Table of Contents

New Mexico STEM Ready! Science Standards Implementation Guide

Overview

A Framework for K-12 Science Education marks a leap forward in how we think about science education and captures the advancements made in understanding how students best learn science that have been made over the last 30 years. The New Mexico Public Education Department and New Mexico public school teachers worked together over the course of June 2021 to construct an Instructional Scope document for the New Mexico STEM Ready! Science Standards. There are many public schools where high quality instructional materials (HQIM) are present, and these should be used in the teaching of science. In public schools where HQIM may be absent, the New Mexico Instructional Scope for Science (NMIS Science) should be used in conjunction with the New Mexico STEM Ready! Science Standards to plan science instruction.

The following describes the layout of the NMIS Science document and how it has been designed to be implemented. New Mexico science teachers worked collaboratively to identify and construct sample phenomena, classroom assessment items, common misconceptions, multi-layered systems of supports (MLSS), and culturally and linguistically responsive (CLR) instructional strategies for each performance expectation in the New Mexico STEM Ready! Science Standards. The best practice of bundling related standards together to capture multiple aspects of a single phenomenon was not done, as local public schools should determine how best to bundle New Mexico STEM Ready! Science Standards based on their needs.

The standards

<u>What:</u> Each performance expectation begins with links to the *Next Generation Science Standards* and a snapshot of the performance expectation with the relevant Science and Engineering Practices (SEP), Disciplinary Core Ideas (DCI), and Cross Cutting Concepts (CCC). Also captured are the connections across the grade level or band (horizontal), connections across grade levels or bands (vertical), and connections to the *Common Core State Standards* (CCSS) in math and English language arts.

The Performance Expectation describes what a student is expected to be able to do at the completion of instruction. They are intended to guide the development of assessments, but they are not the assessment as such. They are not instructional strategies or instructional objectives, but they should influence and guide instruction. Most performance expectations contain a clarification statement and an assessment boundary statement to provide clarity to the performance expectation and guidance to the scope of the expectation, respectively.[1]

The foundation box, which is located below the performance expectation, contains the learning goals that students should achieve and that will be assessed using the performance expectations. The three parts to the foundation box are the science and engineering practices, the disciplinary core ideas, and the crosscutting concepts. The information contained in the foundation box is taken directly from *A Framework for K-12 Science Education*. Also included in the foundation box, where appropriate, are connections to engineering, technology, and applications of science as well as connections to the nature of science. These supplemental goals are related to the other material in the foundation box and are intended to guide instructions, but the outcomes are not included in the performance expectation.

The connections box identifies connections to other disciplinary core ideas at this grade level that are relevant to the standard, identifies the articulation of disciplinary core ideas across grade levels, and identifies connections to the *Common Core State Standards (CCSS)* in mathematics and in English language arts and literacy that align to this standard. The connections box helps support instruction and development of instructional materials.

[1] Pratt, Harold (2013) *The NSTA Reader's Guide to the Next Generation Science Standards.*

Why: The first step of any teacher in planning instruction is to deeply understand the end result that is required. The standards section of the NMIS Science document is placed first so that teachers have quick access to these requirements. The *NGSS* describe the essential learning goals and how those goals will be assessed at each grade level or band.

How: It is generally accepted that planning for instruction begins with the selection of the endpoint, or desired results of the instruction, and working backward through an instructional sequence to the beginning knowledge students have coming into the instruction. The description of such a process has been documented by Wiggins and McTighe in *Understanding by Design* (1998).

For the purpose of the NMIS Science document, a process for moving from the New Mexico STEM Ready! Science Standards to classroom instruction should minimally include the following[2]:

- Read the performance expectation, clarification statement, and assessment boundary.
- Read the disciplinary core idea in the foundation box.
    - Read the applicable disciplinary core idea essay in *A Framework for K-12 Science Education*, located in chapters 5, 6, 7, and 8. As you read, consider the following questions:
        - What are some commonly held student ideas about this topic?
        - How could instruction build on helpful ideas and confront troublesome ideas?
        - What prior ideas or concepts do students need to learn to understand this core idea?
        - What level of abstractness is expected of students?
        - What are some phenomena and experiences that could provide observational or experimental evidence that the DCI is an accurate description of the natural world?
        - What representations or media would be helpful for students to use in making sense of the core idea?
- Read the science and engineering practices associated with the performance expectation.
    - Read the applicable SEP essay in *A Framework for K-12 Science Education* located in chapter 3, consider the following questions:
        - While the PE describes one SEP to be used, others will be needed in the instructional sequence, which ones and in what order will you use them?
        - How will each SEP be used to develop an understanding of the DCI?
        - What practices could students engage in to explore phenomena?
- Read the crosscutting concept associated with the performance expectation.
    - Read the applicable CCC essay in *A Framework for K-12 Science Education* located in chapter 4, consider the following questions:
        - How will the CCC indicated in the PE support the understanding of the core idea?
        - Are there other CCC that could also support learning the core idea?

[2] Bybee, Rodger W. (2013) *Translating the NGSS for Classroom Instruction.*

- Read the connections box
  - When reading the connections to other DCI at this grade level that are relevant to the standard, consider the following question:
    - How can instruction be designed so that students note the connections between the core ideas?
  - When reading the articulation of DCI across grade levels that are relevant to the standard, consider the following questions:
    - Examine the standard at earlier grade levels, do they provide an adequate prior knowledge for the core ideas in the standard being reviewed?
    - Examine the standard at later grade levels, does the standard at this level provide adequate prior knowledge for the core ideas in the later standards?
  - When reading the *CCSS* in mathematics and English language arts (ELA), consider the following questions:
    - Should students have achieved these mathematics and ELA standards to engage in the learning of science, or could they be learned together?
    - In what ways do the referenced mathematics and ELA standards help clarify the science performance expectations?
    - Can any of the science core ideas be included as examples in the mathematics or ELA instruction?
- Create one or more descriptions of the desired results or learning goals for the instruction integrating the three dimensions in the foundation box.
- Determine the acceptable evidence for the assessment of the desired results.
- Create the learning sequence
  - The NMIS Science document includes sample phenomena, classroom assessment items, common misconceptions, general and targeted supports, and CLR considerations that can be used to assist with this process.
- Create the summative assessment and check its alignment with the performance expectation.

Sample Phenomena

What: Natural phenomena are observable events that occur in the universe and that we can use our science knowledge to explain or predict. The goal of building knowledge in science is to develop general ideas, based on evidence, that can explain and predict phenomena. Engineering involves designing solutions to problems that arise from phenomena and using explanations of phenomena to design solutions. In this way, phenomena are the context for the work of both the scientist and the engineer.

Why: Despite their centrality in science and engineering, phenomena have traditionally been a missing piece in science education. Anchoring learning in explaining phenomena supports student agency for wanting to build science and engineering knowledge. Students are able to identify an answer to "why do I need to learn this?" before they even know what "this" is. By centering science education on phenomena that students are motivated to explain, the focus of learning shifts from learning about a topic to figuring out why or how something happens. Explaining phenomena and designing solutions to problems allow students to build general science knowledge in the context of their application to understanding phenomena in the real world, leading to deeper and more transferable knowledge. Students who come to see how science ideas can help explain and model phenomena related to compelling real-world situations learn to appreciate the social relevance of science. They get interested in and identify with science as a way of understanding and improving real-world contexts.

Learning to explain phenomena and solve problems is the central reason students engage in the three dimensions of the *NGSS*. Students explain phenomena by developing and applying the DCI and CCC through use of the SEPs. Phenomena-centered classrooms also give students and teachers a context in which to monitor ongoing progress toward understanding all three dimensions. As students are working toward being able to explain phenomena, three-dimensional formative assessment becomes more easily embedded and coherent throughout instruction.

How: We use phenomena to drive instruction to help students engage in practices to develop the knowledge necessary to explain or predict the phenomena. Therefore, the focus is not just on the phenomenon itself. It is the phenomenon plus the student-generated questions about the phenomenon that guides the learning and teaching. The practice of asking questions or identifying problems becomes a critical part of trying to figure something out.

There could potentially be many different lines of inquiry about the same phenomenon. Teachers should help students identify different aspects of the same phenomenon as the focus of their questions. Students also might ask questions about a phenomenon that motivates a line of investigation that isn't grade appropriate or might not be effective at using or building important disciplinary ideas. Teacher guidance may be needed to help students reformulate questions so they can lead to grade appropriate investigations of important science ideas.

It is important that all students – including English language learners and students from cultural groups underrepresented in STEM – are supported in working with phenomena that are engaging and meaningful to them. Not all students will have the same background or relate to a particular phenomenon in the same way. Educators should consider student perspectives when choosing phenomena and should prepare to support student engagement in different ways. When starting with one phenomenon in your classroom, it is always a good idea to help students identify related phenomena from their lives and their communities to expand the phenomena under consideration.

Not all phenomena need to be used for the same amount of instructional time. Teachers could use an anchoring phenomenon as the overall focus for a unit, along with other investigative phenomena along the way as the focus of an instructional sequence or lesson. They may also highlight everyday phenomena that relate investigative or anchoring phenomena to personally experienced situations. A single phenomenon doesn't have to cover an entire unit, and different phenomena will take different amounts of time to figure out.

The most powerful phenomena are culturally or personally relevant or consequential to students. Such phenomena highlight how science ideas help us explain aspects of real-world contexts or design solutions to science-related problems that matter to students, their communities, and society. An appropriate phenomenon for instruction should help engage all students in working toward the learning goals of instruction as described by the DCIs, SEPs, and CCCs in the foundation box of the standard.

The process of developing an explanation for a phenomenon should advance students' understanding. If students already need to know the target knowledge before they can inquire about the phenomenon, then the phenomenon is not appropriate for initial instruction. Students should be able to make sense of anchoring or investigative phenomena, but not immediately, and not without investigating it using sequences of the science and engineering practices. Phenomena do not need to be flashy or unexpected. Students might not be intrigued by an everyday phenomenon right away because they believe they already know how or why it happens. With careful teacher facilitation, students can become dissatisfied with what they believe they already know and strive to understand it in the context of the DCI that the teacher is targeting.[3]

Classroom Assessment Items

What: Classroom assessments (sometimes referred to as internal assessments) is used to refer to assessments designed or selected by teachers and given as an integral part of classroom instruction. This category of assessment may include teacher-student interactions in the classroom, observations of students, student products that result directly from ongoing instructional activities, quizzes tied to instructional activities, formal classroom exams that cover material from one or more instructional units, or assessments created by curriculum developers and embedded in instructional materials for teacher use. [4]

Classroom assessments can be designed to guide instruction (formative purposes) or to support decisions made beyond the classroom (summative purposes). Assessments used for formative purposes occur during the course of a unit of instruction and may involve both formal tests and informal activities conducted as part of a lesson. They may be used to identify students' strengths and weaknesses, assist students in guiding their own learning, and foster students' sense of autonomy and responsibility for their own learning. Assessments for summative purposes may be administered at the end of a unit of instruction. They are designed to provide evidence of achievement that can be used in decision making, such as assigning grades, making promotion or retention decisions, and classifying test takers according to defined performance categories. The results of all these assessments are evaluated by the teacher or sometimes by groups of teachers. These assessments play an integral role in students' learning experiences while also providing evidence of progress in that learning.

Why: In *Developing Assessments for the Next Generation Science Standards*, the National Research Council shared the following conclusions regarding assessing three-dimensional learning:[5]

- Measuring the three-dimensional science learning called for in the framework and the NGSS requires assessment tasks that examine students' performance of scientific and engineering practices in the context of crosscutting concepts and disciplinary core ideas. To adequately cover the three dimensions, assessment tasks will generally need to contain multiple components. It may be useful to focus on individual practices, core ideas, or crosscutting concepts in the various components of an assessment task, but, together, the components need to support inferences about students' three-dimensional science learning as described in a given performance expectation.

