summary provides descriptions of the artifacts the students are expected to produce (e.g., explanations, models).

The information in this section is used to guide item/task developers as they design and develop candidate assessment items and tasks. The task model variables, taken from the variable features of the design pattern, highlight the decisions that a task developer needs to make. If designers wanted to create sets of parallel or interchangeable tasks, for example, they would need to make parallel decisions with regards to these variables. Overall, the information provided at this design stage helps to highlight the boundary conditions of the tasks and further ensures the tasks under development measure the knowledge, skills and abilities highlighted in the student model. By linking these components to the student model, the rationale or warrant (i.e., the validity argument) for the set of candidate assessment tasks is surfaced.

Evaluation Model and Measurement Model

The evidence model consists of two parts, the evaluation model and the measurement model. The first part, the evaluation model, describes how the students’ responses to the developed task will be captured and scored. It begins to describe where the numbers come from, and it identifies one score or a set of scores. The evidence model provides scoring rules, such as a rubric, that are used to capture students’ responses to the task. The measurement model is a higher level statistical model that looks across tasks and specifies how best to aggregate students’ responses and produce the desired summary scores for the entire assessment. When developing the measurement model, it is important to keep in mind how the different tasks, and their scoring rules, fit together to ensure that the summary scores accurately reflect the measurement of the targeted domain.

Examples of the task templates for three measurement targets, one each at grades 5, 8, and 11, are provided in Appendix E.

Phase 4: Assessment Development

Once the task templates have been developed, the specifications can be used to develop tasks and rubrics. As work proceeds in phase 4, the candidate tasks are organized into test forms and test administration instructions are specified.

Tasks, Rubrics, and Test Forms

Tasks developed from the task template should follow the flow of the task specified in the task model and should incorporate the decisions made with regard to the task model variables. The scoring rules and/or rubrics are derived from the evaluation model. The forms are then developed based in part on the specified measurement model and, in part, on the PLDs used to report students' performance. This approach ensures that each test form (there may be a number of parallel alternate forms) contains items/tasks that are aligned to the purpose of the assessment and serve as the basis for producing comparable summary scores via the measurement model.

[Note: Additional process language will be added here to describe this phase when we move forward with our development of tasks and rubrics using the SCILLSS design patterns and task templates.]

Phase 5: Assessment Delivery

[Note: The administration of field trials is not within the scope of the SCILLSS project for our development of summative, on-demand assessment tasks. However, we will provide additional language here to summarize the elements and considerations for this phase in the development process.]

Summary

The nature of the work at the *domain analysis* phase is designed to support obtaining a deep understanding of the nature of the construct or constructs to be measured, identifying the constructs' relationship to the claims test sponsors wish to make about student achievement, and surfacing the knowledge, skills and abilities required for successful performance on the assessment tasks. The *domain analysis* phase is challenging because it relies heavily on assessment designers' understanding of the multi-dimensional nature of the NGSS and the performance expectations derived from those standards. By focusing on the underlying knowledge, skills, and abilities needed to succeed on the assessment tasks, assessment designers are pressed to think not only about the nature of the content, but also the prerequisite knowledge students need and the skills (e.g., scientific reasoning or literacy) and abilities (mathematical, computational, communicative) developed by students and applied in the novel problem-solving situations presented by the assessment tasks.

The process also requires test designers to make decisions about the nature of the relationships between the three dimensions of the NGSS, and to actively identify opportunities for assessment of the integration of these dimensions. This identification will help inform the next phase of the process, the *domain modeling* stage.

In the *domain modeling* phase, the structure of the assessment begins to emerge. Information is organized to highlight what is going to be measured (i.e., core ideas, crosscutting concepts, or scientific practices), what evidence is needed to make inferences of student achievement, and how tasks can be structured so that the evidence can be gathered systematically. This organizational structure is designed to support assessment developers as they make decisions about how to measure the constructs of interest within a particular domain.

It is important to remember that the design patterns created during the *domain modeling* phase are meant to be at a general, narrative level. The intention during this design phase is <u>not</u> to create specifications for a given task, but instead to provide information and characterizations about the domain in broad terms. By doing so, the domain modeling phase allows for multiple measures to be built from the same set of design patterns. It is not until phase 3, the conceptual assessment framework stage, that the information is narrowed for the specific purpose of designing tasks for implementation in particular form (or forms) of an assessment.

The narrative aspect of the *domain modeling* stage allows for multiple perspectives to be incorporated into the assessment design documents. Content specialists, along with assessment specialists and other stakeholders, can contribute to ensure that the ultimate design document will have information appropriate for a wide range of stakeholders.

The *conceptual assessment framework* phase then structures and focuses the information from the *domain modeling* phase to provide an overview of the collection of tasks that will be developed. This organization of information is designed to support task developers in creating sets of tasks during the *assessment development phase* that match the purpose of the assessment, and support them in developing parallel forms, if desired.

Recommendations

The *domain analysis* process can sometimes seem like a daunting task, as there is a wide range of information related to each domain and it might not be clear how much to include. Below are some suggestions for how to approach the domain analysis:

- Focus on information that can be useful for test developers. This includes:
  - Information that clarifies which behaviors students should engage with; and
  - Information that clarifies which are the critical aspects of the domain.
- Keep in mind what you want to say about the student and revisit the alignment after each stage for consistencies:
  - Include a check that the measurement targets match the overall claim;
  - Include a check that the unpacking includes information related to the measurement targets; and
  - Include a check that the integrated dimension map covers the measurement target as well as the information in the unpacking templates.

Below are some recommendations to keep in mind when engaging in *domain modeling*:

- Keep a wide perspective. Do not try to narrow the information at this point as the documentation generated might be used for other purposes at a later date;
- Revisit the domain analysis documents:
  - Use the Integrated Dimension Map when generating the fKSAs, and
  - Use the elaborations when generating the potential observations, work products and characteristic and variable features; and
- Focus on the fKSAs when developing other fields in the design pattern. It helps to revisit the alignment with the fKSAs once the design documents have been established.

Below is a key recommendation to keep in mind when engaging in *conceptual assessment framework*:

- Be sure to provide sufficient guidance in the task templates so that the structure and features of the tasks are clear. Information in the task templates do not have to be inclusive of all possibilities, but they should be useful for focusing the task developers on the fKSAs as they design and develop items and tasks.

Below is a key recommendation to keep in mind when engaging in *assessment development:*

- Keep the purpose of the assessment and the student model in mind when developing the test items and tasks, and always go back to check for the alignment with the components of the tasks and the overall purpose (the measurement targets) of the task.

It is also useful to keep in mind that engaging in ECD is an iterative process. This means that during each phase of the design process, the assessment information and design templates must be revisited and revised to ensure coherence and alignment among assessment design elements. The end goal is a set of documents that describes the decisions made when developing the assessment and provides support for why those decisions were made. The documents can then be used not only to support the development of similar assessments and assessment tasks, but also to provide support for the validity argument for the assessment (Mislevy, 2007).

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Appendix A. Measurement Targets

Grade 5

Grade 5 Overall Claim
Students demonstrate a sophisticated understanding of the core ideas and applications of practices and crosscutting concepts in the disciplines of science.

Explanatory Statement	Explanatory Statement
Students integrate disciplinary core ideas and crosscutting concepts with scientific practices to investigate and explain how and why phenomena occur, and to design and refine solutions to problems.	Students connect knowledge across the disciplines of science to ask questions, plan and carry out investigations, and analyze and interpret data to support an argument about phenomena in a variety of contexts.

Measurement Target 1 (Topic 1 Bundle): Students are able to investigate and interpret data to draw or support conclusions about the structure and properties of matter, including whether or not matter is conserved, and to identify materials and mixtures based upon their properties or results of a reaction.

- 5-PS1-1. Develop a model to describe that matter is made of particles too small to be seen.
- 5-PS1-2. Measure and graph quantities to provide evidence that regardless of the type of change that occurs when heating, cooling, or mixing substances, the total weight of matter is conserved.
- 5-PS1-3. Make observations and measurements to identify materials based on their properties.
- 5-PS1-4. Conduct an investigation to determine whether the mixing of two or more substances results in new substances.

Measurement Target 2 (Topic 2 Bundle): Students are able to develop and use models to describe the scale and movement of matter in ecosystems, and to argue that energy is required by living things for growth and survival.

- 5-PS1-1. Develop a model to describe that matter is made of particles too small to be seen.
- 5-PS3-1. Use models to describe that energy in animals' food (used for body repair, growth, motion, and to maintain body warmth) was once energy from the sun.
- 5-LS1-1. Support an argument that plants get the materials they need for growth chiefly from air and water.
- 5-LS2-1. Develop a model to describe the movement of matter among plants, animals, decomposers, and the environment.

Measurement Target 3 (Topic 3 Bundle): Students are able to develop models to describe the interactions of the geosphere, biosphere, hydrosphere, and/or atmosphere to address issues related to protecting Earth's resources and environment.

- 5-PS1-1. Develop a model to describe that matter is made of particles too small to be seen.
- 5-ESS2-1. Develop a model using an example to describe ways the geosphere, biosphere, hydrosphere, and/or atmosphere interact.
- 5-ESS2-2. Describe and graph the amounts of salt water and fresh water in various reservoirs to provide evidence about the distribution of water on Earth.
- 5-ESS3-1. Obtain and combine information about ways individual communities use science ideas to protect the Earth's resources and environment.

Measurement Target 4 (Topic 4 Bundle): Students are able to support an argument, using evidence and observable patterns, that the scale of the universe and physical phenomena observed on Earth are a result of its place in the solar system.

- 5-PS2-1. Support an argument that the gravitational force exerted by Earth on objects is directed down.
- 5-ESS1-1. Support an argument that the apparent brightness of the sun and stars is due to their relative distances from the Earth.
- 5-ESS1-2. Represent data in graphical displays to reveal patterns of daily changes in length and direction of shadows, day and night, and the seasonal appearance of some stars in the night sky.

Grade 8

<table>
<tr><th colspan="2">Grade 8 Overall Claim
Students demonstrate a sophisticated understanding of the core ideas and applications of practices and crosscutting concepts in the disciplines of science.</th></tr>
<tr><td>Explanatory Statement
Students integrate disciplinary core ideas and crosscutting concepts with scientific practices to investigate and explain how and why phenomena occur, and to design and refine solutions to problems.</td><td>Explanatory Statement
Students connect knowledge across the disciplines of science to ask questions, plan and carry out investigations, and analyze and interpret data to support an argument about phenomena in a variety of contexts.</td></tr>
<tr><td colspan="2">Measurement Target 1 (Topic 1 Bundle): Students are able to conduct investigations, analyze data related to interactions between objects, and develop and use models in support of an argument to predict or explain the interactions, including connections among energy, forces, and motion.
• MS-PS2-1. Apply Newton’s Third Law to design a solution to a problem involving the motion of two colliding objects.
• MS-PS2-2. Plan an investigation to provide evidence that the change in an object’s motion depends on the sum of the forces on the object and the mass of the object.
• MS-PS2-3. Ask questions about data to determine the factors that affect the strength of electric and magnetic forces.
• MS-PS2-4. Construct and present arguments using evidence to support the claim that gravitational interactions are attractive and depend on the masses of interacting objects.
• MS-PS2-5. Conduct an investigation and evaluate the experimental design to provide evidence that fields exist between objects exerting forces on each other even though the objects are not in contact.
• MS-PS3-1. Construct and interpret graphical displays of data to describe the relationships of kinetic energy to the mass of an object and to the speed of an object.
• MS-PS3-2. Develop a model to describe that when the arrangement of objects interacting at a distance changes, different amounts of potential energy are stored in the system.
• MS-ESS1-2. Develop and use a model to describe the role of gravity in the motions within galaxies and the solar system.

Measurement Target 2 (Topic 2 Bundle): Students are able to develop and interpret models and use mathematical representations and scientific information to make claims about how waves transfer energy and information through various materials.
• MS-PS4-1. Use mathematical representations to describe a simple model for waves that includes how the amplitude of a wave is related to the energy in a wave.
• MS-PS4-2. Develop and use a model to describe that waves are reflected, absorbed, or transmitted through various materials.
• MS-PS4-3. Integrate qualitative scientific and technical information to support the claim that digitized signals are a more reliable way to encode and transmit information than analog signals.</td></tr>
</table>

Measurement Target 3 (Topic 3 Bundle): Students are able to develop and interpret models and analyze information and data to explain the similarities and diversity among organisms, the inheritance of traits through natural selection and human influence, and changes in populations over time.

- MS-LS3-1. Develop and use a model to describe why structural changes to genes (mutations) located on chromosomes may affect proteins and may result in harmful, beneficial, or neutral effects to the structure and function of the organism.
- MS-LS4-1. Analyze and interpret data for patterns in the fossil record that document the existence, diversity, extinction, and change of life forms throughout the history of life on Earth under the assumption that natural laws operate today as in the past.
- MS-LS4-2. Apply scientific ideas to construct an explanation for the anatomical similarities and differences among modern organisms and between modern and fossil organisms to infer evolutionary relationships.
- MS-LS4-3. Analyze displays of pictorial data to compare patterns of similarities in the embryological development across multiple species to identify relationships not evidence in the fully formed anatomy.
- MS-LS4-4. Construct an explanation based on evidence that describes how genetic variations of traits in a population increase some individuals' probability of surviving and reproducing in a specific environment.
- MS-LS4-5. Gather and synthesize information about the technologies that have changed the way humans influence the inheritance of desired traits in organisms.
- MS-LS4-6. Use mathematical representations to support explanations of how natural selection may lead to increases and decreases of specific traits in populations over time.

Measurement Target 4 (Topic 4 Bundle): Students are able to analyze and interpret data, develop and use models, and use evidence and observable patterns in support of arguments that Earth, its organisms, and Earth systems are evolving over time.

- MS-LS4-1. Analyze and interpret data for patterns in the fossil record that document the existence, diversity, extinction, and change of life forms throughout the history of life on Earth under the assumption that natural laws operate today as in the past.
- MS-LS4-2. Apply scientific ideas to construct an explanation for the anatomical similarities and differences among modern organisms and between modern and fossil organisms to infer evolutionary relationships.
- MS-ESS1-1. Develop and use a model of the Earth-sun-moon system to describe the cyclic patterns of lunar phases, eclipses of the sun and moon, and seasons.
- MS-ESS1-2. Develop and use a model to describe the role of gravity in the motions within galaxies and the solar system.
- MS-ESS1-3. Analyze and interpret data to determine scale properties of objects in the solar system.
- MS-ESS1-4. Construct a scientific explanation based on evidence from rock strata for how the geologic time scale is used to organize Earth's 4.6-billion-year- old history.
- MS-ESS3-4. Construct an argument supported by evidence for how increases in human population and per-capita consumption of natural resources impact Earth's systems.

Grade 11

<table>
<tr><th colspan="2">Grade 11 Overall Claim
Students demonstrate a sophisticated understanding of the core ideas and applications of practices and crosscutting concepts in the disciplines of science.</th></tr>
<tr><td>Explanatory Statement
Students integrate disciplinary core ideas and crosscutting concepts with scientific practices to investigate and explain how and why phenomena occur, and to design and refine solutions to problems.</td><td>Explanatory Statement
Students connect knowledge across the disciplines of science to ask questions, plan and carry out investigations, and analyze and interpret data to support an argument about phenomena in a variety of contexts.</td></tr>
<tr><td colspan="2">Measurement Target 1 (Topic 1 Bundle): Students are able to evaluate evidence and apply scientific reasoning related to Earth’s geologic processes and the dynamic feedback between the biosphere and other Earth systems to support an argument about the continual co-evolution of Earth’s systems and life on Earth.
HS-ESS1-5. Evaluate evidence of the past and current movements of continental and oceanic crust and the theory of plate tectonics to explain the ages of crustal rocks.
HS-ESS1-6. Apply scientific reasoning and evidence from ancient Earth materials, meteorites, and other planetary surfaces to construct an account of Earth’s formation and early history.
HS-ESS2-7. Construct an argument based on evidence about the simultaneous coevolution of Earth’s systems and life on Earth.
Measurement Target 2 (Topic 2 Bundle): Students are able to use models and conduct investigations to explain how organisms obtain and use matter and energy in both aerobic and anaerobic conditions, explain the role of photosynthesis and cellular respiration in the carbon cycle, describe how feedback mechanisms maintain living systems and mediate behaviors, and provide evidence to describe the complex structural organization of organisms from the microscopic to the macroscopic.
HS-LS1-2. Develop and use a model to illustrate the hierarchical organization of interacting systems that provide specific functions within multicellular organisms.
HS-LS1-3. Plan and conduct an investigation to provide evidence that feedback mechanisms maintain homeostasis.
HS-LS1-5. Use a model to illustrate how photosynthesis transforms light energy into stored chemical energy.
HS-LS1-6. Construct and revise an explanation based on evidence for how carbon, hydrogen, and oxygen from sugar molecules may combine with other elements to form amino acids and/or other large carbon-based molecules.
HS-LS1-7. Use a model to illustrate that cellular respiration is a chemical process whereby the bonds of food molecules and oxygen molecules are broken and the bonds in new compounds are formed resulting in a net transfer of energy.
HS-LS2-3. Construct and revise an explanation based on evidence for the cycling of matter and flow of energy in aerobic and anaerobic conditions.
HS-LS2-5. Develop a model to illustrate the role of photosynthesis and cellular respiration in the cycling of carbon among the biosphere, atmosphere, hydrosphere, and geosphere.</td></tr>
</table>

Measurement Target 3 (Topic 3 Bundle): Students are able to use models and apply statistics and probability concepts as evidence to explain how genes affect traits and the evolution of populations and describe the mechanisms by which variation among individuals of the same species can be attributed to both genetic and environmental factors.

