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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

What: 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

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

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.

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.

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

- 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?

- 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

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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.

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 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,

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

   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.

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

Engineering and Technology: Engineering Design
MS-ETS1-1
MS-ETS1-2
MS-ETS1-3
MS-ETS1-4

Students who demonstrate understanding can:

MS-ETS1-1. **Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.**

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
Asking Questions and Defining Problems Asking questions and defining problems in grades 6–8 builds on grades K–5 experiences and progresses to specifying relationships between variables, and clarifying arguments and models. • Define a design problem that can be solved through the development of an object, tool, process or system and includes multiple criteria and constraints, including scientific knowledge that may limit possible solutions.	**ETS1.A: Defining and Delimiting Engineering Problems** • The more precisely a design task's criteria and constraints can be defined, the more likely it is that the designed solution will be successful. Specification of constraints includes consideration of scientific principles and other relevant knowledge that are likely to limit possible solutions.	**Influence of Science, Engineering, and Technology on Society and the Natural World** • All human activity draws on natural resources and has both short and long-term consequences, positive as well as negative, for the health of people and the natural environment. • The uses of technologies and limitations on their use are driven by individual or societal needs, desires, and values; by the findings of scientific research; and by differences in such factors as climate, natural resources, and economic conditions.

Connections to MS-ETS1.A: Defining and Delimiting Engineering Problems include:
Physical Science: MS-PS3-3

Articulation of DCIs across grade-bands:
3-5.ETS1.A ; **3-5.ETS1.C** ; **HS.ETS1.A** ; **HS.ETS1.B**

Common Core State Standards Connections:
ELA/Literacy -

RST.6-8.1 Cite specific textual evidence to support analysis of science and technical texts. (MS-ETS1-1)

WHST.6-8.8 Gather relevant information from multiple print and digital sources, using search terms effectively; assess the credibility and accuracy of each source; and quote or paraphrase the data and conclusions of others while avoiding plagiarism and following a standard format for citation. (MS-ETS1-1)

Mathematics -

MP.2 Reason abstractly and quantitatively. *(MS-ETS1-1)*

7.EE.3 Solve multi-step real-life and mathematical problems posed with positive and negative rational numbers in any form (whole numbers, fractions, and decimals), using tools strategically. Apply properties of operations to calculate with numbers in any form; convert between forms as appropriate; and assess the reasonableness of answers using mental computation and estimation strategies. *(MS-ETS1-1)*

Grade	*NGSS Discipline*
MS	**Engineering and Technology 1.1**
ETS1-1	**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.* • Pollution (air or water)

- Water conservation
- Oil spills
- Air quality
- Endangered species
- Bioengineering scenarios, including artificial limbs
- Sustainable design, including green buildings and hazard-resistant structures

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.

Extreme Biosuits: Link Here

This module's essential challenge focuses on biosuit construction. Biosuits, such as spacesuits and hazmat suits, protect scientists and engineers when they work in extreme environments.

Throughout the module, students design a biosuit that must address biological necessities and assure that its user can survive multiple environments while completing key tasks. As students design and build a model biosuit, they develop an understanding of human response to stimuli and the transfer of thermal energy. Students use the science ideas developed in the module to inform and justify their design decisions. Students build heavily on their understanding of engineering and the engineering design process through their work developing, testing, optimizing, and presenting their design solutions.

DAY 1: What is a Biosuit?

Students are introduced to the design problem to develop biosuits capable of protecting scientists and engineers in extreme environments, while allowing them to do their work comfortably. Download

DAY 2: Where the Scientist or Engineer Works

Students research their assigned environment and career, and create models to show the impact their environment may have on a human body. Download

DAY 3: What If a Scientist or Engineer Does Not Wear a Biosuit?

Students investigate what might happen to their scientist or engineer if he or she does not wear a biosuit in their environment. To do so, students conduct an experiment in which they monitor heart rate, breathing rate, blood pressure, skin response, and eye response to cold water. Download

DAYS 4 & 5: Materials We Can Use to Develop a Biosuit

Students link the ideas of human response to stimuli to thermal energy transfer. Students then select biosuit materials that minimize the transfer of thermal energy. Students make material tradeoffs based on budgetary constraints and design criteria. Download

DAYS 6, 7 & 8: How to Build Our Biosuit Models

Students participate in a *critical friends tuning protocol* to give and receive feedback on their biosuit designs and budget. Students reflect on the peer feedback and then redesign their model to optimize its performance. On Days 7 and 8, students construct their biosuit models and prepare a presentation to show how each feature of their biosuit meets all of the criteria for their task assignment and environmental conditions. Download