- The Next Generation Science Standards require that assessment tasks be designed so they can accurately locate students along a sequence of progressively more complex understandings of a core idea and successively more sophisticated applications of practices and crosscutting concepts.

- The NGSS places significant demands on science learning at every grade level. It will not be feasible to assess all the performance expectations for a given grade level with any one assessment. Students will

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[3] Penuel, W. R., Bell, P., Neill, T., Morrison, D., & Tesoriero, G. (2018). *Selecting Anchoring Phenomena for Equitable 3D Teaching*. [OER Professional Development Session from the ACESSE Project] Retrieved from http://stemteachingtools.org/pd/sessione

[4] National Resource Council. (2014). *Developing Assessments for the Next Generation Science Standards.* Committee on Developing Assessments of Science Proficiency in K-12. Board on Testing and Assessments and Board on Science Education, J.W. Pellegrino, M.R. Wilson, J.A. Koenig, and A.S. Beatty, *Editors*. Division of Social Sciences and Education. Washington, DC: The National Academies Press.

[5] National Research Council. (2014). *Developing Assessments for the Next Generation Science Standards.* Committee on Developing Assessments of Science Proficiency in K-12. Board on Testing and Assessment and Board on Science Education. J.W. Pellegrino, M.R. Wilson, J.A. Koenig, and A.S. Beatty, *Editors*. Division of Behavioral and Social Sciences and Education. Washington, DC: The National Academies Press.

need multiple – and varied – assessment opportunities to demonstrate their competence on the performance expectations for a given grade level.

- Effective evaluation of three-dimensional science learning requires more than a one-to-one mapping between the NGSS performance expectations and assessment tasks. More than one assessment task may be needed to adequately assess students' mastery of some performance expectations, and any given assessment task may assess aspects of more than one performance expectations. In addition, to assess both understanding of core knowledge and facility with a practice, assessments may need to probe students' use of a given practice in more than one disciplinary context. Assessment tasks that attempt to test practices in strict isolation from one another may not be meaningful as assessments of the three-dimensional science learning called for by the NGSS. (Developing assessments for NGSS, NRC, pp.44-46)

How: The amount of information that has been generated around designing and creating three-dimensional assessment tasks to meet the conclusions laid out above by the National Research Council has been overwhelming. The following free resources are available through STEM teaching tools to help you navigate this flood of information and translate it into your classroom. You should start by familiarizing yourself with the following STEM Teaching Tools[6]:

- Practice Brief 18 on how teachers can develop formative assessments that fit a three-dimensional view of science learning.
- Practice Brief 26 on how to design formative assessments that engage students in three-dimensional learning.
- Practice Brief 30 on integrating science practices into assessment tasks
- Practice Brief 41 on integrating cross cutting concepts into assessment and instruction
- Practice Brief 33 on designing assessments for emerging bilingual students

In general, one can use the following process to develop classroom assessment tasks:

1. Identify specific learning goals for the desired assessment
2. Brainstorm assessment scenarios that involve phenomena that clearly foreground the identified learning goals
3. Prioritize and select a scenario that best fits the following criteria:
    a. it should allow students from non-dominant communities (e.g., ELLs, students from poverty-impacted communities) to fully engage with the task,
    b. it should involve a compelling phenomenon related to one or more of the DCIs being assessed—and not feel like a test-like task,
    c. it should be quickly understandable by students, and
    d. it should lend itself to a broad range of science and engineering practices.

[6] STEM Teaching Tools (n.d.), http://stemteachingtools.org/tools accessed on July 7, 2021

4. The task formats (practice briefs 30 and 41) provide detailed guidance on how to design assessment components that engage students in the science and engineering practices. Identify the practices that relate to the scenario and use the task formats to craft assessment components
5. Write hypothetical student responses for each prompt: some that reflect limited, partial, and full levels of understanding
6. Share tasks with colleagues and ask for feedback about the alignment of goals, scenarios, and hypothetical student responses

Common Misconceptions

What: This planning support identifies some of the common misconceptions students develop about a scientific topic.

Why: Our brains are highly advanced cause and effect reasoning machines. From birth, we begin to analyze effects to determine causes and provide some sort of reasoning for the whole event. The more events that support our reasoning, the stronger that learning becomes. So, every student in your classroom brings their own unique background knowledge into your classroom. Some of this is aligned to scientific understanding and some of this is misaligned to scientific understanding but aligned to that student's personal experiences. As science educators, we must always create space for students to bring their current understanding about a topic into our classroom so that we can begin to address understandings that are misaligned to scientific understanding. Some of these misunderstandings are not unique to a single student; rather, they are common to many students.

How: When planning with your HQIM look for ways to directly address with students some common misconceptions. The planning supports in this document provide some possible misconceptions and your HQIM might include additional ones. The goal is not to avoid misconceptions, they are a natural part of the learning process, but we want to support students in exploring the misconception and modifying incorrect or partial understandings.

Multi Layered System of Supports (MLSS)

What: The Multi-Layered Systems of Support (MLSS) is designed to support teachers in planning instruction for the needs of all students. Each section identifies general supports (layer 1) for supporting pedagogically sound whole class science instruction and targeted supports (layer 2) for supporting those scholars that teachers identify as not understanding the topic. We recognize there is a need for intensive support (layer 3) for those students needing longer duration or otherwise more intense support with a given topic; however, this was not part of the NM IS Science 1.0 work.

Why: MLSS is a holistic framework that guides educators, those closest to the student, to intervene quickly when students need additional support. The framework moves away from the "wait to fail" model and empowers teachers to use their professional judgement to make data-informed decisions regarding the students in their classroom to ensure academic success with grade level expectations of the New Mexico Science Standards.

How: When planning with your high-quality instructional materials (HQIM) use the suggested universal supports embedded in the sequence of instruction. If you do not have access to HQIM in your school, the universal (layer 1) support in this document can be used in planning your instruction.

Culturally and Linguistically Responsive Instruction

What: Culturally and Linguistically Responsive Instruction (CLRI), or the practice of situational appropriateness, requires educators to contribute to a positive school climate by validating and affirming students' home languages and cultures. Validation is making the home culture and language legitimate, while affirmation is affirming or making clear that the home culture and language are positive assets. It is also the intentional effort to reverse negative stereotypes of non-dominant cultures and languages and must be intentional and purposeful, consistent and authentic, and proactive and reactive. Building and bridging is the extension of validation and affirmation. By building and bridging students learning to toggle between home culture and linguistic behaviors and expectations and the school culture and linguistic behaviors and expectations. The building component focuses on creating connections between the home culture and language and the expectations of school culture and language for success in school. The bridging component focuses on creating opportunities to practice situational appropriateness or utilizing appropriate cultural and linguistic behaviors.

Why: Student understanding of science is shaped by their interactions with phenomena throughout their lives. Science educators must intentionally and purposefully legitimize the home culture and languages of students and validate their ways of knowing and understanding. In addition, create connections between the cultural and linguistic behaviors of the students' home culture and language and the culture and language of scientific understanding.

How: When planning instruction it is critical to consider ways to validate/affirm and build/bridge from your students' cultural and linguistic assets. There has been an overwhelming amount of guidance within STEM education about CLRI. The following STEM teaching tools can be a good place to start wrapping your mind around this topic.[7]

- Practice Brief 15: Promoting equity in science education
- Practice Brief 47: Promoting equitable sensemaking
- Practice Brief 54: Building equitable learning communities
- Practice Brief 11: Indigenous ways of knowing and STEM
- Practice Brief 27: Engaging English language learners in science and engineering practices
- Practice Brief 71: Advancing equity and justice in science education
- Practice Brief 53: Avoiding pitfalls associated with CLRI

The planning supports for each performance expectation provide an example of how to support equity-based teaching practices. Look for additional ways within your HQIM to ensure all students are included in the pursuit of scientific understanding in your classroom.

[7] STEM Teaching Tools (n.d.), http://stemteachingtools.org/tools accessed on July 7, 2021

STANDARDS BREAKDOWN

Students who demonstrate understanding can:

HS-PS1-1. **Use the periodic table as a model to predict the relative properties of elements based on the patterns of electrons in the outermost energy level of atoms.** [Clarification Statement: Examples of properties that could be predicted from patterns could include reactivity of metals, types of bonds formed, numbers of bonds formed, and reactions with oxygen.] [*Assessment Boundary: Assessment is limited to main group elements. Assessment does not include quantitative understanding of ionization energy beyond relative trends.*]

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

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Developing and Using Models Modeling in 9–12 builds on K–8 and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed worlds. • Use a model to predict the relationships between systems or between components of a system.	**PS1.A: Structure and Properties of Matter** • Each atom has a charged substructure consisting of a nucleus, which is made of protons and neutrons, surrounded by electrons. • The periodic table orders elements horizontally by the number of protons in the atom's nucleus and places those with similar chemical properties in columns. The repeating patterns of this table reflect patterns of outer electron states.	**Patterns** • Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena.

Connections to other DCIs in this grade-band:
HS.LS1.C

Articulation of DCIs across grade-bands:
MS.PS1.A ; **MS.PS1.B**

Common Core State Standards Connections:
ELA/Literacy -
RST.9-10.7 Translate quantitative or technical information expressed in words in a text into visual form (e.g., a table or chart) and translate information expressed visually or mathematically (e.g., in an equation) into words. *(HS-PS1-1)*

Grade	*NGSS Discipline*
HS	**Physical Science 1.1**

PS1-1

Sample Phenomena

When available, you should use your locally selected or created high quality instructional materials. However, the following is an example phenomenon you can use if you don't have local instructional materials available.

Investigative phenomena:
This is an excellent phenomenon to discuss chemical reactions and the conservation of mass. This phenomenon can be used at the beginning of a unit on chemical reactions, in this case, students will focus on the combustion reaction of iron and oxygen and not the conservation of mass. Information from the trends of the periodic table will be used to explain why the reaction occurred between the elements.
Burning iron wool and change in mass MVI 0995
Iron Wool Balance

- Why are some elements more reactive than others?
- How can the periodic table be used to make predictions about an element's properties and its behavior in a chemical reaction?
- The periodic table organizes elements according to similar properties so you can tell the characteristics of an element just by looking at its position on the table.

Classroom Assessment Items

When available, you should use your locally selected or created high quality instructional materials. However, the following are example assessment items you can use if you don't have local instructional materials available.

A New Element has been created in the Large Hadron Collider in Cern, Switzerland and you are on the task force to determine where this new element should be placed on the periodic table using its known properties. The International Union of Pure and Applied Chemistry (IUPAC) will be deciding the name of the new element after validating the evidence for its existence.

Using the provided models of periodic table or models of periodic table trends, consider the properties given for the "new element" and Make a claim that locates the "new element" on the periodic table. Justify your claim with evidence and reasoning for each of the models provided. Describe the pattern or trend in each model and how the associated property for the new element relates to that trend, thus providing evidence for the location of the "new element."

Properties of newly discovered element:

- Mass number 304 amu
- Very low ionization energy
- Bonds easily with other elements
- Melting point 50.1 °C
- The smallest electronegativity
- Predicatively the largest atomic radius
- Great metallic character
- Silver in color

Universal Supports	Targeted Supports
• Review subatomic structural model of an atom; use/construct hands-on 3D model showing nucleus, electron, overall atomic parts and their properties (charge, mass); students could use various materials to make their own models, then explain reasoning why they chose certain materials in their model • Use model to show interactions that could occur between electrical charges at the atomic scale (including chemical reactions and nuclear processes); students could demonstrate how their models show interactions • Provide (lecture, video, text article) a historical perspective on the development of the Periodic table; have student groups focus on one perspective studied and report out to the whole group the main points of the idea/people behind the concept • Provide students with a periodic table to color code, identify trends and make notes on to explain the meaning of the organization of the table (graphic organizer) • Have students explain information not presented in the periodic table (other physical features of the element)	• Group students together who are having difficulty with model; offer materials and give individual teacher support to struggling students • Offer individual tutoring time for students who need it

Common Misconceptions

- Changing the number of electrons changes the element (rather than changing proton number)
- Students may not understand the organization or property trends of the periodic table
- Atomic radii should increase from left to right across a row on the periodic table because the number of protons and electrons increases.