- HS-LS1-1. Construct an explanation based on evidence for how the structure of DNA determines the structure of proteins which carry out the essential functions of life through systems of specialized cells.
- HS-LS1-4. Use a model to illustrate the role of cellular division (mitosis) and differentiation in producing and maintaining complex organisms.
- HS-LS3-1. Ask questions to clarify relationships about the role of DNA and chromosomes in coding the instructions for characteristic traits passed from parents to offspring.
- HS-LS3-2. Make and defend a claim based on evidence that inheritable genetic variations may result from: (1) new genetic combinations through meiosis, (2) viable errors occurring during replication, and/or (3) mutations caused by environmental factors.
- HS-LS3-3. Apply concepts of statistics and probability to explain the variation and distribution of expressed traits in a population.
- HS-LS4-1. Communicate scientific information that common ancestry and biological evolution are supported by multiple lines of empirical evidence.
- HS-LS4-2. Construct an explanation based on evidence that the process of evolution primarily results from four factors: (1) the potential for a species to increase in number, (2) the heritable genetic variation of individuals in a species due to mutation and sexual reproduction, (3) competition for limited resources, and (4) the proliferation of those organisms that are better able to survive and reproduce in the environment.

Measurement Target 4 (Topic 4 Bundle): Students are able to evaluate evidence and apply statistics and probability concepts to construct explanations of how genetic variation among organisms and environmental conditions affect survival and reproduction, and apply scientific evidence to explain the concept of biological evolution and the role of natural selection in that process.

- HS-LS4-2. Construct an explanation based on evidence that the process of evolution primarily results from four factors: (1) the potential for a species to increase in number, (2) the heritable genetic variation of individuals in a species due to mutation and sexual reproduction, (3) competition for limited resources, and (4) the proliferation of those organisms that are better able to survive and reproduce in the environment.
- HS-LS4-3. Apply concepts of statistics and probability to support explanations that organisms with an advantageous heritable trait tend to increase in proportion to organisms lacking this trait.
- HS-LS4-4. Construct an explanation based on evidence for how natural selection leads to adaptation of populations.
- HS-LS4-5. Evaluate the evidence supporting claims that changes in environmental conditions may result in: (1) increases in the number of individuals of some species, (2) the emergence of new species over time, and (3) the extinction of other species.

Measurement Target 5 (Topic 5 Bundle): Students are able to evaluate evidence and use mathematical representations to explain how the environment influences populations of organisms over multiple generations, describe the relationship between population size and carrying capacity, and describe the continuous flow of energy and the recycling of matter and nutrients within a system.

- HS-LS2-1. Use mathematical and/or computational representations to support explanations of factors that affect carrying capacity of ecosystems at different scales.
- HS-LS2-2. Use mathematical representations to support and revise explanations based on evidence about factors affecting biodiversity and populations in ecosystems of different scales.
- HS-LS2-4. Use mathematical representations to support claims for the cycling of matter and flow of energy among organisms in an ecosystem.
- HS-LS2-6. Evaluate the claims, evidence, and reasoning that the complex interactions in ecosystems maintain relatively consistent numbers and types of organisms in stable conditions, but changing conditions may result in a new ecosystem.
- HS-LS2-8. Evaluate the evidence for the role of group behavior on individual and species' chances to survive and reproduce.
- HS-LS4-3. Apply concepts of statistics and probability to support explanations that organisms with an advantageous heritable trait tend to increase in proportion to organisms lacking this trait.
- HS-LS4-5. Evaluate the evidence supporting claims that changes in environmental conditions may result in: (1) increases in the number of individuals of some species, (2) the emergence of new species over time, and (3) the extinction of other species.

Measurement Target 6 (Topic 6 Bundle): Students are able to construct evidence-based explanations for the influence of natural resource availability, occurrence of natural hazards, and climate change on human activity; design and evaluate solutions that address relationships among natural resource management, sustainability of human populations, and biodiversity; and create and use simulations to test solutions.

- HS-LS2-7. Design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity.
- HS-LS4-6. Create or revise a simulation to test a solution to mitigate adverse impacts of human activity on biodiversity.
- HS-ESS3-1. Construct an explanation based on evidence for how the availability of natural resources, occurrence of natural hazards, and changes in climate have influenced human activity.
- HS-ESS3-3. Create a computational simulation to illustrate the relationships among management of natural resources, the sustainability of human populations, and biodiversity.

Appendix B. Elaborated Dimensions

Grade 5

Disciplinary Core Ideas

Grade 5, Measurement Target 1	Students are able to investigate and interpret data to draw or support conclusions about the structure and properties of matter, including whether or not matter is conserved, and to identify materials and mixtures based upon their properties or results of a reaction.	
	PS1.A: Structure and Properties of Matter	**PS1.B: Chemical Reactions**
DCIs	• Matter of any type can be subdivided into particles that are too small to see, but even then, the matter still exists and can be detected by other means. A model showing that gases are made from matter particles that are too small to see and are moving freely around in space can explain many observations, including the inflation and shape of a balloon and the effects of air on larger particles or objects. **(5-PS1-1)** • The amount (weight) of matter is conserved when it changes form, even in transitions in which it seems to vanish. **(5-PS1-2)** • Measurements of a variety of properties can be used to identify materials. (Boundary: At this grade level, mass and weight are not distinguished, and no attempt is made to define the unseen particles or explain the atomic-scale mechanism of evaporation and condensation.) **(5-PS1-3)**	• No matter what reaction or change in properties occurs, the total weight of the substances does not change. (Boundary: Mass and weight are not distinguished at this grade level.) **(5-PS1-2)** • When two or more different substances are mixed, a new substance with different properties may be formed. **(5-PS1-4)**
Elaboration of the DCIs	**5-PS1A.a** • Everything around us (matter) is made up of particles that are too small to be seen. • Matter that cannot be seen can be detected in other ways. • Gas (air) has mass and takes up space. • Gas (air) particles, which are too small to be seen, can affect larger particles and objects. • Gas particles freely move around in space, until they hit a material that keeps them from moving further, thus trapping the gas (e.g., air inflating a basketball, an expanding balloon). **5-PS1A.b** • Matter can change in different ways. • Regardless of the type of change, none of the particles are lost, and the total mass of the system is the same. • The mass of substances is the same before and after they change form (e.g., heating, cooling, or mixing).	**5-PS1B.a** • When substances are mixed, the change can result in a new substance. • Substances change during a chemical reaction. • A new substance may have different properties than the individual substances from which it was made. **5-PS1B.b** • In a closed system, the total mass will not change. • The total mass of matter is conserved after heating, cooling, or mixing substances. • During a physical or chemical change, the total mass of the substances does not change. • After a change, the total mass of the new substance(s) will be the same as the total mass of the beginning substances.

<table>
<tr><td>Elaboration of the DCIs Cont'd</td><td colspan="2">5-PS1A.c
Properties can be used to identify materials.
Properties can be measured.
Materials can be identified based on their observable and measurable properties.
Properties of materials may include color, hardness, reflectivity, electrical conductivity, thermal conductivity, response to magnetic forces, and solubility.</td><td></td></tr>
<tr><td>Proficiency Boundaries</td><td colspan="3">Assessment does not include the atomic-scale mechanism of evaporation and condensation or defining the unseen particles.
Assessment does not include density or distinguishing mass and weight.
Students should know that tools are used to measure properties, but they might not know about some tools.
Tasks should focus on heating, cooling, or mixing simple substances.</td></tr>
<tr><td>Prior Knowledge</td><td colspan="3">Matter is anything that occupies space and has weight/mass.
Different kinds of materials can be classified by their observable properties such as color, texture, hardness, and flexibility.
Various materials have properties (i.e., strength, flexibility, hardness, texture, and absorbency) that are best suited to different purposes.
Heating or cooling a substance may cause changes that can be observed.
Sometimes these changes are reversible and sometimes they are not.</td></tr>
<tr><td>Student Misconceptions</td><td colspan="3">Lower elementary school students fail to conserve weight and volume of objects that change shape. When an object's appearance changes in several dimensions, they focus on only one. They cannot imagine a reversed or restored condition and focus mostly on the object's present appearance. [1] The ability to conserve develops gradually. Students typically understand conservation of number between the ages of 6 and 7, of length and amount (solid and liquid) between 7 and 8, of area between 8 and 10, of weight between 9 and 11, and of displaced volume between 13 and 14. These ages will vary when different children are tested, or the same children are tested in different contexts. [2]
Many students cannot discern weight conservation in some tasks until they are 15 years old. The ability to conserve weight in a task involving transformation from liquid to gas or solid to gas may rise from 5% in 9-year-old children to about 70% in 14- to 15-year-old children. [3] More complex changes, such as chemical reactions, especially those where gas is absorbed or released, are still more difficult to grasp as instances of weight conservation. [4]</td></tr>
<tr><td>Articulation of DCIs Across Grade Levels</td><td colspan="2">2.PS1.A (5-PS1-1), (5-PS1-2), (5-PS1-3)
MS.PS1.A (5-PS1-1), (5-PS1-2), (5-PS1-3), (5-PS1-4)</td><td>2.PS1.B (5-PS1-2), (5-PS1-4)
MS.PS1.B (5-PS1-2), (5-PS1-4)</td></tr>
</table>

[1] Gega, P. (1986). *Science in elementary education*. New York: Macmillan Publishing Company.

[2] Donaldson, M. (1978). *Children's minds*. New York: W.W. Norton.

[3] Stavy, R. (1990). Children's conceptions of changes in the state of matter: From liquid (or solid) to gas. *Journal of Research in Science Teaching, 27*, 247-266.

[4] Stavy, R. (1990). Children's conceptions of changes in the state of matter: From liquid (or solid) to gas. *Journal of Research in Science Teaching, 27*, 247-266.

Crosscutting Concepts

Grade 5, Measurement Target 1	Students are able to investigate and interpret data to draw or support conclusions about the structure and properties of matter, including whether or not matter is conserved, and to identify materials and mixtures based upon their properties or results of a reaction.	
	Scale, Proportion, and Quantity	**Cause and Effect**
CCCs[1]	• Natural objects exist from the very small to the immensely large. **(5-PS1-1)** • Standard units are used to measure and describe physical quantities such as weight, time, temperature, and volume. **(5-PS1-2)**, **(5-PS1-3)**	• Cause and effect relationships are routinely identified, tested, and used to explain change. **(5-PS1-4)**
Essential Knowledge and Skills	**5-PS1-1** • Natural objects vary in size (very small to the immensely large). **5-PS1-2** • Matter can change, but, the total mass of the substances is the same. • Matter is conserved. **5-PS1-2 and 5-PS1-3** • Physical quantities (mass, time, temperature, and volume) can be measured. • Physical quantities are measured using standard units. • Measurements of physical properties can be used to describe physical quantities.	**5-PS1-2** • Matter flows and cycles (e.g., water going back and forth between Earth's atmosphere and its surface). • Matter can be transported into, out of, and within systems. **5-PS1-4** • Cause and effect relationships may be identified. • Cause and effect relationships may be tested. • Cause and effect relationships may be used to explain change.
Evidence of a High Level of Performance	• Students can develop a model to describe that natural objects and observable phenomena exist from the very small to the immensely large. • Students measure and graph quantities such as weight, time, temperature, and volume to provide evidence that regardless of the type of change that occurs to a substance or a mix of substances, the total weight of matter is conserved. • Students make observations and measurements to identify materials based on their properties.	• Students identify and test causal relationships and use these relationships to explain change. • Students conduct an investigation to determine whether the mixing of two or more substances results in new substances.

[1] These are the primary Crosscutting Concepts associated with the Performance Expectations for this Measurement Target. Additional Crosscutting Concepts Building to the PEs can be found on the website for the Next Generation Science Standards.

Relationships to Practices[2]	• Scale, proportion, and quantity are essential considerations when deciding how to model a phenomenon. • Relationships between variables (e.g., flow of energy and matter) can be explained by writing mathematical models or equations.	• Observations and data describe cause and effect relationships. • When students perform the practice of "Planning and Carrying Out Investigations," they often address cause and effect.
Prerequisite Knowledge and Skills	• Ability to use relative scales (e.g., bigger and smaller; hotter and colder; faster and slower) to describe objects • Ability to recognize that objects may break into smaller pieces, be put together into larger pieces, or change shapes	• Ability to explain that events have causes that generate observable patterns
Student Challenges	• Elementary and middle school students may think everything that exists is matter, including heat, light, and electricity. [1] Alternatively, they may believe that matter does not include liquids and gases or that they are weightless materials. [2] With specially designed instruction, some middle school students can learn the scientific notion of matter. [3] • Middle school and high school students are deeply committed to a theory of continuous matter. [4] Although some students may think that substances can be divided up into small particles, they do not recognize the particles as building blocks, but as formed as basically continuous substances under certain conditions. [5] • Students at the end of elementary school and beginning of middle school may be at different points in their conceptualization of a "theory" of matter. [6] Although some 3rd graders may start seeing weight as a fundamental property of all matter, many students in 6th and 7th grade still appear to think of weight simply as "felt weight"—something whose weight they can't feel is considered to have no weight at all. Accordingly, some students believe that if one keeps dividing a piece of Styrofoam, one would soon obtain a piece that weighed nothing. [7] • Students of all ages show a wide range of beliefs about the nature and behavior of particles. They lack an appreciation of the very small size of particles; attribute macroscopic properties to particles; believe there must be something in the space between particles; have difficulty in appreciating the intrinsic motion of particles in solids, liquids and gases; and have problems in conceptualizing forces between particles. [8] Despite these difficulties, there is some evidence that carefully designed instruction carried out over a long period of time may help middle school students develop correct ideas about particles. [9]	

[1] Stavy, R. (1991). Children's ideas about matter. *School Science and Mathematics*, *91*, 240-244; Lee, O., Eichinger, D.C., Anderson, C.W., Berkheimer, G.D., Blakeslee, T.S. (1993). *Changing middle school students' conceptions of matter and molecules. Journal of Research in Science Teaching, 30*, 249-270.

[2] Stavy, R. (1991). Children's ideas about matter. *School Science and Mathematics, 91*, 240-244; Mas, C.J., Perez, J.H., Harris, H. (1987). Parallels between adolescents' conceptions of gases and the history of chemistry. *Journal of Chemical Education, 64*, 616-618.

[3] Lee, O., Eichinger, D.C., Anderson, C.W., Berkheimer, G.D., Blakeslee, T.S. (1993). Changing middle school students' conceptions of matter and molecules. *Journal of Research in Science Teaching, 30*, 249-270.

[4] Nussbaum, J. (1985). The particulate nature of matter in the gaseous phase. In R. Driver, E. Guesne & A. Tiberghien (Eds.), Children's ideas in science (pp. 124–144). Milton Keynes, UK: Open University Press.

[2] These are meant to be examples; not an exhaustive list of connections to the practices. Additional Practices Building to the PEs can be found on the website for the Next Generation Science Standards.