Culturally and Linguistically Responsive Instruction

	Guiding Questions and Connections
	• What are the ways you organize information in your own life and in your household? • What examples do you have of this organization? (Contact lists, calendars, etc.) • How can organization of information help you on a daily basis? • Are there areas in your life where organization could help you? • Include research on historical and biographical data for culturally connected individuals who have contributed to the development of this topic. • Students set protocols and ground rules for conducting small group activity, conversation, affirming, and respectful ways of disagreeing. • Are your visuals/article/video representative of all cultural groups?

Students who demonstrate understanding can:

HS-PS1-2. **Construct and revise an explanation for the outcome of a simple chemical reaction based on the outermost electron states of atoms, trends in the periodic table, and knowledge of the patterns of chemical properties.** [Clarification Statement: Examples of chemical reactions could include the reaction of sodium and chlorine, of carbon and oxygen, or of carbon and hydrogen.] [*Assessment Boundary: Assessment is limited to chemical reactions involving main group elements and combustion reactions.*]

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

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Constructing Explanations and Designing Solutions Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories. • Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future.	**PS1.A: Structure and Properties of Matter** • The periodic table orders elements horizontally by the number of protons in the atom's nucleus and places those with similar chemical properties in columns. The repeating patterns of this table reflect patterns of outer electron states. **PS1.B: Chemical Reactions** • The fact that atoms are conserved, together with knowledge of the chemical properties of the elements involved, can be used to describe and predict chemical reactions.	**Patterns** • Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena.

Connections to other DCIs in this grade-band:
HS.LS1.C ; **HS.ESS2.C**

Articulation of DCIs across grade-bands:
MS.PS1.A ; **MS.PS1.B**

Common Core State Standards Connections:

ELA/Literacy -

WHST.9-12.2 Write informative/explanatory texts, including the narration of historical events, scientific procedures/ experiments, or technical processes. (HS-PS1-2)

WHST.9-12.5 Develop and strengthen writing as needed by planning, revising, editing, rewriting, or trying a new approach, focusing on addressing what is most significant for a specific purpose and audience. (HS-PS1-2)

Mathematics -

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 interpret the scale and the origin in graphs and data displays. (HS-PS1-2)

HSN-Q.A.3 Choose a level of accuracy appropriate to limitations on measurement when reporting quantities. *(HS-PS1-2)*

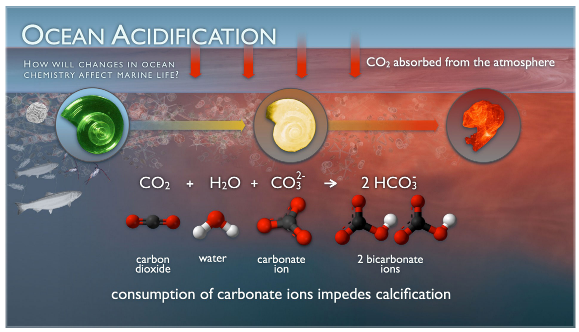
Grade	*NGSS Discipline*
HS	**Physical Science 2.2**
PS1-2	**Sample Phenomena**

When available, you should use your locally selected or created high quality instructional materials. However, the following is an example phenomenon you can use if you don't have local instructional materials available.

How can the information in the periodic table be used to predict and explain the results of chemical reactions between different elements?

Student will observe a variety of reactions as demonstrations or videos and use the periodic table to explain the outcomes:

- Na + Cl ⟶ NaCl NaCl Formation
- Rusting of iron To show that rusting of iron requires both oxygen and water
- Metals reacting with water Reactions Of Metals With Water | Reactions | Chemistry | FuseSchool
- Corrosion on metals Corrosion of Metals | The Chemistry Journey | The Fuse School



Contexts to keep in mind:

- The data presented on the periodic table
- Predicting formulas of compounds made with metals, charges of ions, number of valence electrons
- Identifying an element given some properties, e.g., number of valence electrons
- Identifying an element based on the types of bonds it forms with other elements or itself

Classroom Assessment Items

When available, you should use your locally selected or created high quality instructional materials. However, the following are example assessment items you can use if you don't have local instructional materials available.

Sub-Zero (Link contains entire activity, only use Task A for this PE)

Context

The Alaskan Bering Sea is known for producing one of the world's most prized types of seafood, the Alaskan king crab. Fishermen often endure harsh seas and bone-chilling sub-zero conditions while fishing for these creatures. Staying warm in these difficult conditions is crucial, both for them to survive and to maintain their livelihood. External warming devices, such as hand-warmers, can be very helpful to fishermen and others who face extreme cold temperatures on a regular basis. You will use what you know about electron states, chemical reactions,

	periodic trends and bond energy to plan a device that uses a chemical reaction to help keep a fisherman's hands warm. **Task A Components** Students write the outcome of the dissolution and chemical reaction processes, conserving electrons and elements (i.e., matter is not created or destroyed). Using Table A in Attachment 1, select one dissolution and one chemical reaction to analyze for its ability to heat its surroundings. Create a drawing on Attachment 2 representing the molecular level of compounds before and after the chemical processes. Use your knowledge of outer electron states and patterns of chemical properties (such as the patterns in the periodic table) to construct an explanation of why the chemical reaction occurs or what chemical property leads to dissolution. (Safety Note: Reactions involving alkali metals and water are dangerous and should not be used.) Students create and use a molecular model for dissolution and a molecular model for a chemical reaction to visually represent the change in compounds before and after the chemical process by: ● Identifying the following components: Substances that are entering into the chemical process (reactants), including the types and number of atoms and the location of bonds between atoms. Substances that are produced at the end of the chemical process, including the types and number of atoms and the location of bonds between atoms. Electrons within the valence shells of the atoms, including those electrons involved in bonds between atoms. ● Identifying the following relationships between components: Transfer of electrons as bonds are broken and new bonds are formed, including the movement of electrons between atoms and broken and/or created bonds. Transfer of atoms from one substance to another as substances are created or changed without a loss or gain in the number of atoms of each element. ● Describing the relationships between the type of element(s), the state of valence electrons in the element, and where the bonds break and form to show how the type of chemical process that occurs can be explained and predicted by the patterns in electron states and properties of atoms as seen in the patterns on the periodic table. In their explanation, students make a statement that describes the relationship between 1. The type of chemical process (reaction and dissolution) and expected outcome and 2. The types of elements and the numbers of associated valence electrons following the patterns in the periodic table. Students identify and describe the following evidence for the explanation: ● The movement of elements and electrons in the model ● A property of an element(s) as indicated by the location of that element on the periodic table (e.g., metal or nonmetal, highly reactive, etc.) ● The number of valence electrons of an atom, as predicted by the group location on the periodic table Students describe their reasoning for connecting the evidence to the explanation, including the following: ● The nature of the chemical process is determined by the properties of the elements, with element combinations following expected reactivity patterns from the periodic table (e.g., properties of reactivity; combination of Group 1 + Group 17 elements). ● The chemical process is driven by the stability of the atoms — the valence shell is full through a loss of electrons, a gain in electrons or transfer/sharing of electrons via bonding.

- Which elements interact within the chemical process is determined by the number of valence electrons available to gain or lose so that the elements when combined together can each reach a full valence shell.

Attachment 1. Reference Sheet A

Table A
- ammonium nitrate + water
- calcium chloride anhydrous + water
- lithium chloride + water
- sodium acetate + water
- sodium chloride + water
- sodium carbonate + water
- magnesium sulfate anhydrous + water
- magnesium + 3M hydrochloric acid
- magnesium oxide + 3M hydrochloric acid

Attachment 2. Data Sheet A

Molecular Model System Diagram Compounds:
Before--> After

Model features should include:
- The chemical reaction, the system and the surroundings under study
- The bonds that are broken during the course of the process
- The bonds that are formed during the course of the process
- The energy transfer between the system and surroundings

Universal Supports	Targeted Supports
• Use model (drawn on paper or with materials) to show interactions that could occur between elements at the atomic scale (including chemical reactions and nuclear processes) • Review different types of chemical reactions and bonds; show real world examples of each bond type in various compounds • Explain, review and give students practice problems on balancing chemical equations; use virtual, computer-based interactive activities to show reactions and products • In groups, give students incomplete or flawed chemical equations and have them correct the errors and present their group work for validation to the entire class; teacher can approve or help correct mistakes with each group	• Provide and work practice problems with student groups/individuals who are struggling • Offer individual tutoring time for students who need it

Common Misconceptions

- There are unbalanced chemical equations
- That in some chemical reactions matter disappears
- The octet rule can be used for all elements.

Culturally and Linguistically Responsive Instruction

Guiding Questions and Connections

- Identify chemical reactions that occur within your household.
- Identify explanations (if available) offered in your home for the chemical phenomena observed.
- What types of patterns do you have in your daily life?
- What patterns occur in your household?
- How do we make decisions based on our knowledge of patterns?
- Given a novel reaction, how would you explain what will happen?
- What is the importance of using observed patterns when answering questions about new observations?
- Include research on historical and biographical data for culturally connected individuals who have contributed to the development of this topic.
- Include visuals/articles/videos representative of all cultural groups.

Students who demonstrate understanding can:

HS-PS1-3. **Plan and conduct an investigation to gather evidence to compare the structure of substances at the bulk scale to infer the strength of electrical forces between particles.** [Clarification Statement: Emphasis is on understanding the strengths of forces between particles, not on naming specific intermolecular forces (such as dipole-dipole). Examples of particles could include ions, atoms, molecules, and networked materials (such as graphite). Examples of bulk properties of substances could include the melting point and boiling point, vapor pressure, and surface tension.] [*Assessment Boundary: Assessment does not include Raoult's law calculations of vapor pressure.*]

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

Science and Engineering Practices

Planning and Carrying Out Investigations
Planning and carrying out investigations in 9-12 builds on K-8 experiences and progresses to include investigations that provide evidence for and test conceptual, mathematical, physical, and empirical models.

- Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly.

Disciplinary Core Ideas

PS1.A: Structure and Properties of Matter

- The structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms.

PS2.B: Types of Interactions

- Attraction and repulsion between electric charges at the atomic scale explain the structure, properties, and transformations of matter, as well as the contact forces between material objects. *(secondary)*

Crosscutting Concepts

Patterns

- Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena.

Connections to other DCIs in this grade-band:
HS.ESS2.C

Articulation of DCIs across grade-bands:
MS.PS1.A ; **MS.PS2.B**

Common Core State Standards Connections:
ELA/Literacy -

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-PS1-3)

WHST.9-12.7 Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation. (HS-PS1-3)

WHST.11-12.8 Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the strengths and limitations of each source in terms of the specific task, purpose, and audience; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and overreliance on any one source and following a standard format for citation. (HS-PS1-3)

WHST.9-12.9 Draw evidence from informational texts to support analysis, reflection, and research. *(HS-PS1-3)*

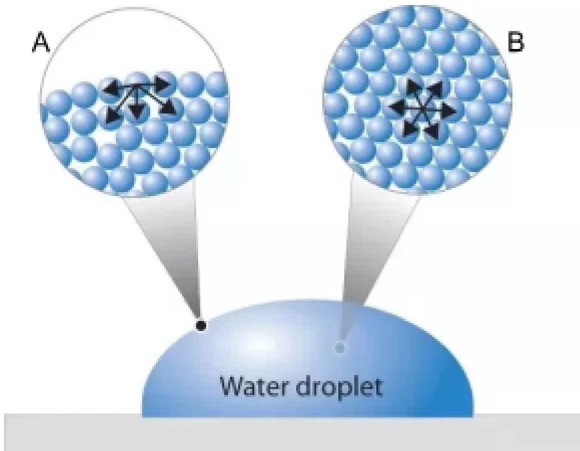
Mathematics -

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 interpret the scale and the origin in graphs and data displays. *(HS-PS1-3)*

HSN-Q.A.3 Choose a level of accuracy appropriate to limitations on measurement when reporting quantities. *(HS-PS1-3)*

Grade	*NGSS Discipline*
HS	**Physical Science 1.3**

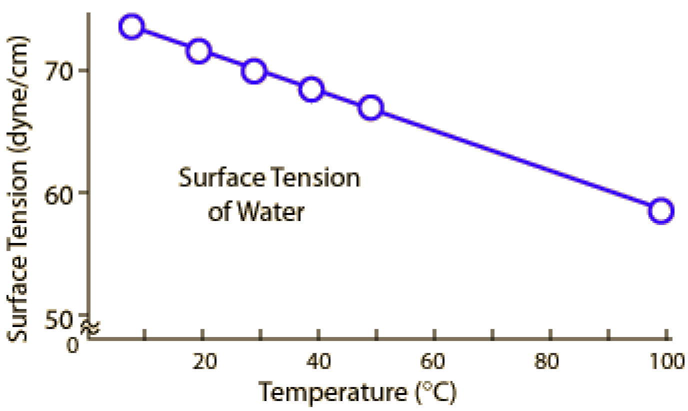
PS1-3	
	Sample Phenomena
	When available, you should use your locally selected or created high quality instructional materials. However, the following is an example phenomenon you can use if you don't have local instructional materials available. Gecko Feet The foot of a gecko has folds upon folds upon folds. This increases the surface area between the foot of the gecko and the surface it is climbing on. Intermolecular forces between the two surfaces allow the gecko to scale vertical surfaces. This phenomenon can be used as an introduction to biomimicry or as an application of intermolecular forces. **Web Resources:** Gecko Feet Inspire Climbing Space Robots, How Do Geckos' Feet Work? Video: Sticky Gecko Feet Space Age Reptiles *This work is licensed by the author(s) under a Creative Commons Attribution-NonCommercial 4.0 International License. Hosted by The Wonder of Science.*
	Classroom Assessment Items
	When available, you should use your locally selected or created high quality instructional materials. However, the following are example assessment items you can use if you don't have local instructional materials available. **Water Striders** Watch the following video from minute 1:00 to 1:15 (will need to be shortened and no sound) Water strider - walking on water Water striders are small insects that are adapted for life on top of still water, using surface tension to their advantage so they can "walk on water." Water striders are about a half-inch long with a thin body and three sets of legs. The water strider's secret is its legs. The legs have tiny hairs which are covered in a waxy substance that repels water and captures air. By repelling water, the tiny water striders stand on the water's surface and move easily. Water Striders are vital creatures in the aquatic food chain. They eat mosquito larvae and land insects that fall into the water. Water Striders are prey for birds, frogs, and toads. **Web Resources:** Water Striders and Water Striders **Task:** 1. Develop a microscopic model to represent all the forces of interactions between at least 8 water molecules in a pond and one leg of the water strider. Include the partial charges and orientation of the individual water molecules and any possible charges on the water striders leg.



2. Using the diagram above, a student compares the water molecules labelled A and B each showing the forces exhibited on other water molecules. Determine if water molecules labelled A or B would have the greatest compression resistance comparable to the water molecules found in the pond. Explain why.

3. Describe the relationship between interactions of the water molecules and compression resistance to explain why the water strider is able to walk on water.

Climate change is causing the temperature of ponds to increase slightly. The following data shows the surface tension, measured in dynes, as the temperature increases.



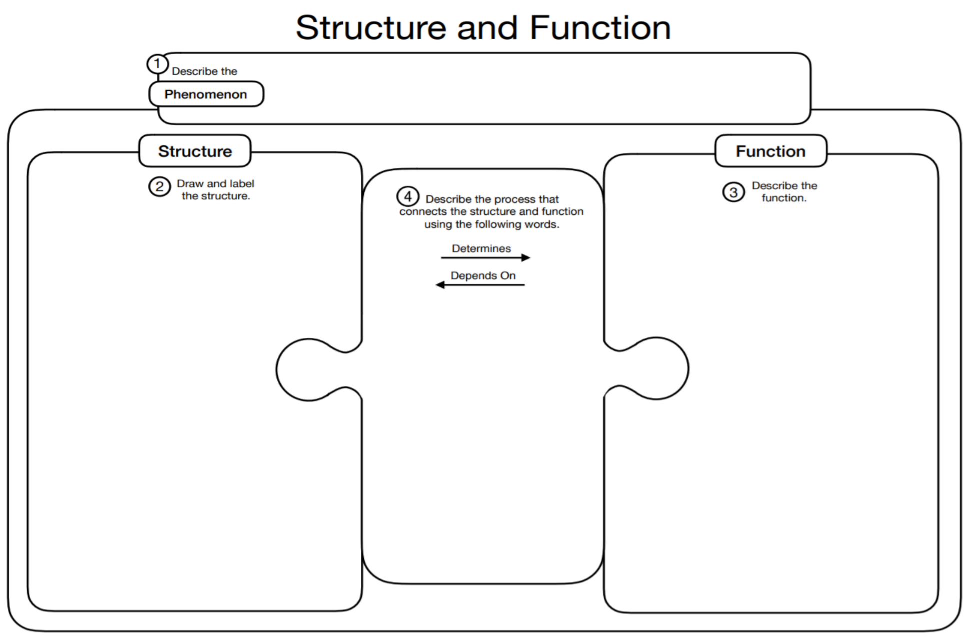
4. Explain the relationship between surface tension and temperature using evidence from the graph.

5. Create a claim describing the compression resistance and the ability of the water strider to walk on water if the pond temperature increases due to global warming.

6. Describe a possible effect on the aquatic food chain that may occur if the temperature of the pond increases by 5°C. The following data table shows the surface tensions of various solvents at a specific temperature.

Solvent	Surface Tension Dynes/cm
Water	72.8
Toluene	28.4
Isopropanol	23.0
n-Butanol	24.8
Acetone	25.2
Methyl propyl ketone	26.6
Methyl amyl ketone	26.1
PM acetate	28.5

7. A student claims that a water strider will be able to walk on the surface of acetone or propanone, which is commonly known as fingernail polish remover. Using evidence from the table, do you agree or disagree with the student? Explain why in terms of the attractive forces between propanone molecules and the water striders leg in terms of structure and function.



Universal Supports	Targeted Supports
• Students can draw Lewis Dot diagrams as a review from prior lessons in a graphic organizer. • Use group discussion to post the structures of familiar compounds. Based upon the structures and remembering that stronger IMFs result in higher boiling points, students can begin to predict the order of the compounds from	• Individualize instruction for struggling students by providing a refresher for drawing Lewis Dot structures which are on the microscopic level and how they relate to the macroscopic level. • Use small groups or partners to share steps when drawing structures. Monitor progress.

lowest to highest boiling points based upon their structures.
- Before conducting small group activity, make sure that all students understand the expectations, instructions, and their role in the performance of the task. The teacher may check for understanding by asking questions regarding the expectations and how to complete the task.

Common Misconceptions

- A common factual misconception is that intermolecular forces are the same as intramolecular forces. Intermolecular forces are the interactions between molecules while intramolecular forces are those bonds within the structure of the molecules.
- Some students may think that the molar mass or atomic mass determines the strength of the London Dispersion Forces which can determine surface tension. It is the number of electrons, and not the molar or atomic mass.

Culturally and Linguistically Responsive Instruction

Guiding Questions and Connections

- Ask for examples of liquids with different viscosities to initiate discussion.
- Discuss experiences with liquids that flow very slowly. Be aware that not all students have experience with heavy syrups or oils. Ask for examples from their cultures.
- Use surface tension to begin discussion of water striders or other insects or objects that float on water that students may have experience with and how hydrogen bonding in water affects surface tension.

Students who demonstrate understanding can:

HS-PS1-4. **Develop a model to illustrate that the release or absorption of energy from a chemical reaction system depends upon the changes in total bond energy.** [Clarification Statement: Emphasis is on the idea that a chemical reaction is a system that affects the energy change. Examples of models could include molecular-level drawings and diagrams of reactions, graphs showing the relative energies of reactants and products, and representations showing energy is conserved.] [*Assessment Boundary: Assessment does not include calculating the total bond energy changes during a chemical reaction from the bond energies of reactants and products.*]

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

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Developing and Using Models Modeling in 9–12 builds on K–8 and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed worlds. • Develop a model based on evidence to illustrate the relationships between systems or between components of a system.	**PS1.A: Structure and Properties of Matter** • A stable molecule has less energy than the same set of atoms separated; one must provide at least this energy in order to take the molecule apart. **PS1.B: Chemical Reactions** • Chemical processes, their rates, and whether or not energy is stored or released can be understood in terms of the collisions of molecules and the rearrangements of atoms into new molecules, with consequent changes in the sum of all bond energies in the set of molecules that are matched by changes in kinetic energy.	**Energy and Matter** • Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system.

Connections to other DCIs in this grade-band:
HS.PS3.A ; **HS.PS3.B** ; **HS.PS3.D** ; **HS.LS1.C**

Articulation of DCIs across grade-bands:
MS.PS1.A ; **MS.PS1.B** ; **MS.PS2.B** ; **MS.PS3.D** ; **MS.LS1.C**

Common Core State Standards Connections:

ELA/Literacy -

SL.11-12.5 Make strategic use of digital media (e.g., textual, graphical, audio, visual, and interactive elements) in presentations to enhance understanding of findings, reasoning, and evidence and to add interest. *(HS-PS1-4)*

Mathematics -

MP.4 Model with mathematics. *(HS-PS1-4)*

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 interpret the scale and the origin in graphs and data displays. *(HS-PS1-4)*

HSN-Q.A.2 Define appropriate quantities for the purpose of descriptive modeling. (HS-PS1-4)

HSN-Q.A.3 Choose a level of accuracy appropriate to limitations on measurement when reporting quantities. *(HS-PS1-4)*

Grade	*NGSS Discipline*
HS	**Physical Science 1.4**
PS1-4	**Sample Phenomena**
	When available, you should use your locally selected or created high quality instructional materials. However, the following is an example phenomenon you can use if you don't have local instructional materials available.

Find a video of a Thermite reaction used to weld railroads together.

- Classroom demo: Thermite Reaction Demo
- Railway welding: Railroad thermite welding

If available, demonstrate a smaller Thermite reaction using two large rusty steel balls, one covered with aluminum foil. Strike the balls against each other using a glancing blow. Sparks should fly indicating an exothermic chemical reaction based upon aluminum and iron oxide reacting to form iron and aluminum oxide. Use the demonstration to write the chemical equation and determine whether it is a redox reaction.

Draw an energy diagram and have students determine where the reactants, products, activation energy, and the change in enthalpy are on the diagram. Refer to the energy diagram throughout the subsequent lessons.

Classroom Assessment Items

When available, you should use your locally selected or created high quality instructional materials. However, the following are example assessment items you can use if you don't have local instructional materials available.