Practices

Grade 5, Measurement Target 1	Students are able to investigate and interpret data to draw or support conclusions about the structure and properties of matter, including whether or not matter is conserved, and to identify materials and mixtures based upon their properties or results of a reaction.		
	Developing and Using Models	**Using Mathematics and Computational Thinking**	**Planning and Carrying Out Investigations**
Practices[1]	• Students can use models to describe phenomena. **(5-PS1-1)**	• Students can measure and graph quantities such as weight to address scientific and engineering questions and problems. **(5-PS1-2)**	• Students can make observations and measurements to produce data to serve as the basis for evidence for an explanation of a phenomenon. **(5-PS1-3)** • Students can conduct an investigation collaboratively to produce data to serve as the basis for evidence, using fair tests in which variables are controlled and the number of trials considered. **(5-PS1-4)**
Essential Knowledge and Skills	**5-PS1-1** • Students can use a model to describe phenomena. • Students can use a model to reason about a phenomenon. • Students can reason about the relationship of the different components of a model. • Students can select and identify relevant aspects of a situation or phenomena to include in the model. • Students can create a representation of a situation or phenomena. • Students can describe the connections between the model and the phenomena.	**5-PS1-2** • Students can use tools for observing, describing, measuring, recording, and graphing data. • Students can use observations, descriptions, measurements, recordings, and graphing to address questions. • Students can plot measurements and other data sets as a line plot on a graph to represent relationships between the data.	**5-PS3-3** • Students can make observations to collect data. • Students can make measurements to collect data. • Students can use data from an investigation as evidence for an explanation of a phenomenon or to support an explanation. **5-PS1-4** • Students can describe how an investigation relates to a question or hypothesis. • Students can plan investigations collaboratively[2] to produce data to serve as the basis for evidence. • Students can conduct investigations collaboratively to produce data to serve as the basis for evidence.

[1] These are the primary Practices associated with the Performance Expectations for this Measurement Target. Additional Practices Building to the PEs can be found on the website for the Next Generation Science Standards.
[2] Note: Students are asked to work collaboratively to plan and conduct investigations; for this age, we should not ask students to work independently in these areas.

Essential Knowledge and Skills Cont'd			• Students can plan investigations collaboratively using fair tests in which variables are controlled and the number of trials considered. • Students can conduct investigations collaboratively using fair tests in which variables are controlled and the number of trials considered.
Evidence of a High Level of Performance	• Students can build and revise simple models and use models to represent events and design solutions.	• Students can collect quantitative measurements of a variety of physical properties and use computation and mathematics to analyze data and compare alternative design solutions.	• Students can plan and carry out investigations that include control variables and provide evidence to support explanations or design solutions.
Prerequisite Knowledge and Skills	• Knowledge of units and unit conversions among different-sized standard measurement units within a given measurement system • Knowledge of bar graphs and histograms • Knowledge of line graphs (Note: CCSSM[3] "Students solve problems involving information presented in line plots" beginning in grade 5) • Knowledge of how and when to use estimations • Knowledge of proportional reasoning skills (Note: Should not be included, as students learn proportions in grade 6, CCSSM[4]) • Ability to write		
Student Challenges	• Upper elementary and middle school students may not understand experimentation as a method of testing ideas, but rather as a method of trying things out or producing a desired outcome. [1] With adequate instruction, it is possible to have middle school students understand that experimentation is guided by particular ideas and questions and that experiments are tests of ideas. [2] Whether it is possible for younger students to achieve this understanding needs further investigation. [3] • When engaged in experimentation, students have difficulty interpreting covariation and noncovariation evidence. [4] For example, students tend to make a causal inference based on a single concurrence of antecedent and outcome or have difficulty understanding the distinction between a variable having no effect and a variable having an opposite effect. [5] • Upper elementary school students can reject a proposed experimental test where a factor whose effect is intuitively obvious is uncontrolled, at the level of "that's not fair". [6] "Fairness" develops as an intuitive principle as early as 7 to 8 years of age and provides a sound basis for understanding experimental design. This intuition does not, however, develop spontaneously into a clear, generally applicable procedure for planning experiments. [7] Although young children have a sense of what it means to run a fair test, they frequently cannot identify all of the important variables, and they are more likely to control those variables that they believe will affect the		

[3] National Governors Association Center for Best Practices, Council of Chief State School Officers. (2010). *Common Core State Standards for Mathematics*. Washington, D.C.: Author.
[4] Ibid.

	result. Accordingly, student familiarity with the topic of the given experiment influences the likelihood that they will control variables. [8] After specially designed instruction, students in 8th grade are able to call attention to inadequate data resulting from lack of controls. [9]
Common Core State Standards for Mathematics Connections	**MP.2** Reason abstractly and quantitatively. **(5-PS1-1), (5-PS1-2), (5-PS1-3)** **MP.4** Model with mathematics. **(5-PS1-1), (5-PS1-2), (5-PS1-3)** **MP.5** Use appropriate tools strategically. **(5-PS1-2), (5-PS1-3)** **5.NBT.A.1** Explain patterns in the number of zeros of the product when multiplying a number by powers of 10, and explain patterns in the placement of the decimal point when a decimal is multiplied or divided by a power of 10. Use whole-number exponents to denote powers of 10. **(5-PS1-1)** **5.NF.B.7** Apply and extend previous understandings of division to divide unit fractions by whole numbers and whole numbers by unit fractions. **(5-PS1-1)** **5.MD.A.1** Convert among different-sized standard measurement units within a given measurement system (e.g., convert 5 cm to 0.05 m), and use these conversions in solving multi-step, real-world problems. **(5-PS1-2)** **5.MD.C.3** Recognize volume as an attribute of solid figures and understand concepts of volume measurement. **(5-PS1-1)** **5.MD.C.4** Measure volumes by counting unit cubes, using cubic cm, cubic in, cubic ft., and improvised units. **(5-PS1-1)**
Common Core State Standards for ELA/Literacy Connections	**RI.5.7** Draw on information from multiple print or digital sources, demonstrating the ability to locate an answer to a question quickly or to solve a problem efficiently. **(5-PS1-1)** **W.5.7** Conduct short research projects that use several sources to build knowledge through investigation of different aspects of a topic. **(5-PS1-2), (5-PS1-3)** **W.5.8** Recall relevant information from experiences or gather relevant information from print and digital sources; summarize or paraphrase information in notes and finished work, and provide a list of sources. **(5-PS1-2), (5-PS1-3)** **W.5.9** Draw evidence from literary or informational texts to support analysis, reflection, and research. **(5-PS1-2), (5-PS1-3)**

[1] Carey, S., Evans, R., Honda, M., Jay, E., Unger, C. (1989). An experiment is when you try it and see if it works: A study of grade 7 students' understanding of the construction of scientific knowledge. *International Journal of Science Education, 11,* 514-549; Schauble, L., Klopfer, L.E., Raghavan, K. (1991). Students' transition from an engineering model to a science model of experimentation. *Journal of Research in Science Teaching, 28*, 859-882; Solomon, J. (1992). Images of physics: How students are influenced by social aspects of science. In Duit, R. (Ed.), *Research in physics learning: Theoretical issues and empirical studies* (pp. 141-154). Kiel, Germany: Institute for Science Education at the University of Kiel.

[2] Carey, S., Evans, R., Honda, M., Jay, E., Unger, C. (1989). An experiment is when you try it and see if it works: A study of grade 7 students' understanding of the construction of scientific knowledge. *International Journal of Science Education, 11,* 514-549; Solomon, J. (1992). Images of physics: How students are influenced by social aspects of science. In Duit, R. (Ed.), *Research in physics learning: Theoretical issues and empirical studies* (pp. 141-154). Kiel, Germany: Institute for Science Education at the University of Kiel.

[3] American Association for the Advancement of Science, Project 2061 (2001). Atlas for Science Literacy, 18.

[4] Kuhn, D., Amsel, E., O'Loughlin, M. (1988). The development of scientific thinking skills. Academic Press.

[5] American Association for the Advancement of Science. (2001). Atlas of science literacy (Vol. 1). Washington, DC: Author.

[6] Shayer, M., Adey, P. (1981). *Towards a science of science teaching.* London: Heinemann.

[7] Wollman, W. (1977). Controlling variables: Assessing levels of understanding. *Science Education, 61*, 371-383; Wollman, W. (1977). Controlling variables: A neo-Piagetian developmental sequence. *Science Education, 61*, 385-391; Wollman, W., Lawson, A. (1977). Teaching the procedure of controlled experimentation: *A Piagetian approach. Science Education, 61*, 57-70.

[8] Linn, M., Swiney, J. (1981). Individual differences in formal thought: Role of cognitions and aptitudes. *Journal of Educational Psychology, 73*, 274-286; Linn, M., Clement, C., Pulos, S. (1983). Is it formal if it's not physics? The influence of content on formal reasoning. *Journal of Research in Science Teaching, 20*, 755-776.

[9] Rowell, J., Dawson, C. (1984). Controlling variables: Testing a programme for teaching a general solution strategy. *Research in Science and Technological Education, 2,* 37-46; Ross, J.A. (1988). Controlling variables: A meta-analysis of training studies. *Review of Educational Research, 58*, 405-457.

Grade 8

Disciplinary Core Ideas

Grade 8, Measurement Target 2	Students are able to develop and interpret models and use mathematical representations and scientific information to make claims about how waves transfer energy and information through various materials.		
	PS4.A: Wave Properties	**PS4.B: Electromagnetic Radiation**	**PS4.C: Information Technologies and Instrumentation**
DCIs	• A simple wave has a repeating pattern with a specific wavelength, frequency, and amplitude. **(MS-PS4-1)** • A sound wave needs a medium through which it is transmitted. **(MS-PS4-2)**	• When light shines on an object, it is reflected, absorbed, or transmitted through the object, depending on the object's material and the frequency (color) of the light. **(MS-PS4-2)** • The path that light travels can be traced as straight lines, except at surfaces between different transparent materials (e.g., air and water, air and glass) where the light path bends. **(MS-PS4-2)** • A wave model of light is useful for explaining brightness, color, and the frequency-dependent bending of light at a surface between media. **(MS-PS4-2)** • However, because light can travel through space, it cannot be a matter wave, like sound or water waves. **(MS-PS4-2)**	• Digitized signals (sent as wave pulses) are a more reliable way to encode and transmit information. **(MS-PS4-3)**
Elaboration of the DCIs	**MS-PS4A.a** • A simple wave has a repeating pattern. • A simple wave has a specific wavelength. • A simple wave has a specific frequency. • A simple wave has a specific amplitude.	**MS-PS4B.a** • When light shines on an object, it can be reflected by the object. • When light shines on an object, it can be absorbed by the object. • When light shines on an object, it can be transmitted by the object.	**MS-PS4C.a** • Digitized signals (sent as wave pulses) are a more reliable way to encode and transmit information than analog signals. • Waves can be used to transmit digital information. • Digitized information is comprised of a pattern of 1s and 0s.

Elaboration of the DCIs Cont'd	• The wavelength and frequency of a wave are related to one another by the speed of travel of the wave. • The higher the frequency of the wave the shorter the wavelength. • The lower the frequency of the wave the longer the wavelength. • The higher the frequency of the wave the higher the amplitude. • The lower the frequency of the wave the lower the amplitude. **MS-PS4A.b** • Sound waves need a medium (air, water, or solid material) to travel through. • Sound is a pressure wave in air or any other material medium.	• When light shines on an object, it can be scattered through the object. • What happens to light when it shines on an object depends on the object's material. • What happens to light when it shines on an object depends on the frequency (color) of the light. • The selective absorption of different wavelengths of white light determines the color of most objects. **MS-PS4B.b** • The path of light travels in a straight line. • The path of light bends at surfaces between different transparent materials (e.g., air and water, air and glass). • Light usually refracts when passing from one material into another. **MS-PS4B.c** • Light can be described using a wave model. • A wave model of light can be used to explain its brightness. • A wave model of light can be used to explain its color. • A wave model of light can be used to explain the bending of light at a surface between media. • Light can travel through a vacuum. • Light cannot be described as a mechanical wave. • At the surface between two media, like any wave, light can be reflected, refracted (its path bent), or absorbed.	

<table>
<tr><td>Proficiency Boundaries</td><td colspan="3">Assessment should be limited to standard repeating waves and should not include electromagnetic waves.
Assessment should be limited to qualitative applications pertaining to light and mechanical waves.
Binary counting is not included.
The specific mechanism of any given device is not included.</td></tr>
<tr><td>Prior Knowledge</td><td colspan="3">Energy can be transferred from place to place by sound, light, heat, and electric currents.
Energy can be converted from one form to another.
The speed of an object is related to the energy of the object.
Waves can cause objects to move.
Waves of the same type can differ in amplitude (height of the wave) and wavelength (spacing between wave peaks).
Light reflecting from objects and entering the eye allows objects to be seen.
Patterns can be used to transfer information.
Digitized information can be transmitted over long distances without significant degradation.</td></tr>
<tr><td>Student Misconceptions</td><td colspan="3">The majority of elementary students and some middle school students who have not received any systematic instruction about light tend to identify light with its source (e.g., light is in the bulb) or its effects (e.g., patch of light). They do not have a notion of light as something that travels from one place to another. As a result, these students have difficulties explaining the direction and formation of shadows, and the reflection of light by objects. For example, some students simply note the similarity of shape between the object and the shadow or say that the object hides the light. Middle school students often accept that mirrors reflect light but, at least in some situations, reject the idea that ordinary objects reflect light. [1] Many elementary and middle school students do not believe that their eyes receive light when they look at an object. Students' conceptions of vision vary from the notion that light fills space ("the room is full of light") and the eye "sees" without anything linking it to the object to the idea that light illuminates surfaces that we can see by the action of our eyes on them. [2] The conception that the eye sees without anything linking it to the object persists after traditional instruction in optics. [3] Some fifth graders can understand seeing as "detecting" reflected light after specially designed instruction. [4]</td></tr>
<tr><td>Articulation of DCIs Across Grade Levels</td><td>4.PS4.A (MS-PS4-1)
HS.PS4.A (MS-PS4-1),
(MS-PS4-2),
(MS-PS4-3)</td><td>4.PS3.B (MS-PS4-1)
4.PS4.A (MS-PS4-1)
4.PS4.B (MS-PS4-2)
HS.PS4.B (MS-PS4-1), (MS-PS4-2)
HS.ESS1.A (MS-PS4-2)
HS.ESS2.A (MS-PS4-2)</td><td>4.PS4.C (MS-PS4-3)
HS.PS4.C (MS-PS4-3)
HS.ESS2.C (MS-PS4-2)
HS.ESS2.D (MS-PS4-2)</td></tr>
</table>

[1] Guesne, E. (1985). Light. In R. Driver, E. Guesne & A. Tiberghien (Eds.), *Children's Ideas in Science* (pp. 10-32). Milton Keynes: Open University Press.; Ramadas, J. & Driver, R. (1989). *Aspects of secondary students' ideas about light.* Leeds: University of Leeds, Centre for Studies in Science and Mathematics Education.

[2] Guesne, E. (1985). Light. In R. Driver, E. Guesne & A. Tiberghien (Eds.), *Children's Ideas in Science* (pp. 10-32). Milton Keynes: Open University Press.

[3] Guesne, E. (1985). Light. In R. Driver, E. Guesne & A. Tiberghien (Eds.), *Children's Ideas in Science* (pp. 10-32). Milton Keynes: Open University Press.

[4] Anderson, C. W., & Smith, E. L. (1986). *Children's conceptions of light and color: Understanding the role of unseen rays* (Res. Series No. 166). Michigan State University, College of Education, Institute for Research on Teaching.

Crosscutting Concepts

Grade 8, Measurement Target 2	Students are able to develop and interpret models and use mathematical representations and scientific information to make claims about how waves transfer energy and information through various materials.	
CCCs[1]	**Patterns**	**Structure and Function**
	• Graphs and charts can be used to identify patterns in data. **(MS-PS4-1)**	• Structures can be designed to serve particular functions by taking into account properties of different materials, and how materials can be shaped and used. **(MS-PS4-2), (MS-PS4-3)** • Structures can be designed to serve particular functions. **(MS-PS4-3)**
Essential Knowledge and Skills	**MS-PS4-1** • Graphs can be used to represent and identify patterns such as direct and inverse relationships. • The unit rate can be interpreted as the slope of a graph for a proportional relationship. • Charts can be used to represent and identify patterns such as direct and inverse relationships. • Images can be used to represent and identify patterns.	**MS-PS4-2 and MS-PS4-3** • Structures can be designed to serve different functions. • The relationship between structure and function may be reciprocal. **MS-PS4-3** • The design of a structure must be based on the properties of its materials. • The design of a structure must be based on its shape. • The design of a structure must be based on how it will be used. • Structure does not always determine function. • Different structures can have the same or similar functions.
Evidence of a High Level of Performance	• Students can reason using multiple sources of information (e.g., graphs, charts, and images) to draw conclusions based on patterns in data.	• Students can apply knowledge of macroscopic and microscopic properties of materials to design a structure to serve a particular function.
Relationships to Practices[2]	• Recognizing patterns in data and seeing relationships between variables. • Recognizing patterns is a large part of working with data. • Patterns are identified best using mathematical concepts. • Patterns in rates of change and other numerical relationships provide information about natural and human designed systems.	• A sense of scale is necessary to know what properties and what aspects of shapes or materials are relevant at a particular magnitude or in modeling particular phenomena. • Modeling complex and microscopic structures and systems and visualizing how their function depends on the shapes, composition, and relationships among its parts. • To communicate findings clearly and persuasively may include an analysis of complex structures and systems to describe how they function.