Total Bond Energy Change in Chemical Reactions

1. Using the phenomena of the Thermite reaction, develop a physical model to illustrate changes in matter and energy to include the following:

Developing and Using Models Graphic Organizer

- A labeled particle diagram to show how the atoms combine and rearrange to form the products
- Identifying the system and surroundings including any energy transfer
- An energy diagram depicting how energy changes as a reaction occurs

Particle diagram (show correctly balanced chemical reaction particles for the Thermite reaction)

Energy diagram (show reactants, products, activation energy, and change in enthalpy)

2. Use your model and the chemical equation for the Thermite reaction to explain how they validate the conservation of energy.

3 . Using the evidence from your model, explain the relationship between energy change and bond formation.

Universal Supports	Targeted Supports
• Write the chemical equation for the Thermite reaction for the class to be put into student graphic organizers. Have students help with balancing the equation correctly. • Provide students with the enthalpy of the reaction so they can draw an accurate energy diagram emphasizing the change in bond energies. • Use think pair share groups to draw an accurate representation of the reaction using an energy diagram showing the correct placement of reactants and products based upon the energies of all species in the reaction.	• Individualize instruction for struggling students by using a generic energy diagram in a small group. • Monitor progress as students discuss each part of the reaction on the energy diagram. Use the analogy of strong magnets requiring energy to pull apart (bonds breaking) and energy being released when strong magnets are attracted to each other (bonds forming).

Common Misconceptions

- A common misconception is that all exothermic reactions occur quickly and are thermodynamically favorable.
- Remind students that the activation energy must be overcome before the reaction can go to completion.

Culturally and Linguistically Responsive Instruction

Guiding Questions and Connections

- For Spanish language cultures, ask for the meaning of ferrocarril noting the specific meaning of ferro and the chemical symbol for iron.
- How are iron railroad tracks welded together in remote areas? Use models of railroad tracks to show all students where joints need to be welded together.
- Because the Thermite reaction can be initiated with the activation energy from a sparkler, ask students when fireworks are used throughout the year in celebration. Include all cultures and nationalities being very aware of cultures that do not use fireworks.
- How can the Thermite reaction be used in other ways that could be helpful in a remote situation?
- How can reactions that give off thermal energy be useful in other societies or cultures?

Students who demonstrate understanding can:

HS-PS1-5. **Apply scientific principles and evidence to provide an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs.** [Clarification Statement: Emphasis is on student reasoning that focuses on the number and energy of collisions between molecules.] [*Assessment Boundary: Assessment is limited to simple reactions in which there are only two reactants; evidence from temperature, concentration, and rate data; and qualitative relationships between rate and temperature.*]

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

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Constructing Explanations and Designing Solutions Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories. • Apply scientific principles and evidence to provide an explanation of phenomena and solve design problems, taking into account possible unanticipated effects.	**PS1.B: Chemical Reactions** • Chemical processes, their rates, and whether or not energy is stored or released can be understood in terms of the collisions of molecules and the rearrangements of atoms into new molecules, with consequent changes in the sum of all bond energies in the set of molecules that are matched by changes in kinetic energy.	**Patterns** • Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena.

Connections to other DCIs in this grade-band:
HS.PS3.A

Articulation of DCIs across grade-bands:
MS.PS1.A ; **MS.PS1.B** ; **MS.PS2.B** ; **MS.PS3.A** ; **MS.PS3.B**

Common Core State Standards Connections:
ELA/Literacy -

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-PS1-5)

WHST.9-12.2 Write informative/explanatory texts, including the narration of historical events, scientific procedures/ experiments, or technical processes. *(HS-PS1-5)*

Mathematics -

MP.2 Reason abstractly and quantitatively. (HS-PS1-5)

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 interpret the scale and the origin in graphs and data displays. *(HS-PS1-5)*

HSN-Q.A.3 Choose a level of accuracy appropriate to limitations on measurement when reporting quantities. *(HS-PS1-5)*

Grade	*NGSS Discipline*
HS	**Physical Science 1.5**
PS1-5	**Sample Phenomena** *When available, you should use your locally selected or created high quality instructional materials. However, the following is an example phenomenon you can use if you don't have local instructional materials available.*

The following phenomenon is a demonstration that can be used to demonstrate reaction rates and generate student questions.Reaction rates are subject to many factors including concentration of reactants and the temperature at which a reaction occurs.

Have any form of zinc available. A galvanized nail will suffice. Add about 5 mL of concentrated (not over 6 M) hydrochloric acid to a test tube. Add about 5 mL of dilute hydrochloric acid to a second test tube. Place about 1 gram of zinc or one galvanized nail in each of the test tubes. Ask students for any observations. Remind them of collisions between the ions in the reaction as they observe each solution. Note any difference in reaction rates. As the lesson progresses, remind students of the concentration of the hydrochloric acid and how changing the concentration will affect the rate.

Use the same materials as above, but use only the concentrated (6M HCl) acid in two test tubes. Place one test tube in an ice bath, the other in warm water. Use caution with additional heat. Place the zinc into each test tube and make observations for the rate of the reaction. On a particulate level, discuss the difference in rates of reaction.

Classroom Assessment Items

When available, you should use your locally selected or created high quality instructional materials. However, the following are example assessment items you can use if you don't have local instructional materials available.

Hawaii Eruptions

You are helping an elementary school student with a science project. They wish to model a volcanic eruption similar to the one shown in the video. The reaction of baking soda with vinegar produces water, carbon dioxide and sodium acetate, $NaC_2H_3O_2$ is frequently used to model this phenomena.

$$NaHCO_3(s) + HC_2H_3O_2(aq) \dashrightarrow H_2O(l) + CO_2(g) + NaC_2H_3O_2(aq)$$

The student is looking for the best combination of baking soda and vinegar to get the most effective eruption. The student used 50 mL of vinegar in each trial. The data table below shows information on the trials that the student has conducted.

Trial	Mass of Baking Soda	Temperature, °C	Concentration of Vinegar	Volume of gas produced at 1 atm*	Reaction Time*
1	10.0 g	80.0	1.0M	10.0 mL	10.0 s
2	10.0 g	80.0	2.0M	18.0 mL	5.0 s
3	10.0 g	80.0	0.1 M	3.0 mL	32.0 s
4	10.0 g	40.0	1.0 M	10.0 mL	20.0 s

* This data will be replaced with actual experimental data.*

Prompt

1) The student needs help interpreting the data. Citing data from the table above, describe the patterns you observe.

2) Complete the table below.

Factor	Describe how the factor affected the rate of the reaction.	Describe how changing this factor affected the energy of the collisions.	Describe how changing this factor a number of collisions.
Mass of Baking Soda			
Temperature			
Concentration of vinegar			

3) Make a claim about which factor the student should manipulate to maximize the volume of gas produced by the volcano. Cite the evidence you used to make this claim.

4) Provide reasoning, in terms of Collision Theory, to support the claim you made in question 3.

5) Select two trials and draw a model for each to show how changing the factor (chosen in question 3) affects the rate of reaction.

Trial_____________________	Trial_____________________

Universal Supports	Targeted Supports
• Model the reaction between baking soda and vinegar. ○ Utilize Think, Pair, Share strategy and ask for students to discuss how to slow down the reaction so that the production of gas is slow and steady instead of rapid and violent. • Demonstrate how a 20% serial dilution of vinegar is made using test tubes, Beral pipettes, distilled water, and bottled vinegar. Students can draw an illustration of a solution being diluted in their graphic organizers. • Before conducting small group activity, make sure that all students understand the expectations, instructions, and their role in the performance of the task. The teacher may check for understanding by asking questions regarding the expectations and how to complete the task. • Use turn-taking strategies, timer, and model meaningful participation to avoid "knower" or a few students dominating the conversation.	• In small groups demonstrate how making a serial solution can be easier to visualize when using a colored solution. Use a packet of colored drink mix (Kool-Aid) to start the dilution. Make a 20% serial dilution placing each into a test tube in a test tube rack so that students can see the color change. Ask which solution seems stronger and why. • Monitor progress as students work together on serial dilutions in the lab and provide individualized feedback.

Common Misconceptions

- A large amount of a solid compound would react faster than a small amount of the same solid in powder form. The ground solid will react faster because it has greater surface area than the solid in its more massive state.

Culturally and Linguistically Responsive Instruction

Guiding Questions and Connections

- Many students are in households that practice thrifty habits. Ask students if they have ever tasted dilute juices that have too much water in them.
    - Growing up in a household with five active children, concentrated orange juice was always diluted well beyond the recommended dilution stated on the concentrate can.
- Consider all students and how they prepare beverages (tea, coffee, chocolate milk mix, etc.) in their households. Ask for experiences when solutions were too dilute.

Students who demonstrate understanding can:

HS-PS1-6. **Refine the design of a chemical system by specifying a change in conditions that would produce increased amounts of products at equilibrium.*** [Clarification Statement: Emphasis is on the application of Le Chatelier's Principle and on refining designs of chemical reaction systems, including descriptions of the connection between changes made at the macroscopic level and what happens at the molecular level. Examples of designs could include different ways to increase product formation including adding reactants or removing products.] [*Assessment Boundary: Assessment is limited to specifying the change in only one variable at a time. Assessment does not include calculating equilibrium constants and concentrations.*]

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

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Constructing Explanations and Designing Solutions Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories. • Refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations.	**PS1.B: Chemical Reactions** • In many situations, a dynamic and condition-dependent balance between a reaction and the reverse reaction determines the numbers of all types of molecules present. **ETS1.C: Optimizing the Design Solution** • Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (trade-offs) may be needed. *(secondary)*	**Stability and Change** • Much of science deals with constructing explanations of how things change and how they remain stable.

Connections to other DCIs in this grade-band:
HS.PS3.B

Articulation of DCIs across grade-bands:
MS.PS1.B

Common Core State Standards Connections:
ELA/Literacy -
WHST.9-12.7 Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation. *(HS-PS1-6)*

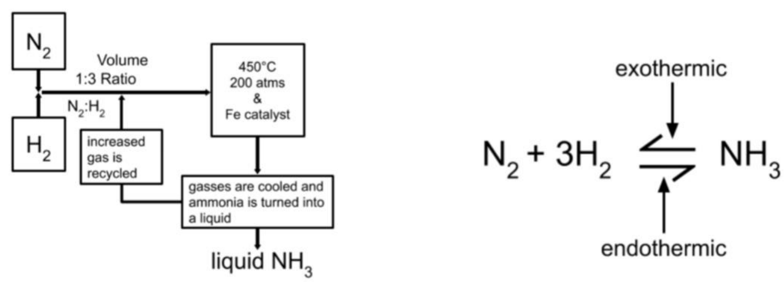
Grade	*NGSS Discipline*
HS	**Physical Science 1.6**
PS1-6	**Sample Phenomena** *When available, you should use your locally selected or created high quality instructional materials. However, the following is an example phenomenon you can use if you don't have local instructional materials available.* Watch dramatic moment huge explosion at chemical plant sends 'fireball' into air

Across the world there are several factories that produce ammonia. One of the most common processes used for this is the Haber process. In Teeside, UK, the Terra Nitrogen plant exploded. They reported that this was caused by a mixture of N2, H2, and NH3 gases. It is well known that H2 is very explosive.

Classroom Assessment Items

When available, you should use your locally selected or created high quality instructional materials. However, the following are example assessment items you can use if you don't have local instructional materials available.