[1] These are the primary Crosscutting Concepts associated with the Performance Expectations for this Measurement Target. Additional Crosscutting Concepts Building to the PEs can be found on the website for the Next Generation Science Standards.
[2] These are meant to be examples; not an exhaustive list of connections to the practices. Additional Practices Building to the PEs can be found on the website for the Next Generation Science Standards.

Prerequisite Knowledge and Skills	• Ability to use patterns to identify cause and effect relationships, and use graphs and charts to identify patterns in data • Ability to identify patterns in rates of change and other numerical relationships	• Ability to model complex and microscopic structures and systems and visualize how their functions depend on the shapes, composition, and relationships among their parts • Ability to design structures to serve particular functions by taking into account properties of different materials, and how materials can be shaped and used
Student Challenges	• Middle school students tend to invoke personal experiences as evidence to justify a particular hypothesis. They seem to think of evidence as selected from what is already known or from personal experience or second-hand sources, not as information produced by experiment. [1] Most sixth graders can judge whether evidence is related to a theory, although they do not always evaluate this evidence correctly. [2] When asked to use evidence to judge a theory, students of all ages may make only theory-based responses with no reference made to the presented evidence. Sometimes this appears to be because the available evidence conflicts with the students' beliefs. [3]	

[1] Roseberry, A., Warren, B., Conant, F. (1992). Appropriating scientific discourse: Findings from language minority classrooms. *Journal of the Learning Sciences, 2*, 61-94.

[2] Kuhn, D., Amsel, E., O'Loughlin, M., Beilin, H. (1988). *The development of scientific thinking skills.* London: Academic Press.

[3] Kuhn, D., Amsel, E., O'Loughlin, M. (1988). *The development of scientific thinking skills.* London: Academic Press.

Practices

Grade 8, Measurement Target 2	Students are able to develop and interpret models and use mathematical representations and scientific information to make claims about how waves transfer energy and information through various materials.		
	Using Mathematics and Computational Thinking	**Developing and Using Models**	**Obtaining, Evaluating, and Communicating Information**
Practices[1]	• Students can use mathematical representations to describe and/or support scientific conclusions and design solutions. **(MS-PS4-1)**	• Students can develop and use a model to describe phenomena. **(MS-PS4-2)**	• Students can integrate qualitative scientific and technical information in written text with that contained in media and visual displays to clarify claims and findings. **(MS-PS4-3)**
Essential Knowledge and Skills	**MS-PS4-1** • Students can use mathematical representations to describe scientific conclusions. • Students can use mathematical representations to support scientific conclusions. • Students can use mathematical representations to describe design solutions. • Students can use mathematical representations to support design solutions.	**MS-PS4-2** • Students can use a model to predict phenomena. • Students can use a model to describe phenomena. • Students can develop a model to predict phenomena. • Students can develop a model to describe phenomena. • Students can identify appropriate aspects of a given phenomenon to include in a model. • Students can explain the relationships among the components of a model. • Students can create an accurate representation of a given phenomenon. • Students can describe the relationship between a given phenomenon and a model of that phenomenon.	**MS-PS4-3** • Students can interpret qualitative scientific information in written text. • Students can interpret qualitative scientific information in media and visual displays. • Students can integrate qualitative scientific information from different sources. • Students can use integrated qualitative scientific information to clarify claims and findings. • Students can cite evidence and draw inferences from text. • Students can determine the central ideas or conclusions of a text. • Students can compare and contrast the information from multiple sources. • Students can draw evidence from informational texts to support analysis, reflection, and research.
Evidence of a High Level of Performance	• Students can design and use mathematical representations to support a solution to a problem.	• Students can create a model to represent a given phenomenon and use the model to describe and predict aspects of the phenomenon.	• Students can interpret and evaluate qualitative data from different sources and justify conclusions using data.

[1] These are the primary Practices associated with the Performance Expectations for this Measurement Target. Additional Practices Building to the PEs can be found on the website for the [Next Generation Science Standards.]

Prerequisite Knowledge and Skills	• Knowledge of units and unit conversions • Knowledge of ratio relationships • Ability to interpret qualitative data • Ability to represent proportional relationships • Knowledge of linear relationships
Student Challenges	• Typical student beliefs about mathematical inquiry include the following: There is only one correct way to solve any mathematics problem; mathematics problems have only one correct answer; mathematics is done by individuals in isolation; mathematical problems can be solved quickly or not at all; mathematical problems and their solutions do not have to make sense; and that formal proof is irrelevant to processes of discovery and invention. [1] These beliefs limit students' mathematical behavior. [2] Further research is needed to assess when and how students can understand that mathematical inquiry is a cycle in which ideas are represented abstractly, the abstractions are manipulated, and the results are tested against the original ideas. We must also learn at what age students can begin to represent something by a symbol or expression, and what standards students use to judge when solutions to mathematical problems are useful or adequate. [3] • Prior to instruction, or after traditional instruction, many middle and high school students continue to focus on perceptual rather than functional similarities between models and their referents, and think of models predominantly as small copies of real objects. [4] Consequently, students often interpret models they encounter in school science too literally and unshared attributes between models and their referents are a cause of misunderstanding. [5] Some middle and high school students view visual representations such as maps or diagrams as models, but only a few students view representations of ideas or abstract entities as models. [6] • Only a few middle and high school students think that models are useful in developing and testing ideas and that the usefulness of a model can be tested by comparing its implications to actual observations. [7] • Middle school and high school students accept the idea that scientists can have more than one model for the same thing. [8] However, having multiple models may mean for them that one could have literally a different view of the same entity, or that one could emphasize different aspects of the same entity—omitting or highlighting certain things to provide greater clarity. Students are rarely aware that there could be different models to explain something or to evaluate alternative hypotheses. They find multiple model use in school science confusing and rarely use multiple models to think about phenomena; even if they do, the idea that one model is "right" and "real" persists. [9] Students may know that models can be changed, but changing a model for them means (typical of high school students) adding new information or (typical of middle school students) replacing a part that was made wrong. [10]
Common Core State Standards for Mathematics Connections	• **MP.2** Reason abstractly and quantitatively. **(MS-PS4-1)** • **MP.4** Model with mathematics. **(MS-PS4-1)** • **6.RP.A.1** Understand the concept of a ratio and use ratio language to describe a ratio relationship between two quantities. **(MS-PS4-1)** • **6.RP.A.3** Use ratio and rate reasoning to solve real-world and mathematical problems. **(MS-PS4-1)** • **7.RP.A.2** Recognize and represent proportional relationships between quantities. **(MS-PS4-1)** • **8.F.A.3** Interpret the equation y = mx + b as defining a linear function, whose graph is a straight line; give examples of functions that are not linear. **(MS-PS4-1)**

Common Core State Standards for ELA/Literacy Connections	• **RST.6-8.1** Cite the textual evidence that most strongly supports an analysis of what the text says explicitly as well as inferences drawn from the text. **(MS-PS4-3)** • **RST.6-8.2** Determine the central ideas or conclusions of a text; provide an accurate summary of the text distinct from prior knowledge or opinions. **(MS-PS4-3)** • **RST.6-8.9** Compare and contrast the information gained from experiments, simulations, video, or multimedia sources with that gained from reading a text on the same topic. (**MS-PS4-3)** • **WHST.6-8.9** Draw evidence from informational texts to support analysis, reflection, and research. **(MS-PS4-3)** • **SL.8.5** Integrate multimedia and visual displays into presentations to clarify information, strengthen claims and evidence, and add interest. **(MS-PS4-1), (MS-PS4-2)**

[1] Schoenfeld, A. (1985*). Mathematical problem solving. Mathematical problem solving*. New York: Academic Press; Schoenfeld, A. (1989). Explorations of students' mathematical beliefs and behavior. *Journal for Research in Mathematics Education, 20*, 338-355; Schoenfeld, A. (1989). Problem solving in context(s). In Charles, R. (Ed.), *The teaching and assessing of mathematical problem solving* (pp. 82-92). Reston, VA: NCTM.

[2] Schoenfeld, A. (1985). *Mathematical problem solving. Mathematical problem solving.* New York: Academic Press.

[3] American Association for the Advancement of Science. (2001). Atlas of science literacy (Vol. 1). Washington, DC: Author.

[4] Grosslight, L., Unger, C., Jay, E., Smith, C. (1991). Understanding models and their use in science: Conceptions of middle and high school students and experts. *Journal of Research in Science Teaching, 28*, 799-822; Treagust, D., Chittleborough, G., Mamiala, T. (2002). Students' understanding of the role of scientific models in learning science*. International Journal of Science Education, 24*, 357-368; Schwarz, C., White, B. (2005). Metamodeling knowledge: Developing students' understanding of scientific modeling. *Cognition and Instruction, 23*, 165-205.

[5] Coll, R., France, B., Taylor, I. (2005). The role of models and analogies in science education: Implications from research. *International Journal of Science Education, 27*, 183-198; Harrison, A., Treagust, D. (1996). Secondary students' mental models of atoms and molecules: Implications for teaching science. *Science Education, 80*, 509-534.

[6] Grosslight, L., Unger, C., Jay, E., Smith, C. (1991). Understanding models and their use in science: Conceptions of middle and high school students and experts*. Journal of Research in Science Teaching, 28*, 799-822.

[7] Grosslight, L., Unger, C., Jay, E., Smith, C. (1991). Understanding models and their use in science: Conceptions of middle and high school students and experts. *Journal of Research in Science Teaching, 28*, 799-822.

[8] Grosslight, L., Unger, C., Jay, E., Smith, C. (1991). Understanding models and their use in science: Conceptions of middle and high school students and experts*. Journal of Research in Science Teaching, 28*, 799-822.

[9] Harrison, A., Treagust, D. (1996). Secondary students' mental models of atoms and molecules: Implications for teaching science. *Science Education, 80*, 509-534; Harrison, A., Treagust, D. (2000). A typology of school science models. *International Journal of Science Education, 22*, 1011-1026.

[10] Grosslight, L., Unger, C., Jay, E., Smith, C. (1991). Understanding models and their use in science: Conceptions of middle and high school students and experts*. Journal of Research in Science Teaching, 28*, 799-822

Grade 11

Disciplinary Core Ideas

Grade 11, Measurement Target 1	Students are able to evaluate evidence and apply scientific reasoning related to Earth's geologic processes and the dynamic feedback between the biosphere and other Earth systems to support an argument about the continual co-evolution of Earth's systems and life on Earth.				
	ESS1.C: The History of Planet Earth	**ESS2.B: Plate Tectonics and Large-Scale System Interactions**	**ESS2.D: Weather and Climate**	**ESS2.E: Biogeology**	**PS1.C: Nuclear Processes**
DCIs	• Continental rocks, which can be older than 4 billion years, are generally much older than the rocks of the ocean floor, which are less than 200 million years old. **(HS-ESS1-5)** • Although active geologic processes, such as plate tectonics and erosion, have destroyed or altered most of the very early rock record on Earth, other objects in the solar system, such as lunar rocks, asteroids, and meteorites, have changed little over billions of years. Studying these objects can provide information about Earth's formation and early history. **(HS-ESS1-6)**	• Plate tectonics is the unifying theory that explains the past and current movements of the rocks at Earth's surface and provides a framework for understanding its geologic history. **(HS-ESS1-5)**	• Gradual atmospheric changes were due to plants and other organisms that captured carbon dioxide and released oxygen. **(HS-ESS2-7)**	• The many dynamic and delicate feedbacks between the biosphere and other Earth systems cause a continual co-evolution of Earth's surface and the life that exists on it. **(HS-ESS2-7)**	• Spontaneous radioactive decays follow a characteristic exponential decay law. **(HS-ESS1-5), (HS-ESS1-6)** • Nuclear lifetimes allow radiometric dating to be used to determine the ages of rocks and other materials. **(HS-ESS1-5), (HS-ESS1-6)**

Elaboration of the DCIs	**HS.ESS1C.b** • According to the theory of plate tectonics, evidence of the past and current movements of continental and oceanic crust can be used to explain the ages of crustal rocks. • Sea floor spreading adds new crust to the ocean floor. • Earth's internal and surface processes operate at different spatial and temporal scales to form continental and ocean-floor features. • Continental rocks can be older than 4 billion years. • Rocks of the ocean floor are less than 200 million years old. **HS.ESS1C.c** • Active geologic processes have destroyed or altered most of the very early rock record on Earth. • Some objects in the solar system have changed very little over billions of years. • Studying these objects can help deduce the	**HS.ESS2B.a** • Plate tectonics is the theory that explains the past and current movement of Earth's plates. • Plate tectonics also provides a framework for understanding Earth's geologic history.	**HS.ESS2D.b** • Plants contribute to the make-up of Earth's atmosphere by absorbing carbon dioxide and releasing oxygen. • Carbon continuously cycles from one sphere to another. • In the past, the relative amount of carbon that cycled through the hydrosphere, atmosphere, lithosphere or geosphere, and biosphere was partially due to the activity of plants and other organisms.	**HS.ESS2E.a** • Feedback (negative or positive) can stabilize or destabilize a system. • The feedbacks between life on Earth and the Earth's systems cause life on Earth to evolve and the surface of the Earth to undergo changes at the same time. • Examples of feedback include how an increase in greenhouse gases causes a rise in global temperatures that melts glacial ice, thus reducing the amount of sunlight reflected from Earth's surface, which in turn increases surface temperatures and further reduces the amount of ice.	**HS.PS1C.b** • Radioactive elements found in rocks decay at a constant rate. • The half-life of a radioactive element is the time it takes for half of the radioactive atoms to decay. • Scientists compare the amount of a radioactive element in a rock with the amount of the stable element into which the radioactive element decays. • Scientists use radioactive dating to determine the absolute ages of rocks and other materials.

	solar system's age and history.				
Elaboration of the DCIs Cont'd	dy objects in the solar system cks, asteroids, meteorites) to ıes about Earth's history.				
Proficiency Boundaries	• Students do not need to demonstrate comprehensive understanding of the mechanisms of how the biosphere interacts with all of Earth's other systems. • Assessment is limited to alpha, beta, and gamma radioactive decays.				
Prior Knowledge	Rock formations and the fossils they contain are used to establish relative ages of major events in Earth's history.	Earth's plates have moved great distances, collided, and spread apart.	There are patterns of interactions in ecosystems in terms of the relationships among and between organisms and abiotic components of ecosystems.	The evolution and proliferation of living things over geological time have changed the rates of weathering and erosion of land surfaces, altered the composition of Earth's soils and atmosphere, and affected the distribution of water in the hydrosphere.	Some unstable but long-lived isotopes are present in rocks and minerals. Knowledge of their nuclear lifetimes allows radiometric dating to be used to determine the ages of rocks and other materials from the isotope ratios present.
Student Misconceptions	• Students of all ages may hold the view that the world was always as it is now, or that any changes that have occurred must have been sudden and comprehensive. [1] The students in these studies did not, however, have any formal instruction on the topics investigated. Moreover, middle school students taught by traditional means are not able to construct coherent explanations about the causes of volcanoes and earthquakes. [2]				
Articulation of DCIs Across Grade Levels	**MS.ESS1.C** (HS-ESS1-5), (HS-ESS1-6), (HS-ESS2-1)	**MS.ESS2.B** (HS-ESS1-5), (HS-ESS1-6), (HS-ESS2-1)	**MS.ESS2.D** (HS-ESS2-1)	**NA**	**NA**

[1] Freyberg, P. (1985). Implications across the curriculum. In R. Osborne & P. Freyberg (Eds.) *Learning in Science* (pp. 125-135). Auckland, NZ: Heinemann.

[2] Duschl, R., Smith, M., Kesidou, S., Gitomer, D., Schauble, L. (1992). *Assessing student explanations for criteria to format conceptual change learning environments*. Paper presented at the annual meeting of the American Educational Research Association. San Francisco, CA.

Crosscutting Concepts

Grade 11, Measurement Target 1	Students are able to evaluate evidence and apply scientific reasoning related to Earth's geologic processes and the dynamic feedback between the biosphere and other Earth systems to support an argument about the continual co-evolution of Earth's systems and life on Earth.	
CCCs[1]	**Patterns**	**Stability and Change**
	• Empirical evidence is needed to identify patterns. **(HS-ESS1-5)**	• Much of science deals with constructing explanations of how things change and how they remain stable. **(HS-ESS1-6), (HS-ESS2-7)**
Essential Knowledge and Skills	**HS-ESS1-5** • Evidence is required when identifying a pattern in an observed phenomenon. • Evidence is required to explain the pattern in a system under study. • Evidence is required to support a claim about the pattern in a system under study.	**HS-ESS1-6 and HS-ESS2-7** • Science deals with constructing explanations of how things change. • Science deals with constructing explanations of how things remain stable.
Evidence of a High Level of Performance	• Students recognize that different patterns may be observed at each of the scales at which a system is studied. • Students use empirical evidence to support the explanation about the ages of crustal rocks (e.g., pattern of the continental crust being older than the oceanic crust; pattern that the oldest continental rocks are located at the center of continents, with the ages decreasing from their centers to their margin; and pattern that the ages of oceanic crust are greatest nearest the continents and decrease in age with proximity to the mid-ocean ridges).	• Students can evaluate models of complex systems and comprehend subtle issues of stability or of sudden or gradual change over time. • Students recognize that much of science deals with constructing historical explanations of how things evolved to be the way they are today, which involves modeling rates of change and conditions under which the system is stable or changes gradually, as well as explanations of any sudden change.
Relationships to Practices[2]	• Patterns can be used to support an argument. • Data analysis serves to identify and characterize patterns. • Patterns can be used as empirical evidence for causality in supporting explanations of phenomena.	• Observations and data describe how things change. • Reasoning and data can be used to explain how things evolved to be the way they are today. • Arguments can be supported by quantifying and modeling changes in systems over very short or very long periods of time.

[1] These are the primary Crosscutting Concepts associated with the Performance Expectations for this Measurement Target. Additional Crosscutting Concepts Building to the PEs can be found on the website <u>for the Next Generation Science Standards.</u>

[2] These are meant to be examples; not an exhaustive list of connections to the practices. Additional Practices Building to the PEs can be found on the website for the <u>Next Generation Science Standards.</u>

Prerequisite Knowledge and Skills	• Ability to recognize that macroscopic patterns are related to the nature of microscopic and atomic-level structure • Ability to identify patterns in rates of change and other numerical relationships that provide information about natural and human designed systems • Ability to use patterns to identify cause and effect relationships, and use graphs and charts to identify patterns in data	• Ability to explain stability and change in natural or designed systems by examining changes over time, and considering forces at different scales, including the atomic scale • Ability to explain how changes in one part of a system might cause large changes in another part
Student Challenges	• Middle and high school student thinking about chemical change tends to be dominated by the obvious features of the change. [1] For example, some students think that when something is burned in a closed container, it will weigh more because they see the smoke that was produced. Further, many students do not view chemical changes as interactions. They do not understand that substances can be formed by the recombination of atoms in the original substances. Rather, they see chemical change as the result of a separate change in the original substance, or changes, each one separate, in several original substances. For example, some students see the smoke formed when wood burns as having been driven out of the wood by the flame. [2] • Fourth graders' representations of changes over time are "data-driven" in the sense that the particular data in the problem are the most important. This contrasts with "system-driven" representations in which the emphasis is on overall patterns. Unfortunately, students are typically introduced to system-driven representations while they still think it is a wrong or meaningless way to convey information. [3]	

[1] Driver, R. (1985). Beyond appearances: The conservation of matter under physical and chemical transformations. In Driver, R. (Ed.), *Children's ideas in science* (pp. 145-169). Milton Keynes, UK: Open University Press.

[2] Andersson, B. (1990). Pupils' conceptions of matter and its transformations (Age 12-16). In Lijnse, P., Licht, P., de Vos, W., & Waarlo, A.J. (Eds.), *Relating macroscopic phenomena to microscopic particles* (pp. 12-35). Utrecht: CD-þ Press.

[3] Tierney, C., Nemirovsky, R. (1991). Children's spontaneous representations of changing situations. *Hands On!, 14*, 7-10.

Practices

Grade 11, Measurement Target 1	Students are able to evaluate evidence and apply scientific reasoning related to Earth's geologic processes and the dynamic feedback between the biosphere and other Earth systems to support an argument about the continual co-evolution of Earth's systems and life on Earth.	
	Engaging in Argument from Evidence	**Constructing Explanations and Designing Solutions**
Practices[1]	• Evaluate evidence behind currently accepted explanations or solutions to determine the merits of arguments. **(HS-ESS1-5)** • Construct an oral and written argument or counter-arguments based on data and evidence. **(HS-ESS2-7)**	• Apply scientific reasoning to link evidence to the claims to assess the extent to which the reasoning and data support the explanation or conclusion. **(HS-ESS1-6)**
Essential Knowledge and Skills	**HS-ESS1-5** • Students can evaluate the claims behind currently accepted explanations to determine the merits of arguments. • Students can evaluate the claims behind currently accepted solutions to determine the merits of arguments. • Students can evaluate the evidence behind currently accepted explanations to determine the merits of arguments. • Students can evaluate the evidence behind currently accepted solutions to determine the merits of arguments. • Students can evaluate the reasoning behind currently accepted explanations to determine the merits of arguments. • Students can evaluate the reasoning behind currently accepted solutions to determine the merits of arguments. **HS-ESS2-7** • Students can construct an oral argument based on data and evidence. • Students can construct a written argument based on data and evidence. • Students can construct an oral counter-argument based on data and evidence. • Students can construct a written counter-argument based on data and evidence.	**HS-ESS1-6** • Students can apply scientific reasoning to link evidence to the claims to assess the extent to which the reasoning and data support the explanation. • Students can apply scientific theory to link evidence to the claims to assess the extent to which the reasoning and data support the explanation. • Students can apply scientific modeling to link evidence to the claims to assess the extent to which the reasoning and data support the explanation. • Students can apply scientific reasoning to link evidence to the claims to assess the extent to which the reasoning and data support the conclusion. • Students can apply scientific theory to link evidence to the claims to assess the extent to which the reasoning and data support the conclusion. • Students can apply scientific modeling to link evidence to the claims to assess the extent to which the reasoning and data support the conclusion.
Evidence of a High Level of Performance	• Students can identify possible weaknesses in either data or an argument and explain why their criticism is justified, and recognize the criteria used to judge claims for new	• Students can undertake complex engineering design projects related to major local, national, or global issues. Students can evaluate research on the nature of the given

[1] These are the primary Practices associated with the Performance Expectations for this Measurement Target. Additional Practices Building to the PEs can be found on the website for the [Next Generation Science Standards.]

<table>
<tr><td></td><td>knowledge and the formal means by which scientific arguments are constructed.</td><td>problems, review others’ proposed solutions, or weigh the strengths and weaknesses of various alternatives, and discern possible unanticipated effects.</td></tr>
<tr><td>Prerequisite Knowledge and Skills</td><td colspan="2">Ability to use linear equations and systems of linear equations to represent, analyze, and solve a variety of problems
Ability to analyze situations and solve problems
Knowledge of how to recognize patterns of association in bivariate data
Ability to write a scientific argument</td></tr>
<tr><td>Student Challenges</td><td colspan="2">Some high school students believe scientists and engineers are more capable of making decisions about public issues related to science and technology than the general public. Students believe that scientists and engineers know all the facts and are not influenced by personal motives and interests. [1]
Students of all ages as well as adults may change variables one at a time to test a claim whose outcome may be construed as negative (e.g., honey makes a cake taste bad). But when the outcome is construed as positive (e.g., honey makes a cake taste good), they may hold constant what they believe is contributing to the positive outcome. [2]
Students may cite data in their arguments, but they may fail to cite sufficient evidence for claims. In addition, references to data in students' arguments often fail to articulate how specific data relate to specific claims. [3] Students may believe that data literally speak for themselves—that they are self-evident—rather than providing raw material for supporting or judging a claim. [4]
Some middle school students tend to invoke personal experiences as evidence to justify a particular hypothesis. Specifically, they seem to think of evidence as selected from what is already known or from personal experience or second-hand sources, not as information produced by experiment. [5]
Students do not necessarily consider only the evidence that is presented to them but make additional assertions about the context of the problem, or even introduce inferences that go beyond the boundaries of the evidence presented and that introduce bias in the outcome. [6]</td></tr>
<tr><td>Common Core State Standards for Mathematics Connections</td><td colspan="2">MP.2 Reason abstractly and quantitatively. (HS-ESS1-5), (HS-ESS1-6)
HSN-Q.A.1 Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and define appropriate quantities for the purpose of descriptive modeling (HS-ESS1-5), (HS-ESS1-6)
HSN-Q.A.3 Choose a level of accuracy appropriate to limitations on measurement when reporting quantities (HS-ESS1-5), (HS-ESS1-6)
HSF-IF.B.5 Relate the domain of a function to its graph and, where applicable, to the quantitative relationship it describes. (HS-ESS1-6)
HSS-ID.B.6 Represent data on two quantitative variables on a scatter plot and describe how those variables are related. (HS-ESS1-6)</td></tr>
<tr><td>Common Core State Standards for ELA/Literacy Connections</td><td colspan="2">RST.11-12.1 Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account. (HS-ESS1-5), (HS-ESS1-6)
RST.11-12.8 Evaluate the hypotheses, data, analysis, and conclusions in a science or technical text, verifying the data when possible and corroborating or challenging conclusions with other sources of information. (HS-ESS1-5), (HS-ESS1-6)
WHST.9-12.1 Write arguments focused on discipline-specific content. (HS-ESS1-6), (HS-ESS2-7)
WHST.9-12.2 Write informative/explanatory texts, including the narration of historical events, scientific procedures/ experiments, or technical processes. (HS-ESS1-5)</td></tr>
</table>

[1] Fleming, R. (1987). High school graduates' beliefs about science-technology-society II. The interaction among science, technology, society. *Science Education, 71*, 163-186; Aikenhead, G.S. (1987). High school graduates' beliefs about science-technology-society III. Characteristics and limitations of scientific knowledge. *Science Education, 71*, 459-487.

[2] Zimmerman, C. (2000). The development of scientific reasoning skills. *Developmental Review, 20*, 99-149; Zimmerman, C. (2005). *The development of scientific reasoning skills: What psychologists contribute to an understanding of elementary science learning*. Report to the National Research Council, Committee on Science Learning Kindergarten through Eighth Grade. Washington, DC: National Research Council.

[3] Sandoval, W.A., Millwood, K.A. (2005). The quality of students' use of evidence in written scientific explanations. *Cognition and Instruction, 23*, 23-55.

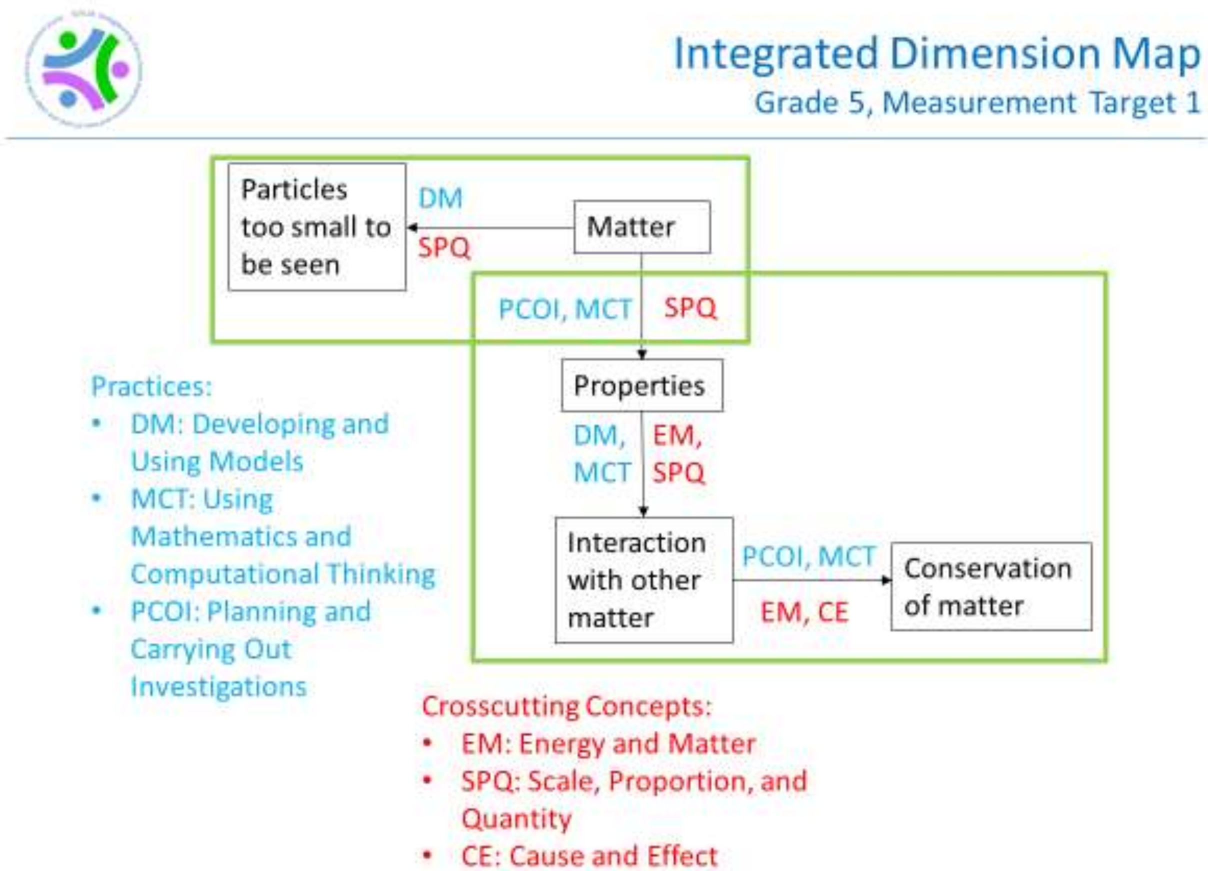
[4] Driver, R., Leach, J., Millar, R., Scott, P. (1996). *Young people's images of science*. Buckingham: Open University Press; Sandoval, W.A., Millwood, K.A. (2005). The quality of students' use of evidence in written scientific explanations*. Cognition and Instruction, 23*, 23-55.

[5] Roseberry, A., Warren, B., Conant, F. (1992). *Appropriating scientific discourse: Findings from language minority classrooms.* (Working paper 1-92). Cambridge, MA: TERC; Ratcliffe, M. (1999). Evaluation of abilities in interpreting media reports of scientific research. *International Journal of Science Education, 21*, 1085-1099.

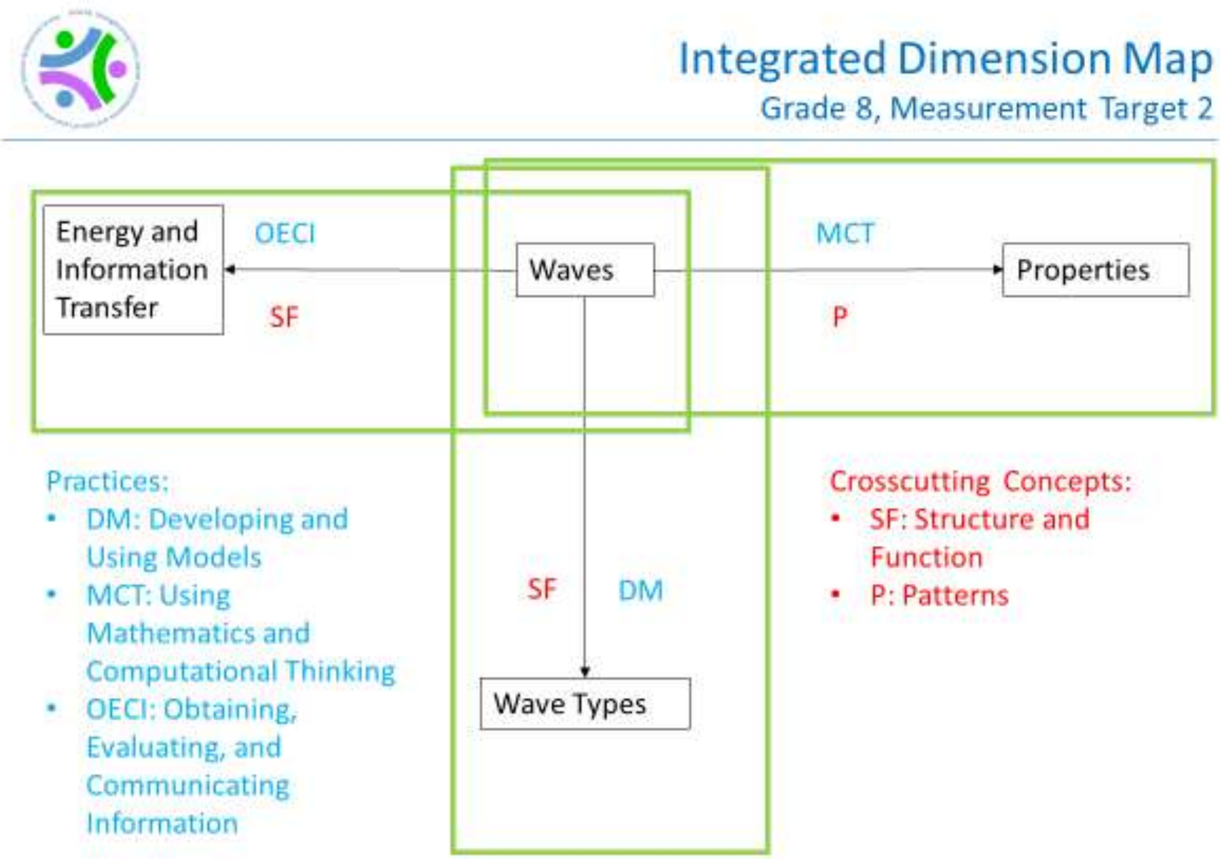
[6] Driver, R., Newton, P., Osborne, J. (2000). Establishing the norms of scientific argumentation in classrooms. *Science Education, 84*, 287-312.