Stimulus



Cause & Effect

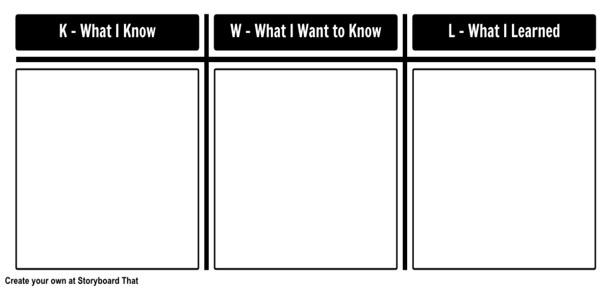
Factor	Impact on NH_3 Production
↑ H_2	
↑ N_2	
↑ Temperature	
↑ Pressure	
↑ Fe	

- Explain the most likely reason the explosion occurred and what factor could cause this to happen.
- You are an engineer and have been contacted by Terra Nitrogen to refine the current design of their factory to avoid future explosions. Propose a design keeping in mind that the copy's main concerns are reliability, safety and environmental impacts.

HS-PS1-6 Assessment - Terra Nitrogen Explosion

Universal Supports

- Make sure that all students understand the expectations, instructions, and their role in the performance of the task. The teacher may check for understanding by asking questions regarding the expectations and how to complete the task.
- Use turn-taking strategies, timer, and model meaningful participation to avoid “knower” or a few students dominating the conversation.
- Utilize a KWL chart
- Swap and Compare activity
  - Students are encouraged to present their KWL chart in class after p[resentation of KWL students are encouraged to compare their KWL and look for similarities on the learned concept.
  - Students are encouraged to list down ideas or concepts that are the same in the KWL and the teacher addresses those ideas.



Targeted Supports

- Provide targeted individualized interventions
- Small group instruction to address student misconceptions

Common Misconceptions

- Nothing is happening at equilibrium
  - Concept to address the misconception:The equilibrium constant is equal to the rate constant of the forward reaction divided by that of the reverse reaction.
- Equilibrium constants are constant under all conditions
  - Concept to address misconception: Le Chatelier's Rule
- In chemical equilibrium there are equal parts reactants and products and, once a chemical reaction reaches equilibrium, the reaction has stopped.
  - Concept to address misconception: But neither is true: an equilibrium reaction is a dynamic process where reactants, in any proportion, are continuously turning into products and vice-versa.

	[9.3 Misconceptions about Chemical Equilibrium (animation)](#)
	Culturally and Linguistically Responsive Instruction
	Guiding Questions and Connections
	• Use instructional resources (videos, images, articles) that are representative of all cultural groups in your classroom. • Why does this phenomenon matter to you, to your community or others, to scientists?

Students who demonstrate understanding can:

HS-PS1-7. **Use mathematical representations to support the claim that atoms, and therefore mass, are conserved during a chemical reaction.** [Clarification Statement: Emphasis is on using mathematical ideas to communicate the proportional relationships between masses of atoms in the reactants and the products, and the translation of these relationships to the macroscopic scale using the mole as the conversion from the atomic to the macroscopic scale. Emphasis is on assessing students' use of mathematical thinking and not on memorization and rote application of problem-solving techniques.] [*Assessment Boundary: Assessment does not include complex chemical reactions.*]

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

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Using Mathematics and Computational Thinking Mathematical and computational thinking at the 9–12 level builds on K–8 and progresses to using algebraic thinking and analysis, a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms, and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions. • Use mathematical representations of phenomena to support claims.	**PS1.B: Chemical Reactions** • The fact that atoms are conserved, together with knowledge of the chemical properties of the elements involved, can be used to describe and predict chemical reactions.	**Energy and Matter** • The total amount of energy and matter in closed systems is conserved. - - - - - - - - - - - - - - - - - - ***Connections to Nature of Science*** **Scientific Knowledge Assumes an Order and Consistency in Natural Systems** • Science assumes the universe is a vast single system in which basic laws are consistent.

Connections to other DCIs in this grade-band:
HS.LS1.C ; **HS.LS2.B** ; **HS.PS3.B**

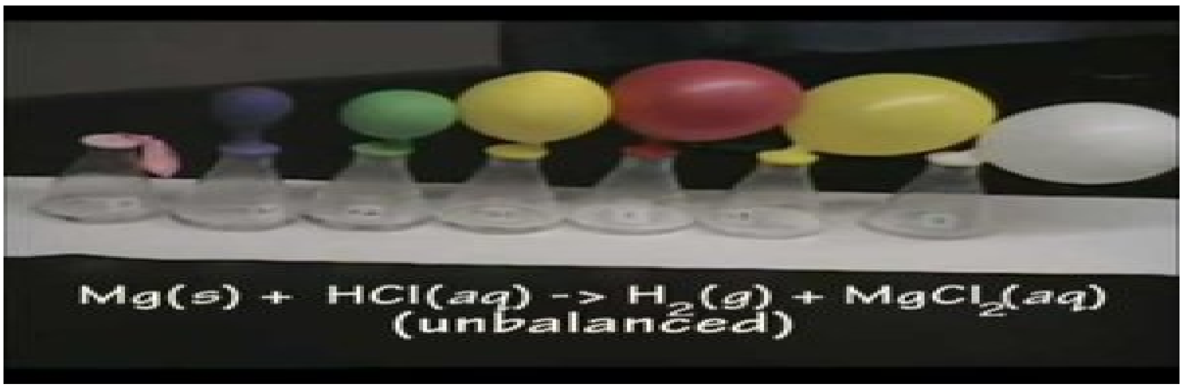
Articulation of DCIs across grade-bands:
MS.PS1.A ; **MS.PS1.B** ; **MS.LS1.C** ; **MS.LS2.B** ; **MS.ESS2.A**

Common Core State Standards Connections:
Mathematics -

MP.2	Reason abstractly and quantitatively. (HS-PS1-7)
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 interpret the scale and the origin in graphs and data displays. (HS-PS1-7)
HSN-Q.A.2	Define appropriate quantities for the purpose of descriptive modeling. *(HS-PS1-7)*
HSN-Q.A.3	Choose a level of accuracy appropriate to limitations on measurement when reporting quantities. *(HS-PS1-7)*

Grade	*NGSS Discipline*
HS	**Physical Science 1.7**
PS1-7	**Sample Phenomena** *When available, you should use your locally selected or created high quality instructional materials. However, the following is an example phenomenon you can use if you don't have local instructional materials available.* **Phenomenon: Limiting reactants: Reaction of magnesium Metal to Hydrochloric acid**

The law of conservation of mass states that mass in an isolated system is neither created nor destroyed by chemical reactions or physical transformations. According to the law of conservation of mass, the mass of the products in a chemical reaction must equal the mass of the reactants.Consider the reaction of magnesium metal with hydrochloric acid to produce magnesium chloride and hydrogen gas.
[Limiting Reactant]



Classroom Assessment Items

When available, you should use your locally selected or created high quality instructional materials. However, the following are example assessment items you can use if you don't have local instructional materials available.

A student wanted to investigate conservation of matter using the reaction between a piece of zinc in a solution of hydrochloric acid. She measured the mass of the zinc, a test tube containing hydrochloric acid, and a balloon. She placed the zinc in the test tube with the hydrochloric solution, quickly placed a balloon over the test tube, and observed a chemical reaction where a gas was produced.

The following data table was created based on her measurements:

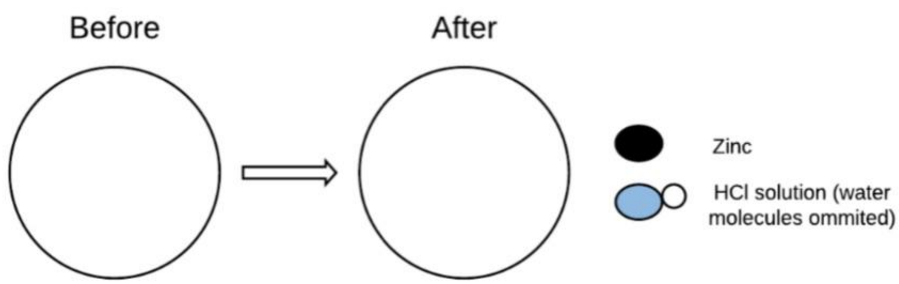
	Initial Mass	Final Mass
Test Tube +Solution	68.6 g	74.9 g
Balloon	2.1 g	---
Zinc	6.5 g	---
Balloon + gas	---	2.3 g

Answer the following questions:

1. Balance the chemical equation that is represented by this process to indicate that atoms are conserved during a chemical reaction. Add phases of matter (i.e., solid, liquid, gas, or aqueous) in the parenthesis.

$$\_\_\_\_\_ Zn(\ ) + \_\_\_\_\_ HCl(\ ) \rightarrow \_\_\_\_\_ ZnCl_2(\ ) + \_\_\_\_\_ H_2(\ )$$

2. Using the balanced equation you constructed above, draw a representation of atoms and molecules that will be present BEFORE and AFTER the reaction has occurred in the container provided. Assume the reaction proceeded to the fullest extent possible.



3. Calculate the number of moles of zinc placed in the test tube.

4. Calculate the mass of the hydrogen gas produced by this reaction.

5. Based on your answer to number 4, calculate the number of moles of hydrogen gas produced.

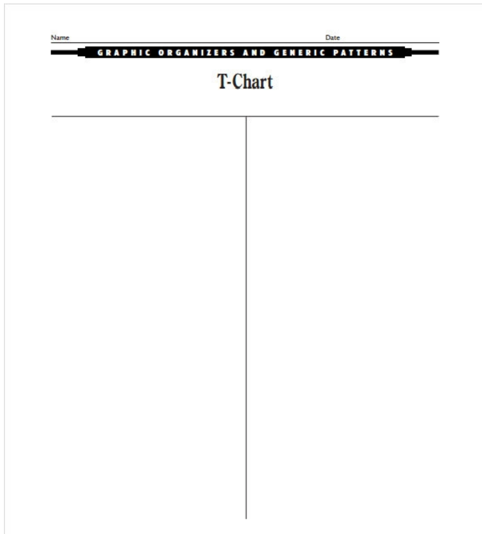
6. Using the coefficients in your balanced equation, what is the ratio of moles of zinc reacted to moles of hydrogen gas produced. How does this compare to the ratio of moles calculated in questions 3 and 5?

7. Using data from the table, and referring to the chemical reaction, compare the sum of the initial masses to the sum of the final masses. Show your work.

8. A student claims that mass is conserved in this chemical reaction. Support the claim with your calculations and data provided.

HS-PS1-7 Assessment - Reaction of zinc and hydrochloric acid (NY)

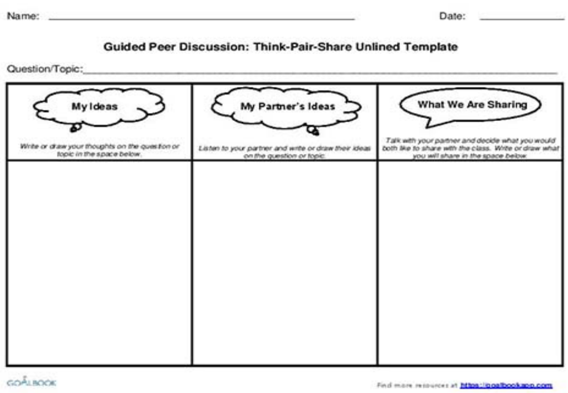
Universal Supports	Targeted Supports
- POE Strategy (Predict, Observe and Explain) - Encourage students to write their predictions on what will happen to the Magnesium metals after dropping it to the Hydrochloric acid. - Students will create a T chart and on the right side of the chart students are encouraged to write their observations and on the left side of the chart is the explanation of their observations. - Think Pair Share activity - Students are encouraged to find a partner to share their T chart. - Students discuss their T chart and are encouraged to fill out the graphic organizer. - Teacher will move around the class and address whatever misconceptions written on the chart.	- Monitor the students to provide individualized interventions. - Provide detailed graphic organizers to support students keeping their science notebooks organized. - Provide extension opportunities for students or additional readings to go deeper in learning, for those students with high interests.