Appendix C. Integrated Dimensions Maps

Grade 5

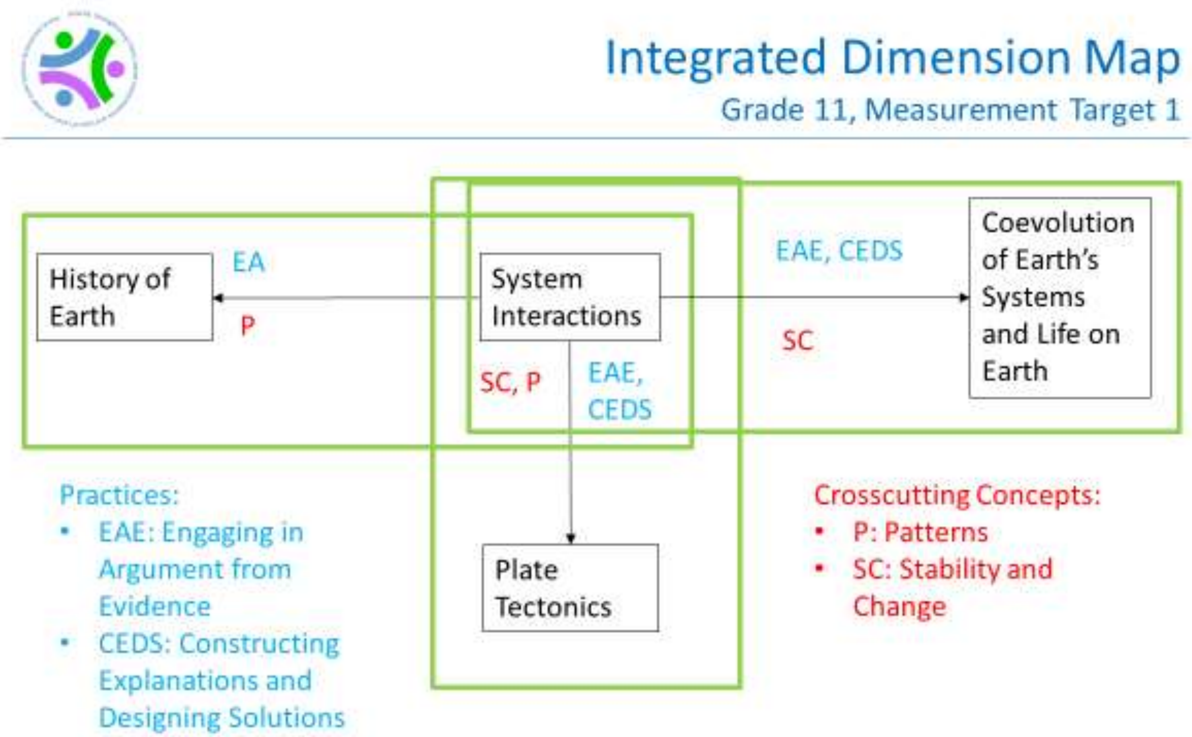


Grade 8



Integrated Dimension Map
Grade 8, Measurement Target 2
Energy and Information Transfer
OECI
SF
Waves
MCT
P
Properties
SF
DM
Wave Types
Practices:
• DM: Developing and Using Models
• MCT: Using Mathematics and Computational Thinking
• OECI: Obtaining, Evaluating, and Communicating Information
Crosscutting Concepts:
• SF: Structure and Function
• P: Patterns

Grade 11


Integrated Dimension Map
Grade 11, Measurement Target 1
History of Earth
EA
P
System Interactions
EAE, CEDS
SC
Coevolution of Earth's Systems and Life on Earth
SC, P
EAE, CEDS
Plate Tectonics
Practices:
• EAE: Engaging in Argument from Evidence
• CEDS: Constructing Explanations and Designing Solutions
Crosscutting Concepts:
• P: Patterns
• SC: Stability and Change

Appendix D. Design Patterns

Grade 5

<table>
<tr><th colspan="5">Grade 5 Overall Claim
Students demonstrate a sophisticated understanding of the core ideas and applications of practices and crosscutting concepts in the disciplines of science.</th></tr>
<tr><td>Explanatory Statements</td><td colspan="2">Students integrate disciplinary core ideas and crosscutting concepts with scientific practices to investigate and explain how and why phenomena occur, and to design and refine solutions to problems.</td><td colspan="2">Students connect knowledge across the disciplines of science to ask questions, plan and carry out investigations, and analyze and interpret data to support an argument about phenomena in a variety of contexts.</td></tr>
<tr><td colspan="5">Measurement Target 1 (Topic 1 Bundle): Students are able to investigate and interpret data to draw or support conclusions about the structure and properties of matter, including whether or not matter is conserved, and to identify materials and mixtures based upon their properties or results of a reaction.</td></tr>
<tr><td>Focal Knowledge, Skills, and Abilities (fKSAs)</td><td>5.1a Students are able to investigate the properties of matter using measurements to support a conclusion related to identifying materials.</td><td>5.1b Students are able to investigate or create an explanation around conservation of matter using measurements when substances are mixed, or undergo a change in form, properties, or state.</td><td>5.1c Students are able to identify what properties differ and what stays the same in a mixture or reaction.</td><td>5.1d Students are able to create a model that describes matter as made of particles too small to be seen.</td></tr>
<tr><td>Rationale</td><td>• Students will describe the evidence from data that properties of materials can be used to identify materials.
• Students will use quantitative and qualitative data to identify materials based on their properties.
• Students will measure and describe physical quantities such as weight, time, temperature, and volume.</td><td>• Students will describe that the total weights of the substances did not change, regardless of the reaction or changes in properties that were observed.
• Students will identify and describe the purpose of an investigation.
• Students will use quantitative and qualitative data to describe physical quantities such as weight, time, temperature, and volume.</td><td>• Students will use evidence, related to properties, to determine whether new substances are formed by mixing two or more substances.
• Students will identify the change (cause) to a system (i.e., mixing of two or more substances) and quantify the result (effect).
• Students will use quantitative and qualitative data to describe physical quantities such as weight, time, temperature, and volume.</td><td>• Students will develop and use models to demonstrate understanding that matter is made of particles too small to be seen.
• Students will use the model to make a prediction about a phenomenon (e.g., an expanding balloon, evaporating liquids, substances that dissolve in a solvent, effects of wind).</td></tr>
</table>

Additional Knowledge, Skills, and Abilities (aKSAs)	• Declarative knowledge related to properties of matter • Knowledge of tools and measurements • Knowledge of units • Ability to construct a response supported with quantitative and qualitative data	• Declarative knowledge related to properties of matter • Declarative knowledge related to changes to matter (e.g., changes caused by heating or cooling can be reversed and some cannot) • Knowledge of tools and measurements • Knowledge of units • Ability to construct a response supported with quantitative and qualitative data	• Declarative knowledge related to properties of matter • Declarative knowledge related to changes to matter (e.g., changes caused by heating or cooling can be reversed and some cannot) • Knowledge of tools and measurements • Knowledge of units • Ability to construct a response supported with quantitative and qualitative data	• Declarative knowledge related to properties of matter • Understanding that systems and processes vary in size • Knowledge that a model explains or predicts
Potential Observations	• Correct calculations • Appropriate units • Correct use of quantitative and qualitative data to identify materials based on their properties • Correct use of scientific terminology • Complete and appropriate explanation that materials can be identified based on their observable and measurable properties	• Correct calculations • Appropriate units • Correct use of quantitative and qualitative data to identify materials based on their properties • Correct use of scientific terminology • Complete and appropriate explanation of relationships	• Correct calculations • Appropriate units • Correct use of quantitative and qualitative data to serve as evidence for whether the mixing of the two or more tested substances results in one or more new substances • Correct use of scientific terminology • Complete and appropriate explanation of relationships	• Correct description of relationship between components of a model • Correct explanation that matter is made of particles too small to be seen • Correct use of scientific terminology

Potential Work Products	• Use units of weight, time, temperature, and other variables to explain the relationships among different types of quantities • Use of quantitative and qualitative data to support conclusions • Identification of which measurements to take • Measurements or observations made • Description of how observations and measurements are used to identify materials based on their properties	• Use units of weight, time, temperature, and other variables to explain the relationships among different types of quantities • Use of quantitative and qualitative data to support conclusions • Identification of which measurements to take • Measurements or observations made • Description of how observations and measurements are used to address scientific questions about the conservation of the amount of matter	• Use of quantitative and qualitative data to support conclusions • Identification of which measurements to take • Measurements or observations made • Description of how cause and effect relationships are used to explain change (i.e., mixing of two or more substances)	• A representation of matter that is too small to be seen (this could be splitting something into smaller and smaller pieces, or it could be a picture of something like air going into a balloon) • Use of a model to make sense of phenomena (e.g., an expanding balloon, evaporating liquids, substances that dissolve in a solvent, effects of wind)
Characteristic Features	• All items require evidence of qualitative and quantitative thinking. • All items must prompt students to make connections between observed phenomenon or evidence and reasoning underlying the observation/evidence. • All items must elicit core ideas as defined in *Framework for K-12 Science Education* (NRC, 2012). • Students use scientific reasoning and process skills in observational (nonexperimental) investigations. • All items must include elements from at least two dimensions.	• All items require evidence of qualitative and quantitative thinking. • All items must prompt students to make connections between observed phenomenon or evidence and reasoning underlying the observation/evidence. • All items must elicit core ideas as defined in *Framework for K-12 Science Education* (NRC, 2012). • Students use scientific reasoning and process skills in observational (nonexperimental) investigations. • All items must include elements from at least two dimensions.	• All items require evidence of qualitative and quantitative thinking. • All items must prompt students to make connections between observed phenomenon or evidence and reasoning underlying the observation/evidence. • All items must elicit core ideas as defined in *Framework for K-12 Science Education* (NRC, 2012). • Students use scientific reasoning and process skills in observational (nonexperimental) investigations. • All items must include elements from at least two dimensions.	• All items must prompt students to make connections between observed phenomenon or evidence and reasoning underlying the observation/evidence. • All items must elicit core ideas as defined in *Framework for K-12 Science Education* (NRC, 2012). • Students use scientific reasoning and process skills. • All items must include elements from at least two dimensions.

Variable Features	• Properties presented (e.g., color, conductivity, magnetic, conductors) • Format of "real-world" phenomenon under investigation: image, data, text, combination • Standard units used (e.g., grams, liters) • Evidence needed to identify the substance	• Properties of substances presented • Reaction presented • Changes in properties presented during and/or after (e.g., heated, cooled, and/or mixed) • Format of "real-world" phenomenon under investigation: image, data, text, combination • Standard units used (e.g., grams)	• Properties of substances presented • Reaction presented • Changes in properties presented during and/or after (e.g., state of matter, color, texture, odor) • Format of "real-world" phenomenon under investigation: image, data, text, combination • Standard units used (e.g., grams, liters)	• Complexity of scientific concept(s) to be modeled • Function of the model: To explain a mechanism underlying a phenomenon; to predict future outcomes; to describe a phenomenon; to generate data to inform how the world work • The degree to which components of the model are provided

Grade 8

Grade 8 Overall Claim Students demonstrate a sophisticated understanding of the core ideas and applications of practices and crosscutting concepts in the disciplines of science.			
Explanatory Statements	Students integrate disciplinary core ideas and crosscutting concepts with scientific practices to investigate and explain how and why phenomena occur, and to design and refine solutions to problems.	Students connect knowledge across the disciplines of science to ask questions, plan and carry out investigations, and analyze and interpret data to support an argument about phenomena in a variety of contexts.	
Measurement Target 2 (Topic 2 Bundle): Students are able to develop and interpret models and use mathematical representations and scientific information to make claims about how waves transfer energy and information through various materials.			
Focal Knowledge, Skills, and Abilities (fKSAs)	**8.2a** Students are able to use a mathematical model to describe wave properties and patterns relating to the amounts of energy present or transmitted.	**8.2b** Students are able to use a model to describe a phenomenon involving reflection, absorption, or transmission properties of different materials for light and matter waves.	**8.2c** Students are able to support a claim about a phenomenon that includes the idea that digitized signals are a more reliable way to encode and transmit information than analog signals.
Rationale	• Students will describe and predict characteristic properties of waves. • Students will recognize patterns as an organizing concept for understanding wave properties. • Students will use models and mathematical thinking to demonstrate understanding of wave properties.	• Students will describe and predict characteristic behaviors of waves when the waves interact with matter. • Students will develop and use models to demonstrate understanding of wave behavior.	• Students will apply an understanding of waves as a means to send digital information. • Students will apply concepts of structure and function. • Students will obtain, evaluate, and communicate information to demonstrate understanding of wave behavior.
Additional Knowledge, Skills, and Abilities (aKSAs)	• Declarative knowledge related to properties of waves • Knowledge that a model explains or predicts • Knowledge of tools and measurements • Knowledge of direct and inverse relationships	• Declarative knowledge related to behavior of waves • Declarative knowledge of phases of matter (gas, liquid, solid) • Declarative knowledge of relationship between wavelength of light absorbed and color of an object • Knowledge that a model explains or predicts	• Declarative knowledge related to transmission of data, including defining a *signal* as a method of transmitting information over a distance • Vocabulary related to structure and function • Knowledge that structures can be designed to serve particular functions • Use evidence and reasoning to construct an evidence-based account of the phenomenon

Potential Observations	• Correct calculations • Appropriate units • Correct description of relationship between components of a model • Correct predictions based on patterns • Correct application of direct and inverse relationships • Correct explanation that sound requires a medium to travel through • Correct use of scientific terminology • Complete and appropriate explanation of relationships	• Correct description of wave behaviors in various mediums • Correct description of relationship between components of a model • Correct explanation that light can travel through a vacuum • Correct use of scientific terminology	• Correct application of wave technologies to communicate information • Correct use of scientific terminology • Correct description of characteristics of digital signals compared to analog signals • Integration of qualitative scientific and technical information
Potential Work Products	• Explanation of relationships among wave properties • Prediction of relationships among wave properties • Model showing relationships among wave properties • Use of mathematical representations to describe and/or support scientific conclusions	• Prediction of wave behaviors when the waves interact with matter • Model representing wave behaviors (i.e., drawing, simulation) • Use of a model to make sense of phenomena involving reflection, absorption, or transmission properties of different materials for light and matter waves	• Comparison of reliability of analog version and digital version of a tool for communicating information • Description of application of wave technologies to communicate information (i.e., transmission of light pulses in fiber optic cables, radio wave pulses in Wi-Fi devices, conversion of stored binary patterns to make sound or text on a computer)
Characteristic Features	• All items require evidence of qualitative and quantitative thinking. • All items must prompt students to make connections between observed phenomenon or evidence and reasoning underlying the observation/evidence (e.g., related to standard repeating waves). • All items must elicit core ideas as defined in *Framework for K-12 Science Education* (NRC, 2012). • All items must include elements from at least two dimensions.	• All items require evidence of qualitative applications related to light waves and mechanical waves. • All phenomena for which a model is developed must be observable (e.g., wave behaviors in various mediums). • All items must elicit core ideas as defined in *Framework for K-12 Science Education* (NRC, 2012). • All items must include elements from at least two dimensions.	• All items require evidence of correct interpretation of qualitative data. • All items must prompt students to make connections between observed phenomenon or evidence and reasoning underlying the observation/evidence (e.g., digital tools as wave pulses). • All items must elicit core ideas as defined in *Framework for K-12 Science Education* (NRC, 2012). • All items must include elements from at least two dimensions.

Variable Features	• Complexity of scientific concept(s) to be modeled • Core idea targeted in model (e.g., the Doppler Effect, transverse and longitudinal waves) • Function of the model: To explain a mechanism underlying a phenomenon; to predict future outcomes; to describe a phenomenon; to generate data to inform how the world works	• Complexity of scientific concept(s) to be modeled • Core idea targeted in model (e.g., light sources, the materials, polarization of light, ray diagrams) • Function of the model: To explain a mechanism underlying a phenomenon; to predict future outcomes; to describe a phenomenon; to generate data to inform how the world works	• Complexity of scientific concept(s) to be described • Core idea targeted in model (e.g., light waves, radio waves, sound pulses, laser pulses, microwaves, and infrared waves) • Devices and functions (e.g., telescopes, cell phones, wired or wireless computer networks)

Grade 11

Grade 11 Overall Claim Students demonstrate a sophisticated understanding of the core ideas and applications of practices and crosscutting concepts in the disciplines of science.			
Explanatory Statements	Students integrate disciplinary core ideas and crosscutting concepts with scientific practices to investigate and explain how and why phenomena occur, and to design and refine solutions to problems.	Students connect knowledge across the disciplines of science to ask questions, plan and carry out investigations, and analyze and interpret data to support an argument about phenomena in a variety of contexts.	
Measurement Target 1 (Topic 1 Bundle): Students are able to evaluate evidence and apply scientific reasoning related to Earth's geologic processes and the dynamic feedback between the biosphere and other Earth systems to support an argument about the continual co-evolution of Earth's systems and life on Earth.			
Focal Knowledge, Skills, and Abilities (fKSAs)	**11.1a** Students are able to investigate how Earth's internal and surface processes operate at different spatial and temporal scales to explain the ages of crustal rocks.	**11.1b** Students are able to apply scientific reasoning and evidence to construct an account of Earth's formation and early history.	**11.1c** Students are able to construct an argument, using causal links and feedback mechanisms between changes in the biosphere and changes in Earth's other systems, that there is simultaneous co-evolution of Earth's systems and life on Earth.
Rationale	• Students will use empirical evidence of patterns to evaluate the merits of an argument. • Students will recognize and interpret patterns in systems at different scales. • Students construct an argument for why the principle that scientific knowledge is based on the assumption that natural laws operate today as they did in the past and that they will continue to do so in the future helps us understand that plate tectonics provides a framework for understanding Earth's geologic history.	• Students will describe that Earth's history can be understood through the study of other objects in the solar system, such as asteroids and meteorites, that have changed minimally over billions of years. • Students will use explanations of how things change and how they remain stable in assessing the extent to which the reasoning and data support the explanation or conclusion.	• Students will describe the dynamic causes, effects, and feedbacks between the biosphere and Earth's other systems. • Students will use explanations of how things change and how they remain stable in constructing an argument or counter-argument based on data and evidence.
Additional Knowledge, Skills, and Abilities (aKSAs)	• Declarative knowledge related to plate tectonics • Declarative knowledge of the fossil record • Knowledge that patterns can be used to predict and explain phenomena • Knowledge that patterns can be observed in systems at different scales • Organize data to support or refute ideas	• Declarative knowledge related to plate tectonics • Knowledge that Earth's systems interact over scales that range from microscopic to global in size, and they operate over fractions of a second to billions of years and that these interactions have shaped Earth's history and will determine its future	• Declarative knowledge related to feedbacks between the biosphere and Earth's other systems • Declarative knowledge of Earth's spheres (i.e., the atmosphere, the biosphere, the hydrosphere, and the lithosphere) • Knowledge of how things change and how they remain stable • Identify evidence to support a claim

	• Use reasoning to connect the evidence to support an explanation	• Knowledge of how things change and how they remain stable • Use evidence and reasoning to construct an evidence-based account of the phenomenon	• Generalize or summarize data or information from multiple sources of evidence
Potential Observations	• Appropriateness of the evidence used • Correctness of the observations • Correctness of the temporal and spatial scales used • Correctness of the use of scientific terminology in their explanation • Completeness and appropriateness of their explanations • Support of logical and reasonable arguments about the motion of crustal plates • Use of scientific reasoning and process skills • Cite patterns as empirical evidence for causality in supporting explanations of phenomena • Organize data to support or refute ideas	• Appropriateness of the evidence used • Correctness of the scientific reasoning • Accuracy of the explanation • Completeness and appropriateness of their explanation • Correctness of the use of scientific terminology in their explanation • Use of scientific reasoning and process skills • Cite patterns as empirical evidence for causality in supporting explanations of phenomena • Organize data to support or refute ideas • Use reasoning to connect the evidence to support an explanation	• Identify causal or correlational effects • Correctness of the scientific reasoning • Identify causal links and feedback mechanisms • Determine the usefulness of the data • Completeness and appropriateness of their argument • Correctness of the use of scientific terminology in their argument • Use of scientific reasoning and process skills in investigations • Support of their claim by generalizing from multiple sources of evidence • Use of scientific reasoning and process skills • Use of logical and reasonable arguments
Potential Work Products	• Generate or identify an explanation of how Earth's internal and surface processes operate at different spatial and temporal scales based on findings • Explain the relationship between the motion of continental plates and the patterns in the ages of crustal rocks	• Use of evidence from Earth materials, meteorites, and other planetary surfaces to construct Earth's formation and early history • Identify or justify provided inferences to connect the evidence to the account of Earth's formation and early history • Generate or identify an explanation of how things change and how they remain stable based on findings	• Identify or explain how photosynthetic life altered the atmosphere through the production of oxygen • Identify or use logical and reasonable arguments to support that there is simultaneous co-evolution of Earth's system and life on Earth • Describe patterns in changes in the biosphere and changes in Earth's other systems as empirical evidence for causality in supporting explanations of phenomena

Characteristic Features	• Models provided in stimulus materials must illustrate a process or why a phenomenon exists (e.g., plate movement). • All items are presented in a context that revolves around movement of crustal rocks. • All phenomena for which a model is developed must be observable or fit available evidence (e.g., plate tectonics to explain the ages of crustal rocks). • All items must elicit core ideas as defined in *Framework for K-12 Science Education* (NRC, 2012). • All items must include elements from at least two dimensions.	• All items must prompt students to make connections between observed phenomenon or evidence and reasoning underlying the observation/evidence (e.g., the absolute ages of ancient materials [obtained by radiometric dating of meteorites, moon rocks, and Earth's oldest minerals], the sizes and compositions of solar system objects, and the impact cratering record of planetary surfaces). • All items must elicit core ideas as defined in *Framework for K-12 Science Education* (NRC, 2012). • All items must include elements from at least two dimensions.	• All items must prompt students to make connections between observed phenomenon or evidence and reasoning underlying the observation/evidence (e.g., changes in the biosphere and changes in Earth's other systems; ancient versus current atmospheric composition). • All items require the use of data and evidence to support a logical argument in a context that revolves around changes in the biosphere and changes in Earth's other systems. • All items must elicit core ideas as defined in *Framework for K-12 Science Education* (NRC, 2012). • All items must include elements from at least two dimensions.
Variable Features	• Complexity of empirical evidence needed to identify patterns • Sources of information (e.g., graphs, charts, data, text, and images) describing "real-world" phenomenon • What characteristics are included (given or determined by the student) • Core idea targeted in model (e.g., the degree to which nuclear processes are included)	• Complexity of the scientific reasoning required to link evidence to the claims • Complexity of the scientific reasoning required to assess the extent to which the reasoning and data support the explanation or conclusion • The evidence to be used to construct an explanation	• The data to be used to determine causal or correlational effects between systems • Complexity of the scientific reasoning required to assess the extent to which the reasoning and data support the argument • Sources of information (e.g., graphs, charts, data, text, and images) describing "real-world" phenomenon

Appendix E. Task Templates

Grade 5

<table>
<tr><td colspan="5">Grade 5 Overall Claim
Students demonstrate a sophisticated understanding of the core ideas and applications of practices and crosscutting concepts in the disciplines of science.</td></tr>
<tr><td>Explanatory Statements</td><td colspan="2">Students integrate disciplinary core ideas and crosscutting concepts with scientific practices to investigate and explain how and why phenomena occur, and to design and refine solutions to problems.</td><td colspan="2">Students connect knowledge across the disciplines of science to ask questions, plan and carry out investigations, and analyze and interpret data to support an argument about phenomena in a variety of contexts.</td></tr>
<tr><td colspan="5">Measurement Target 1: Students are able to investigate and interpret data to draw or support conclusions about the structure and properties of matter, including whether or not matter is conserved, and to identify materials and mixtures based upon their properties or results of a reaction.</td></tr>
<tr><td colspan="5">Summary (Topic 1 Bundle): The bundle organizes performance expectations with a focus on helping students begin to understand the conservation of matter and its particulate nature. Instruction developed from this bundle should always maintain the three-dimensional nature of the standards and is not limited to the practices and concepts directly linked with any of the bundle performance expectations.
Develop a model to describe that matter is made of particles too small to be seen.
Measure and graph quantities to provide evidence that regardless of the type of change that occurs when heating, cooling, or mixing substances, the total weight of matter is conserved.
Make observations and measurements to identify materials based on their properties.
Conduct an investigation to determine whether the mixing of two or more substances results in new substances.</td></tr>
<tr><td colspan="5"></td></tr>
<tr><td>Focal Knowledge, Skills, and Abilities (fKSAs)</td><td>5.1a Students are able to investigate the properties of matter using measurements to support a conclusion related to identifying materials.</td><td colspan="2">Rationale</td><td>Students will describe the evidence from data that properties of materials can be used to identify materials.
Students will use quantitative and qualitative data to identify materials based on their properties.
Students will measure and describe physical quantities such as weight, time, temperature, and volume.</td></tr>
<tr><td>Student Model</td><td colspan="4">(One overall summary variable of proficiency) Not yet defined.</td></tr>
<tr><td>Task Model</td><td colspan="4">Given a brief real-world scenario describing an observable phenomenon, the student applies mathematical and computational thinking to measure a variety of properties to identify materials and uses the results for an explanation of the phenomenon. Example: Given a representation of baking soda mixed with vinegar, the student accurately constructs a conclusion, supported with data, that the baking soda reacts in a specific way with vinegar, unlike other materials.</td></tr>
</table>

<table>
<tr><td>Work Product Summary</td><td colspan="3">Students identify a material based on provided properties and explain their answer using relevant scientific information.
Students identify a material using observations and/or measurements about its properties and explain their answer using relevant scientific information.
Students ask questions about what measurements can be used to identify materials.
Students use observations and measurements to provide the data necessary to address the purpose of the investigation.
Students collect and record data, according to the investigation plan.</td></tr>
<tr><td>Task Model Variables</td><td>How properties are presented
Which properties are used (e.g., color, hardness, reflectivity, electrical conductivity, thermal conductivity, response to magnetic forces, and solubility)
Which material(s) are given
How similar the materials are regarding the properties</td><td>Notes on Task Features and Task Variables</td><td>Tasks do not include density or distinguishing mass and weight. Examples of materials to be identified could include baking soda and other powders, metals, minerals, and liquids. Examples of properties could include color, hardness, reflectivity, electrical conductivity, thermal conductivity, response to magnetic forces, and solubility; density is not intended as an identifiable property.</td></tr>
<tr><td>Example Phenomena</td><td colspan="3">Recording tape is magnetic.
Mixing baking soda and vinegar makes a lot of foam.</td></tr>
<tr><td>Measurement Model</td><td colspan="3">Univariate Rasch partial-credit psychometric model</td></tr>
<tr><td>Evaluation Model</td><td colspan="3">Is the explanation logical?
Does the response demonstrate an understanding of how properties can be used to identify materials?</td></tr>
<tr><td colspan="4"></td></tr>
<tr><td>Focal Knowledge, Skills and Abilities (fKSAs)</td><td>5.1b Students are able to investigate or create an explanation around conservation of matter using measurements when substances are mixed, or undergo a change in form, properties, or state.</td><td>Rationale</td><td>Students will describe that the total weights of the substances did not change, regardless of the reaction or changes in properties that were observed.
Students will identify and describe the purpose of an investigation.
Students will use quantitative and qualitative data to describe physical quantities such as weight, time, temperature, and volume.</td></tr>
<tr><td>Student Model</td><td colspan="3">(One overall summary variable of proficiency) Not yet defined.</td></tr>
<tr><td>Task Model</td><td colspan="3">Given a brief real-world scenario describing an observable phenomenon, the student applies mathematical and computational thinking to produce data that can serve as the basis for evidence for an explanation of a phenomenon (e.g., when matter changes, its weight does not change).
Example: Given a representation of water molecules in solid form, the student accurately constructs a representation of water molecules in liquid form and explains why a frozen water bottle that weighs 500 mg will weigh the same amount when the water melts.</td></tr>
</table>

<table>
<tr><td>Work Product Summary</td><td colspan="3">Students use measurements and data to serve as the basis of an explanation of what happens to the mass of the new substance when the substances are combined.
Students use measurements and data to serve as the basis of an explanation of what happens to the mass of a substance when it changes state.
Students use measurements and data to serve as the basis of an explanation of what happens to the mass of a substance when it changes form.
Students measure or graph the given quantities using standard units.
Students measure and/or calculate the difference between the total weight of the substances before and after they are mixed and/or reacted.</td></tr>
<tr><td>Task Model Variables</td><td>How materials are presented
The change in state under investigation
Which material(s) are given
Which measurement tool(s) are given</td><td>Notes on Task Features and Task Variables</td><td>Whether or not students conduct an investigation collaboratively to produce data to serve as the basis for evidence, fair tests are used in which variables are controlled and the number of trials considered.</td></tr>
<tr><td>Example Phenomena</td><td colspan="3">When matter changes, its weight does not change.
The amount (weight) of matter is conserved when it changes form, even in transitions in which it seems to vanish (e.g., dissolving sugar in water).</td></tr>
<tr><td>Measurement Model</td><td colspan="3">Univariate Rasch partial-credit psychometric model</td></tr>
<tr><td>Evaluation Model</td><td colspan="3">How is evidence used to support an explanation?
Does it provide evidence that students can apply their knowledge and skills appropriately?</td></tr>
<tr><td colspan="4"></td></tr>
<tr><td>Focal Knowledge, Skills, and Abilities (fKSAs)</td><td>5.1c Students are able to identify what properties differ and what stays the same in a mixture or reaction.</td><td>Rationale</td><td>Students will use evidence, related to properties, to determine whether new substances are formed by mixing two or more substances.
Students will identify the change (cause) to a system (i.e., mixing of two or more substances) and quantify the result (effect).
Students will use quantitative and qualitative data to describe physical quantities such as weight, time, temperature, and volume.</td></tr>
<tr><td>Student Model</td><td colspan="3">(One overall summary variable of proficiency) Not yet defined.</td></tr>
<tr><td>Task Model</td><td colspan="3">Given a brief real-world scenario describing an observable phenomenon, the student applies the property of conservation along with knowledge of the chemical properties of particular elements, to describe and predict the outcomes of reactions. Example: Given a representation of a candle going out after a jar is placed over it (i.e., running out of oxygen causes the reaction to stop) the student explains that the reaction of vinegar and baking soda produces a gas (i.e., carbon dioxide) that also makes the flame go out, thus has different properties than does oxygen.</td></tr>
</table>