Name Date

GRAPHIC ORGANIZERS AND GENERIC PATTERNS

T-Chart



Name: Date:

Guided Peer Discussion: Think-Pair-Share Unlined Template

Question/Topic:

My Ideas	My Partner's Ideas	What We Are Sharing
Write or draw your thoughts on the question or topic in the space below.	Listen to your partner and write or draw their ideas on the question or topic.	Talk with your partner and decide what you would both like to share with the class. Write or draw what you will share in the space below.

Common Misconceptions

- Students think that the limiting reactant is simply whichever reactant is present in a smaller amount.
    - **Concept to address misconception:** The masses of reactants must be converted to moles and the mole ratio must be taken into account.

(Introduction to Limiting Reactant and Excess Reactant)

Culturally and Linguistically Responsive Instruction

Guiding Questions and Connections

- The limiting reactant (or **limiting reagent**) is the reactant that gets consumed first in a chemical reaction and therefore limits how much product can be formed.From this statement think about some limiting reactant of your life and list some ways on how you are going to deal with it.
- In a small group students will list some examples of limiting reactants of their everyday life.
- Students will discuss what will happen if we use up most of our resources? How are we going to deal with the problems?

Students who demonstrate understanding can:

HS-PS1-8. **Develop models to illustrate the changes in the composition of the nucleus of the atom and the energy released during the processes of fission, fusion, and radioactive decay.** [Clarification Statement: Emphasis is on simple qualitative models, such as pictures or diagrams, and on the scale of energy released in nuclear processes relative to other kinds of transformations.] [*Assessment Boundary: Assessment does not include quantitative calculation of energy released. Assessment is limited to alpha, beta, and gamma radioactive decays.*]

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

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Developing and Using Models Modeling in 9–12 builds on K–8 and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed worlds. • Develop a model based on evidence to illustrate the relationships between systems or between components of a system.	**PS1.C: Nuclear Processes** • Nuclear processes, including fusion, fission, and radioactive decays of unstable nuclei, involve release or absorption of energy. The total number of neutrons plus protons does not change in any nuclear process.	**Energy and Matter** • In nuclear processes, atoms are not conserved, but the total number of protons plus neutrons is conserved.

Connections to other DCIs in this grade-band:
HS.PS3.A** ; **HS.PS3.B** ; **HS.PS3.C** ; **HS.PS3.D** ; **HS.ESS1.A** ; **HS.ESS1.C

Articulation of DCIs across grade-bands:
MS.PS1.A** ; **MS.PS1.B** ; **MS.ESS2.A

Common Core State Standards Connections:
Mathematics -

MP.4	Model with mathematics. *(HS-PS1-8)*
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 interpret the scale and the origin in graphs and data displays. (HS-PS1-8)
HSN-Q.A.2	Define appropriate quantities for the purpose of descriptive modeling. (HS-PS1-8)
HSN-Q.A.3	Choose a level of accuracy appropriate to limitations on measurement when reporting quantities. *(HS-PS1-8)*

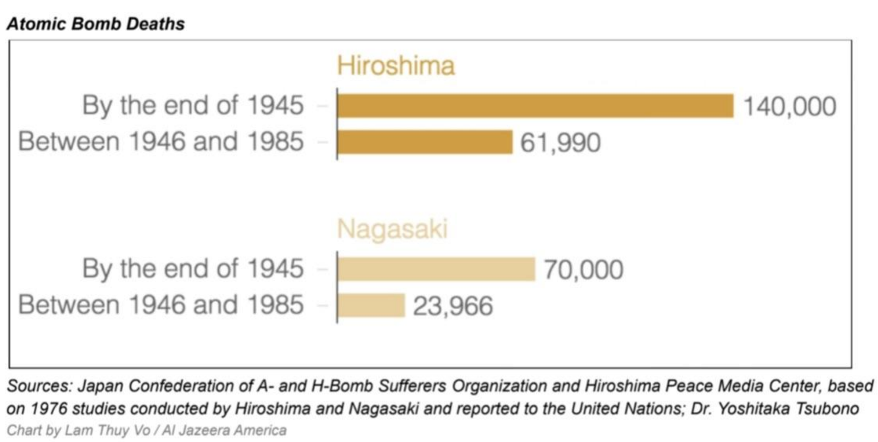
Grade	*NGSS Discipline*
HS	**Physical Science 1.8**
PS1-8	**Sample Phenomena** *When available, you should use your locally selected or created high quality instructional materials. However, the following is an example phenomenon you can use if you don't have local instructional materials available.* **Radioactivity : Fission vs Fusion** A nuclear reaction is semantically considered to be the process in which two nuclei, or a nucleus and an external subatomic particle, collide to produce one or more new nuclides. Thus, a nuclear reaction must cause a transformation of at least one nuclide to another. The decay of unstable atoms releases radiation, this

phenomenon of radioactivity of unstable atoms exists in all matter, we are surrounded by natural radiation. Radiation can also come from man-made sources, through military, medical or industrial applications.

Classroom Assessment Items

When available, you should use your locally selected or created high quality instructional materials. However, the following are example assessment items you can use if you don't have local instructional materials available.

The nuclear bombs Little Boy and Fat Man dropped on Hiroshima and Nagasaki respectively killed thousands of Japanese citizens. They were the first weapon used that continued to kill people decades after the explosion.



Little Boy derived its explosive power from the nuclear fission of uranium-235 whereas bombs dropped earlier in WWII prior were incendiary bombs. The explosive power of incendiary bombs derived from a chemical reaction between oxygen and combinations of fuels including TNT, napalm, magnesium, oil, thermite, phosphorous, etc.

a. Develop a model to illustrate the difference between a nuclear fission reaction and a chemical reaction. Include both the particles involved and the energy involved.

b. Nuclear weapons were the first weapons that continued to kill people decades after the explosion. These deaths were related to the radiation involved in nuclear reactions.

- Explain the terms radioactive decay and half-life.
- Write the balanced reaction for the alpha decay of uranium-235.
- Write the balanced reaction for fission of uranium-235 to form barium-139 and one other nuclei.
- The half-life of uranium-235 is 7.04×10^8 years. If 200.0 g of unused uranium-235 is left unreacted, how long will it take for only 25.0 g to remain? Show you work.
- In addition to alpha particles and beta particles, nuclear reactions also release gamma radiation. Draw a model of gamma radiation and explain how you can classify it as either a transverse or a longitudinal wave.
- Describe and explain how the speed of gamma radiation is different when traveling through empty space, air, and human body cells.
- Briefly summarize how it is possible that the nuclear bombs Little Boy and Fat Man continued to kill people decades after the explosion (refer to the charts above).

Sources: Hiroshima: The great taboo. (n.d.). Retrieved from Hiroshima: the Great Taboo

Universal Supports	Targeted Supports
• Before conducting small group activity, make sure that all students understand the expectations, instructions, and their role in the performance of the task. The teacher may check for understanding by asking questions regarding the expectations and how to complete the task.	• Provide targeted individualized interventions • Provide detailed graphic organizers to allow students to organize their thoughts

- Use turn-taking strategies, timer, and model meaningful participation to avoid "knower" or a few students dominating the conversation.
- *S*et protocols and ground rules for conducting small group activity, conversation, affirming, and respectful ways of disagreeing. Involve students in setting these protocols and ground rules.
- Conduct a collaborative small group and assign roles to each member of the group.
  A leader a recorder and reporter
  - Have them research about widespread radioactive contamination in Los Alamos (More radioactive contaminants found at Los Alamos housing site)

Common Misconceptions

- Students may think that if a fission reaction releases energy, then a fusion reaction must absorb energy.
  - **Concept to address the misconception:** The process of nuclear fission involves the splitting of very large nuclei into nuclei of intermediated mass, along with the release of large amounts of energy.
    - A chain reaction occurs when a critical mass of fissionable material undergoes the fission process very rapidly.
    - Both reactions release energy and fusion reactions release a great deal more than fission. In both cases, mass is lost and converted to energy according to Einstein's equation.
    - The mass of the products in a fission reaction is less than the mass of the reactants. In a fusion reaction, the mass of the product nucleus is also slightly less than the mass of the original nuclei that were fused.

Culturally and Linguistically Responsive Instruction

Guiding Questions and Connections

- Why does this phenomenon matter to you, to your community or others, to scientists?

Section 3: Resources

Science is not just a body of knowledge that reflects current understanding of the world; it is also a set of practices used to establish, extend, and refine that knowledge. [8] Our core science instruction must also allow for students to develop their science and engineering practices over time in addition to disciplinary core ideas. We know that children enter kindergarten with a surprisingly complex way of thinking about the world.[9] We know that students need sustained opportunities to work with and develop the underlying ideas and to appreciate those ideas' interconnections over a period of years rather than weeks or months.[2] We know that in order for students to develop a sustained attraction to science and for them to appreciate the many ways in which it is pertinent to their daily lives, classroom learning experiences in science need to connect with their own interests and experiences.[1] To this end, the National Research Council lays out a three-dimensional framework that is foundational to the development of the *Next Generation Science Standards (NGSS)*.

Dimension 1 describes the scientific and engineering practices (SEP). Dimension 2 describes the crosscutting concepts (CCC). Dimension 3 describes the core ideas (DCI) in the science disciplines and the relationships among science, engineering, and technology. All three of these dimensions must be interwoven in curriculum, instruction, and assessment.[1]

Engaging in the Practices of Science

Students provided sustained opportunities to engage in the practices of science and engineering better understand how knowledge develops and provides them an appreciation of the diverse strategies used to investigate, model, and explain the world.[1] The practices for K-12 science classrooms are:

1. Asking questions (science) and defining problems (engineering)
    a. Science asks:
        i. What exists and what happens?
        ii. Why does it happen?
        iii. How does one know?
    b. Engineering asks:
        i. What can be done to address a particular human need or want?
        ii. How can the need be better specified?
        iii. What tools or technologies are available, or could be developed, for addressing this need?
    c. Both ask:
        i. How does one communicate about phenomena, evidence, explanations, and design solutions?
2. Developing and using models
    a. Mental models: functional, used for thinking, making predictions, and making sense of experiences.
    b. Conceptual models: allow scientists and engineers to better visualize and understand phenomena and problems.

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[8] National Research Council. (2012). *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas.* Committee on a Conceptual Framework for New K-12 Science Education Standards. Board on Science Education, Division of Behavioral and Social Sciences and Education. Washington, DC: The National Academies Press.

[9] National Research Council. (2007). *Taking Science to School: Learning and Teaching Science in Grades K-8.* Committee on Science Learning, Kindergarten through Eighth Grade. R.A. Duschl, H.A. Schweingruber, and A.W. Shouse (Eds.). Board of Science Education, Center for Education. Division of Behavioral and Social Sciences and Education. Washington, DC: The National Academies Press.

   c. Are used to represent current understanding of a system (or parts of a system) under study, to aid in the development of questions or explanations, and to communicate ideas to others.
3. Planning and carrying out investigations
   a. Used to systematically describe the world and to develop and test theories and explanations of how the world works.
4. Analyzing and interpreting data
   a. Once collected, data are presented in a form that can reveal any patterns and relationships and that allows results to be communicated to others.
5. Using mathematics and computational thinking
   a. Enables the numerical representation of variables, the symbolic representation of relationships between physical entities, and the prediction of outcomes.
6. Constructing explanations (science) and designing solutions (engineering)
   a. Explanations are accounts that link scientific theory with specific observations or phenomena.
   b. Engineering solutions must include specifying constraints, developing a design plan, producing and testing models/prototypes, selecting among alternative design features to optimize achievement, and refining design ideas based on prototype performance.
7. Engaging in argument from evidence
   a. Scientists and engineers use reasoning and argumentation to make their case concerning new theories, proposed explanations, novel solutions, and/or fresh interpretations of old data.
8. Obtaining, evaluating, and communicating information
   a. Being literate in science and engineering requires the ability to read and understand their literature. Science and engineering are ways of knowing that are represented and communicated by words, diagrams, charts, graphs, images, symbols, and mathematics.