Grade 8

<table>
<tr><td colspan="5">Grade 8 Overall Claim
Students demonstrate a sophisticated understanding of the core ideas and applications of practices and crosscutting concepts in the disciplines of science.</td></tr>
<tr><td>Explanatory Statements</td><td colspan="2">Students integrate disciplinary core ideas and crosscutting concepts with scientific practices to investigate and explain how and why phenomena occur, and to design and refine solutions to problems.</td><td colspan="2">Students connect knowledge across the disciplines of science to ask questions, plan and carry out investigations, and analyze and interpret data to support an argument about phenomena in a variety of contexts.</td></tr>
<tr><td colspan="5">Measurement Target 2 (Topic 2 Bundle): Students are able to develop and interpret models and use mathematical representations and scientific information to make claims about how waves transfer energy and information through various materials.</td></tr>
<tr><td colspan="5">Summary (Topic 2 Bundle): This bundle organizes performance expectations with a focus on helping students build understanding of how waves transfer energy and information. Instruction developed from this bundle should always maintain the three-dimensional nature of the standards and is not limited to the practices and concepts directly linked with any of the bundle performance expectations.
• Use mathematical representations to describe a simple model for waves that includes how the amplitude of a wave is related to the energy in a wave.
• Develop and use a model to describe that waves are reflected, absorbed, or transmitted through various materials.
• Integrate qualitative scientific and technical information to support the claim that digitized signals are a more reliable way to encode and transmit information than analog signals.</td></tr>
<tr><td colspan="5"></td></tr>
<tr><td>Focal Knowledge, Skills and Abilities (fKSAs)</td><td>8.2a Students are able to use a mathematical model to describe wave properties and patterns relating to the amounts of energy present or transmitted.</td><td colspan="2">Rationale</td><td>• Students will describe and predict characteristic properties of waves.
• Students will recognize patterns as an organizing concept for understanding wave properties.
• Students will use models and mathematical thinking to demonstrate understanding of wave properties.</td></tr>
<tr><td>Student Model</td><td colspan="4">(One overall summary variable of proficiency) Not yet defined.</td></tr>
<tr><td>Task Model</td><td colspan="4">Given a brief real-world scenario describing an observable phenomenon, the student applies scientific concepts appropriately to construct a model (using drawings and words) and uses the model to make an accurate prediction about the phenomenon. Example: Student develops a model (drawing, image, computer simulation) to show how sound waves move from a ringing cell phone through the air and uses this model to make an appropriate prediction about whether students will hear the phone if it is put in a vacuum chamber.</td></tr>
</table>

<table>
<tr><td>Work Product Summary</td><td colspan="3">Students construct a model and use the model to explain a phenomenon.
Students identify repeating patterns represented in the wave model (amplitude, wavelength, frequency, period).
Students construct a model and use the model to make a prediction about a phenomenon.
Students identify and explain relationships among wave properties (direct proportion between energy and amplitude; reciprocal relationship between frequency and period; inverse relationship between frequency and wavelength; speed = frequency x wavelength).
Students use a given model to make a prediction about a phenomenon (i.e., changes to frequency if the wavelength is changed).</td></tr>
<tr><td>Task Model Variables</td><td>Type of wave being studied (mechanical or light)
Type of model used (drawing, image, animated simulation)</td><td>Notes on Task Features and Task Variables</td><td>Task should focus on standard repeating waves. A variety of model types can be used to represent wave behavior.</td></tr>
<tr><td>Example Phenomena</td><td colspan="3">Mechanical waves (sound waves, water waves, waves in a Slinky or a vibrating string)
Waves traveling through different mediums/phases (gas, liquid, solid)
Light waves traveling without a medium
Patterns in wave properties can be used to show why one sound transmits more energy than another</td></tr>
<tr><td>Measurement Model</td><td colspan="3">Univariate Rasch partial-credit psychometric model</td></tr>
<tr><td>Evaluation Model</td><td colspan="3">Does the description of patterns represent the components shown in the model?
Does the explanation of relationships among wave properties provide evidence that students can make interpretations and draw conclusions from qualitative and quantitative data?
How is the model used to support the explanation?</td></tr>
<tr><td colspan="4"></td></tr>
<tr><td>Focal Knowledge, Skills, and Abilities (fKSAs)</td><td>8.2b Students are able to use a model to describe a phenomenon involving reflection, absorption, or transmission properties of different materials for light and matter waves.</td><td>Rationale</td><td>Students will describe and predict characteristic behaviors of waves when the waves interact with matter.
Students will develop and use models to demonstrate understanding of wave behavior.</td></tr>
<tr><td>Student Model</td><td colspan="3">(One overall summary variable of proficiency) Not yet defined.</td></tr>
<tr><td>Task Model</td><td colspan="3">Given a model, the student uses the model to make a prediction about a phenomenon. Example: The student uses a model to explain why light bends and make predictions about the behavior of light waves when they interact with different matter.</td></tr>
</table>

<table>
<tr><td>Work Product Summary</td><td colspan="3">Students make predictions about the behavior of light when it interacts with each of the provided materials.
Students will draw conclusions based on the results from testing their predictions.
Students identify patterns of wave behavior based on test results.
Students create a drawing or a computer simulation to represent the observed wave behaviors.</td></tr>
<tr><td>Task Model Variables</td><td>Which type of materials provided
The number of materials provided
The type of light source
Providing more than one type of light source</td><td>Notes on Task Features and Task Variables</td><td>Providing a variety of light sources (flashlight, candle, laser pointer) allows students to explore how the interaction of light with a particular material can vary depending on the type of light source.</td></tr>
<tr><td>Example Phenomena</td><td colspan="3">Light is reflected from a shiny metal material.
All frequencies of light except yellow are absorbed by a banana.
Light is transmitted through transparent glass.
Light is partially transmitted through translucent glass.
Light refracts into its component wavelengths when passed through a prism.
Sound waves travel as longitudinal waves in nature and behave as a transverse wave in solids.
Sound waves are produced in our daily life (e.g., hitting a glass with a spoon, pushing a chair etc.).</td></tr>
<tr><td>Measurement Model</td><td colspan="3">Univariate Rasch partial-credit psychometric model</td></tr>
<tr><td>Evaluation Model</td><td colspan="3">How is evidence used to support an explanation of patterns of wave behavior?
Does the explanation provide evidence that students can make interpretations and draw conclusions from qualitative data?
How is the model used to support the explanation?</td></tr>
<tr><td colspan="4"></td></tr>
<tr><td>Focal Knowledge, Skills, and Abilities (fKSAs)</td><td>8.2c Students are able to support a claim about a phenomenon that includes the idea that digitized signals are a more reliable way to encode and transmit information than analog signals.</td><td>Rationale</td><td>Students will apply an understanding of waves as a means to send digital information.
Students will apply concepts of structure and function.
Students will obtain, evaluate, and communicate information to demonstrate understanding of wave behavior.</td></tr>
<tr><td>Student Model</td><td colspan="3">(One overall summary variable of proficiency) Not yet defined.</td></tr>
</table>

<table>
<tr><td>Task Model</td><td colspan="3">Given a brief real-world scenario describing an observable phenomenon, the student applies scientific concepts appropriately to construct an argument about the design of a device which serves a particular function. Example: The student is provided with text and/or images describing a function of a device (e.g., conversion of stored binary patterns to make sound or text on a computer screen) and appropriately clarifies claims and findings.</td></tr>
<tr><td>Work Product Summary</td><td colspan="3">Students interpret qualitative information to explain the comparative function and reliability of an analog version and digital version of a particular tool used for communicating information.
Students use scientific and technical information to support a claim that the digitization of that technology has advanced science and scientific investigations (e.g., digital probes, including thermometers and pH probes; audio recordings).</td></tr>
<tr><td>Task Model Variables</td><td>The type of tool for communicating information
Boundaries for the purpose of the tool</td><td>Notes on Task Features and Task Variables</td><td>Providing boundaries for the purpose of the tool (i.e., it will be expected to transmit information over short distances) relates structure (analog) to function (short distances)</td></tr>
<tr><td>Example Phenomena</td><td colspan="3">Comparing an analog watch with a digital watch
Comparing an analog television with a digital television
Fiber optic cable used to transmit light pulses
Radio wave pulses in cellphones
Sound or text on a computer screen generated by converting stored binary patterns</td></tr>
<tr><td>Measurement Model</td><td colspan="3">Univariate Rasch partial-credit psychometric model</td></tr>
<tr><td>Evaluation Model</td><td colspan="3">How is qualitative evidence used to support a claim regarding the advantages of digital tools?
Does the explanation provide evidence that students can make interpretations and draw conclusions from qualitative data?
Does the explanation provide evidence of student understanding that waves can be used to send digital information?
Does the explanation provide evidence of student understanding of structure and function?</td></tr>
</table>

Grade 11

<table>
<tr><td colspan="4">Grade 11 Overall Claim
Students demonstrate a sophisticated understanding of the core ideas and applications of practices and crosscutting concepts in the disciplines of science.</td></tr>
<tr><td>Explanatory Statements</td><td colspan="2">Students integrate disciplinary core ideas and crosscutting concepts with scientific practices to investigate and explain how and why phenomena occur, and to design and refine solutions to problems.</td><td>Students connect knowledge across the disciplines of science to ask questions, plan and carry out investigations, and analyze and interpret data to support an argument about phenomena in a variety of contexts.</td></tr>
<tr><td colspan="4">Measurement Target 1 (Topic 1 Bundle): Students are able to evaluate evidence and apply scientific reasoning related to Earth's geologic processes and the dynamic feedback between the biosphere and other Earth systems to support an argument about the continual co-evolution of Earth's systems and life on Earth.</td></tr>
<tr><td colspan="4">Summary (Topic 1 Bundle): The bundle organizes performance expectations with a focus on helping students build understanding of the changes to Earth over time. Instruction developed from this bundle should always maintain the three-dimensional nature of the standards and recognize that instruction is not limited to the practices and concepts directly linked with any of the bundle performance expectations.
• Evaluate evidence of the past and current movements of continental and oceanic crust and the theory of plate tectonics to explain the ages of crustal rocks.
• Apply scientific reasoning and evidence from ancient Earth materials, meteorites, and other planetary surfaces to construct an account of Earth's formation and early history.
• Construct an argument based on evidence about the simultaneous co-evolution of Earth's systems and life on Earth.</td></tr>
<tr><td colspan="4"></td></tr>
<tr><td>Focal Knowledge, Skills, and Abilities (fKSAs)</td><td>11.1a Students are able to investigate how Earth's internal and surface processes operate at different spatial and temporal scales to explain the ages of crustal rocks.</td><td>Rationale</td><td>• Students will use empirical evidence of patterns to evaluate the merits of an argument.
• Students will recognize and interpret patterns in systems at different scales.
• Students construct an argument for why the principle that scientific knowledge is based on the assumption that natural laws operate today as they did in the past and that they will continue to do so in the future helps us understand that plate tectonics provides a framework for understanding Earth's geologic history.</td></tr>
<tr><td>Student Model</td><td colspan="3">(One overall summary variable of proficiency) Not yet defined.</td></tr>
<tr><td>Task Model</td><td colspan="3">Given a brief real-world scenario describing a phenomenon, the student applies scientific concepts appropriately to describe how patterns observed from the evidence support his or her explanation (e.g., oceanic crust grows asymmetrically). Example: The student is asked to show what is happening inside Earth to explain the movement of plates and to use a drawing/model to support his or her explanation about why the oldest rock was further away from the plate boundary.</td></tr>
</table>

<table>
<tr><td>Work Product Summary</td><td colspan="3">• Students are provided an opportunity to explore and examine geological processes and phenomena and explain global features and events in terms of geological processes and timescales.
• Students provide critiques of arguments about how the relationship between the motion of continental plates and the patterns in the ages of crustal rocks.
• Students construct an argument for why some system changes are irreversible, using as evidence that spontaneous radioactive decays follow a characteristic exponential decay law.
• Students use observations and measurements to provide the empirical evidence necessary to support their argument.</td></tr>
<tr><td>Task Model Variables</td><td>• How phenomena are presented
• The scale of the phenomena
• Which plate boundary types are provided
• Which components of internal and surface processes are provided
• Temporal and spatial scales
• What is the format and nature of empirical evidence</td><td>Notes on Task Features and Task Variables</td><td>Whether or not the students are asked to evaluate others' methods and explanations from a scientific perspective and use appropriate language and representations when communicating their findings</td></tr>
<tr><td>Example Phenomena</td><td colspan="3">• Oceanic crust grows asymmetrically.
• Earth looks different than it used to (e.g., changes in ozone, depletion of glaciers).</td></tr>
<tr><td>Measurement Model</td><td colspan="3">Univariate Rasch partial-credit psychometric model</td></tr>
<tr><td>Evaluation Model</td><td colspan="3">• Is appropriate evidence used to support the explanation?
• Is the explanation logical and complete?</td></tr>
<tr><td colspan="4"></td></tr>
<tr><td>Focal Knowledge, Skills, and Abilities (fKSAs)</td><td>11.1b Students are able to apply scientific reasoning and evidence to construct an account of Earth's formation and early history.</td><td>Rationale</td><td>• Students will describe that Earth's history can be understood through the study of other objects in the solar system, such as asteroids and meteorites, that have changed minimally over billions of years.
• Students will use explanations of how things change and how they remain stable in assessing the extent to which the reasoning and data support the explanation or conclusion.</td></tr>
<tr><td>Student Model</td><td colspan="3">(One overall summary variable of proficiency) Not yet defined.</td></tr>
<tr><td>Task Model</td><td colspan="3">Given a brief real-world scenario describing a phenomenon, the student applies scientific concepts appropriately to construct an explanation of how things change and/or how they remain stable using evidence to support his or her explanation. Example: The student identifies accurate similarities and differences between Mars and Earth's surface/interior/geologic processes to reconstruct the early history of Earth.</td></tr>
<tr><td>Work Product Summary</td><td colspan="3">• Students make directional hypotheses that specify what happens to the rock record on Earth when active geologic processes occur.
• Students analyze data using tools, technologies, and/or models to make valid and reliable scientific claims that objects in the solar system, such as lunar rocks, asteroids, and meteorites have changed little over billions of years.
• Students use reasoning to connect the evidence to construct the explanation of Earth's formation and early history.</td></tr>
</table>

Task Model Variables	• How phenomena are presented • Which Earth processes are included • Which objects in the solar system are included • Which measurement tool(s) are given • What is the format and nature of empirical evidence	**Notes on Task Features and Task Variables**	Whether or not the student communicates information about the idea that scientific investigations use a variety of methods, tools, and techniques to revise and produce new knowledge, including knowledge about Earth's formation and early history
Example Phenomena	• Pictures of Mars appear to show canyons similar to those on Earth. • Earth looks different than it used to.		
Measurement Model	Univariate Rasch partial-credit psychometric model		
Evaluation Model	• How is evidence used to support an explanation? • Does the explanation provide evidence that students can apply their knowledge and skills appropriately?		
Focal Knowledge, Skills, and Abilities (fKSAs)	**11.1c** Students are able to construct an argument, using causal links and feedback mechanisms between changes in the biosphere and changes in Earth's other systems, that there is simultaneous co-evolution of Earth's systems and life on Earth.	**Rationale**	• Students will describe the dynamic causes, effects, and feedbacks between the biosphere and Earth's other systems. • Students will use explanations of how things change and how they remain stable in constructing an argument or counter-argument based on data and evidence.
Student Model	(*One overall summary variable of proficiency*) Not yet defined.		
Task Model	Given a brief real-world scenario describing a phenomenon, the student applies scientific concepts appropriately to construct an argument that supports the claim for why the phenomenon occurs. Example: The student constructs and supports an argument that supports the claim that over billions of years, the simultaneous co-evolution of Earth's systems and life on Earth produced both the ozone layer and current climatic conditions with feedback from life that evolved.		
Work Product Summary	• Students use a model to predict the relationships between the biosphere and other Earth systems, including the feedbacks that cause a continual co-evolution of Earth's surface and the life that exists on it. • Students construct an explanation based on valid and reliable evidence obtained from a variety of sources about how the many dynamic and delicate feedbacks between the biosphere and other Earth systems cause a continual co-evolution of Earth's surface and the life that exists on it. • Students evaluate scientific and/or technical information about how gradual atmospheric changes were due to plants and other organisms capturing carbon dioxide and releasing oxygen, assessing the evidence and usefulness of each source. • Students identify and describe different patterns at each of the scales at which the continual co-evolution of Earth's surface and the life that exists on it is studied.		

<table>
<tr>
<td>Task Model Variables</td>
<td>
How phenomena are presented
The scale of the phenomena
Which relationships between systems or between components of a system are provided
The Earth processes included
The Earth systems included
Atmospheric composition over time
Role of photosynthetic organisms
The causal links or feedback mechanisms addressed
Which measurement tool(s) are given
What is the format and nature of empirical evidence
</td>
<td>Notes on Task Features and Task Variables</td>
<td>Whether or not the student communicates information about the idea that scientific investigations use a variety of methods, tools, and techniques to revise and produce new knowledge, including knowledge about how the biosphere and other Earth systems cause a continual co-evolution of Earth’s surface and the life that exists on it</td>
</tr>
<tr>
<td>Example Phenomena</td>
<td colspan="3">
Free oxygen is present in Earth’s atmosphere.
Compost helps plants grow.
Earth’s surface contains considerably greater amounts of ferric iron oxide than it used to.
</td>
</tr>
<tr>
<td>Measurement Model
Evaluation Model</td>
<td colspan="3">Univariate Rasch partial-credit psychometric model

How is evidence used to support an argument?
Does the argument provide evidence that students can apply interpretations, explanations, and/or conclusions from evidence?
</td>
</tr>
</table>