STEM teaching tools develop briefs to assist STEM teachers with issues that arise in the teaching of STEM. Here are some briefs that address scientific practices. All of these can be found at www.stemteachingtools.org/tools

Why focus on science and engineering practices – and not "inquiry?" Why is "the scientific method" mistaken? - STEM teaching tool #32

For decades science education has engaged students in a version of science inquiry that reduces the investigation of the natural world to a fixed, linear set of steps—sometimes devoid of a deep focus on learning and applying science concepts. Rigid representations of a single "scientific method" do not accurately reflect the complex thinking or work of scientists. The new vision calls for engaging students in multifaceted science and engineering practices in more complex, relevant, and authentic ways as they conduct investigations.

Practices should not stand alone: how to sequence practices in a cascade to support student investigations – STEM teaching tool #3

Science and engineering practices should strongly shape instruction—and be integrated with disciplinary core ideas and cross-cutting concepts. Some people might treat the practices as "stand alone" activities to engage students, but research shows that it is more effective to think about designing instruction as a cascade of practices. Practices should be sequenced and intertwined in different ways to support students in unfolding investigations.

What is meant by engaging youth in scientific modeling? - STEM teaching tool #8

A model is a representation of an idea or phenomenon that otherwise may be difficult to understand, depict, or directly observe. Models are integral to the practice of science and are used across many disciplines in a variety of ways. Scientists develop, test, refine, and use models in their research and to communicate their findings. Helping students develop and test models supports their learning and helps them understand important aspects of how science and engineering work.

Beyond a written C-E-R: supporting classroom argumentative talk about investigations – STEM teaching tool #17

Argumentation, a central scientific practice, relies on the coordination of claims, evidence, and reasoning (C-E-R). C-E-R scaffolds can help students compose a written argument for an investigation. However, there are additional important dimensions to argumentation beyond individually written claims. Classroom discussions that require students to make evidence-based claims and collectively build understanding also reflect argumentation. Several types of discussions can be used and can help build a supportive classroom culture.

Why should students learn to plan and carry out investigations in science and engineering? - STEM teaching tool #19

The NRC Framework for K-12 Science Education specifies eight science and engineering practices to be incorporated into science education from kindergarten through twelfth grade. One of these is planning and carrying out investigations. Although many existing instructional models and curricula involve engaging students in planned investigations, this tool will help you think about ways you can promote student agency by having them plan and conduct science investigations.

How can assessments be designed to engage students in the range of science and engineering practices? - STEM teaching tool #26

The new vision for K-12 science education calls for engaging students in three-dimensional science learning. This approach requires us to figure out new ways to assess student learning across these multiple dimensions—including the eight science and engineering practices. But there aren't many assessment tasks that require students to apply their understanding of core ideas using practices. In this tool, we describe how to use "task formats" to guide the development of such items. The formats can also spark ideas for designing classroom instruction.

Integrating science practices into assessment tasks – STEM teaching tool #30

This detailed and flexible tool suggests activity formats to help teachers create three-dimensional assessments based on real-world science and engineering practices. In response to this felt need being expressed among educators, researchers at the Research + Practice Collaboratory have developed a series of "task format" tables, which suggest different possible templates for student activities that integrate real-world science and engineering practices with disciplinary core ideas. This tool also combines two of the Research + Practice Collaboratory's major focuses: formative assessment and engaging learners in STEM practices. This tool offers between four and eight possible task formats for each of the science and engineering practices listed in the Next Generation Science Standards. It can be a great way for educators to brainstorm new activities or to adapt their existing lesson plans to this new three-dimensional vision.

Engaging students in computational design during science investigations – STEM teaching tool #56

Inquiry in science has become increasingly computational over the past several decades. The broad availability of computational devices, sensor networks, visualizations, networking infrastructure, and programming have revolutionized the way science and engineering investigations are carried out. Computational thinking practices enable unique modes of scientific inquiry that allow scientists to create models and simulations to generate data, and to understand and predict complex phenomena. K-12 science classrooms are natural contexts in which students can engage in computational thinking practices during their investigations.

Designing productive uncertainty into investigations to support meaningful engagement in science practices – STEM teaching tool #60

We want students to engage from the earliest ages in science and engineering practices with sincere curiosity and purpose. Science investigations can be viewed as "working through uncertainty." However, 3D instructional materials often try to support engagement in science practices by making them very explicit and scaffolding the process to make it easy to accomplish—arguably, too easy. An alternative approach that emphasizes productive uncertainty focuses on how uncertainty might be strategically built into learning environments so that students establish a need for the practices and experience them as meaningful ways of developing understanding.

Crosscutting concepts

A Framework for K-12 Education identifies seven concepts that bridge disciplinary boundaries. These concepts provide students with an organizational framework for connecting knowledge from the various disciplines into a coherent and scientifically based view of the world.[1] These crosscutting concepts are:

1. Patterns – guide organization and classification, prompt questions about relationships and the factors that influence them.
2. Cause and effect: mechanisms and explanations – a major activity of science is investigating and explaining causal relationships and the mechanisms by which they are mediated. Such mechanisms can then be tested across contexts and used to predict and explain events in new contexts.
3. Scale, proportion, and quantity – in considering phenomena, it is critical to recognize what is relevant at different measures of size, time, and energy and to recognize how changes in scale, proportion, or quantity affect a system's structure or performance.
4. Systems and system models – Defining systems under study provides tools for understanding and testing ideas that are applicable throughout science and engineering.
5. Energy and matter: flows, cycles, and conservation – Tracking fluxes of energy and matter into, out of, and within systems helps one understand the systems' possibilities and limitations.
6. Structure and function – The way in which an object or living thing is shaped and its substructure determine many of its properties and functions.
7. Stability and change – conditions of stability and determinants of rates of change or evolution of a system are critical elements of study.

STEM teaching tools develop briefs to assist STEM teachers with issues that arise in the teaching of STEM. Here are some briefs that address scientific practices. All of these can be found at www.stemteachingtools.org/tools

Prompts for integrating crosscutting concepts into assessment and instruction – STEM teaching tool #41

This set of prompts is intended to help teachers elicit student understanding of crosscutting concepts in the context of investigating phenomena or solving problems. These prompts should be used as part of a multi-component extended task. These prompts were developed using the Framework for K-12 Science Education and Appendix G of the Next Generation Science Standards, along with relevant learning sciences research.

The planning and implementation of instruction in your classroom should allow your students multiple and sustained opportunities to learn disciplinary core ideas through the science and engineering practices, as well as using appropriate crosscutting concepts as lenses to understand the disciplinary core idea and its relationship to other core ideas.

Planning Guidance for Culturally and Linguistically Responsive Instruction

"Equity in science education requires that all students are provided with equitable opportunities to learn science and become engaged in science and engineering practices; with access to quality space, equipment, and teachers to support and motivate that learning and engagement; and adequate time spent on science. In addition, the issue of connecting to students' interests and experiences is particularly important for broadening participation in science[1]"

In order to ensure our students from marginalized cultures and languages view themselves as confident and competent learners and doers of science within and outside of the classroom, educators must intentionally plan ways to counteract the negative or missing images and representations that exist in our curricular resources. The guiding questions below support the design of lessons that validate, affirm, build, and bridge home and school culture for learners of science:

> **Validate/Affirm:** How can you design your classroom to intentionally and purposefully legitimize the home culture and languages of students and reverse the negative stereotypes regarding the science abilities of students of marginalized cultures and languages?
>
> **Build/Bridge:** How can you create connections between the cultural and linguistic behaviors of your students' home culture and language and the culture and language of school science to support students in creating identities as capable scientists that can use science within school and society?

STEM Teaching tools highlight ways of working on specific issues that arise during STEM teaching. Here are some tools that have been created to guide STEM instruction around the concept of culturally and linguistically responsive instruction. All of these can be found at www.stemteachingtools.org/tools

How can we promote equity in science education? - STEM teaching tool #15

Equity should be prioritized as a central component in all educational improvement efforts. All students can and should learn complex science. However, achieving equity and social justice in science education is an ongoing challenge. Students from non-dominant communities often face "opportunity gaps" in their educational experience. Inclusive approaches to science instruction can reposition youth as meaningful participants in science learning and recognize their science-related assets and those of their communities.

Building an equitable learning community in your science classroom – STEM Teaching Tool #54

Equitable classroom communities foster trusting and caring relationships. They make cultural norms explicit in order to reduce the risk of social injuries associated with learning together. Teachers are responsible for disrupting problematic practices and developing science classroom communities that welcome all students into safe, extended science learning opportunities. However, this is tricky work. This tool describes a range of classroom activities designed to cultivate communities that open up opportunities for all students to learn.

How can you advance equity and justice through science teaching? - STEM teaching tool #71

Inequities are built into the systems of science education such that "students of color, students who speak first languages other than English, and students from low-income communities… have had limited access to high-quality, meaningful opportunities to learn science." Intersecting equity projects can guide the teaching and learning of science towards social justice. Science educators who engage in these projects help advance Indigenous self-determination (details) and racial justice by confronting the consequences of legacies of injustice and promoting liberatory approaches to education.

Focusing science and engineering learning on justice-centered phenomena across PK-12 – STEM Teaching tool #67

In the Framework vision for science education, students engage in active investigations to make sense of natural phenomena and analyze and build solutions to problems. Basing these investigations on justice-centered phenomena can be a powerful and rightful way to support science and engineering learning. Justice-centered investigations can open up important opportunities for students to engage in projects that support equity for communities and to see how the application of science and engineering are fundamentally entwined with political and ethical questions, dimensions, and decisions.

Teaching STEM in ways that respect and build upon indigenous peoples' rights – STEM teaching tool #10

Indigenous ways of knowing are sometimes thought to be in opposition to and detrimental to the learning of Western Science or STEM. Consequently, indigenous ways of knowing are rarely engaged to support learning. If STEM learning is to be meaningful and transformative for Indigenous youth, respecting Indigenous peoples' rights and related critical issues, including Indigenous STEM, settler-colonialism, and decolonization, must be understood and explicitly addressed in Indigenous youths' informal and formal STEM learning experiences.

How can formative assessment support culturally responsive argumentation in a classroom community? - STEM teaching tool #25

Argumentation has long been seen as an important practice in science and thus in science education. Formative assessment can be used to help students value the contributions and perspectives of others as they engage in argumentation to make sense of natural phenomena. Educators can use these strategies to help foster argumentation that is culturally responsive, meaning it draws from and respects students' cultural resources, backgrounds, and personal experiences. Culturally responsive formative assessment happens within a community of learners where the teacher has cultivated explicit norms for increasing student-centered discourse, making decisions for their own purposes through democratic processes, and using clear guidelines for maintaining mutual respect.

Engaging English learners in science and engineering practices – STEM teaching tool #27

Routinely engaging all students in the practices of science and engineering is a crucial fixture of the new vision for K-12 science education. The practices can be seen as a barrier to participation for English Learners (ELs), or they can be viewed as an opportunity to provide rich instruction that builds science-related competencies and identities. Certain elements of the practices and related instructional approaches can be beneficial for students learning science while also learning the language of instruction.

How can I promote equitable sensemaking by setting expectations for multiple perspectives? - STEM teaching tool #47

In a phenomena-focused, 3D approach to science learning, students use science practices to consider each other's ideas based on available interpretations and evidence. To promote deep and equitable learning, plan purposefully to ensure that the various perspectives that students bring to making sense of phenomena are solicited, clarified, and considered. It is important to support students as they develop a shared understanding of the different perspectives in the group.