DAYS 9 & 10: Biosuit Testing, Presentation, and Reflection

Students present their research, test their biosuit model, and suggest design optimizations based on performance test results. Download

Universal Supports	Targeted Supports
• **Layer 1:** When it is necessary to develop a design solution students will need to define the criteria and the constraints for the specific problem, taking into account the impact on people and the natural environment. With each design solution, the students will also have to have prior understanding of the particular scientific concepts that relate to the problem they are solving.	• **Layer 2:** Some students may need further assistance on determining the actual problem that needs to be solved and coming up with a solution that matches the problem. Some students may need additional assistance with being precise in their design and clarification on the influence of science, engineering, and technology on the natural world.

Common Misconceptions

- A problem only has one true solution.
- -Some problems cannot be solved.
- -A solution can be perfect, with no limitations or drawbacks.
- -Everyone will benefit from the best solution.
- Students may confuse the terms criteria and constraints.
- Students may think there is only one solution to any given problem.

Culturally and Linguistically Responsive Instruction

Guiding Questions and Connections

The teacher could use these questions in science classroom discussions to bring out student's thoughts, ideas and cultures:

Validate-Ask Students: What knowledge and experiences have you had that might help us as a class explain how to design a solution that matches a specific problem?
Ex. Students can share experiences they have had with problem solving and the teacher can help them to determine the criteria and constraints from those problems.

Affirm-Ask Students: What questions do we need to answer to test your ideas about what factors contribute to making a great design?
Ex. Students will be presented with a problem where they design a solution and apply the factors they determined to make a great design.

Build and Bridge-Ask Students: Why does this phenomenon matter to you, to your community or others, and to scientists?
Ex. The teacher can ask how science, engineering, and technology impact their lives?

Students who demonstrate understanding can:

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

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

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

Connections to MS-ETS1.B: Developing Possible Solutions Problems include:
Physical Science: MS-PS1-6, MS-PS3-3, **Life Science:** MS-LS2-5

Articulation of DCIs across grade-bands:
3-5.ETS1.A ; **3-5.ETS1.B** ; **3-5.ETS1.C** ; **HS.ETS1.A** ; **HS.ETS1.B**

Common Core State Standards Connections:

ELA/Literacy -

- **RST.6-8.1** Cite specific textual evidence to support analysis of science and technical texts. *(MS-ETS1-2)*
- **RST.6-8.9** Compare and contrast the information gained from experiments, simulations, video, or multimedia sources with that gained from reading a text on the same topic. (MS-ETS1-2)
- **WHST.6-8.7** Conduct short research projects to answer a question (including a self-generated question), drawing on several sources and generating additional related, focused questions that allow for multiple avenues of exploration. (MS-ETS1-2)
- **WHST.6-8.9** Draw evidence from informational texts to support analysis, reflection, and research. *(MS-ETS1-2)*

Mathematics -

- **MP.2** Reason abstractly and quantitatively. *(MS-ETS1-2)*
- **7.EE.3** Solve multi-step real-life and mathematical problems posed with positive and negative rational numbers in any form (whole numbers, fractions, and decimals), using tools strategically. Apply properties of operations to calculate with numbers in any form; convert between forms as appropriate; and assess the reasonableness of answers using mental computation and estimation strategies. *(MS-ETS1-2)*

Grade	*NGSS Discipline*
MS	**Engineering and Technology 1.2**
ETS1-2	**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.* • Pollution (air or water) • - Water conservation • - Oil spills • - Air quality • - Endangered species • - Bioengineering • - Sustainable design, including green buildings and hazard resilient buildings/structures **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.

Bridge Types: Tensile & Compressive Forces Link Here

Summary

Students explore how tension and compression forces act on three different bridge types. Using sponges, cardboard and string, they create models of beam, arch and suspension bridges and apply forces to understand how they disperse or transfer these loads.

Introduction/Motivation

(Optional: Provide each student with a copy of the Bridge Notes Worksheet to fill-in what they know about bridges before the activity and take notes on during the introduction portion of the activity.)

What impacts do bridges have on our communities and cities? Bridges provide essential links between places, providing us with access to resources, other places and other people. Bridges enable roadways to pass through varying terrain, over waterways and through mountains with minimal deviation, saving time in transport or commute or even connecting areas that would otherwise be inaccessible. Who designs these bridges? Civil engineers do. Think about bridges as a way that engineers help us bring worlds together. (Show a map of Vancouver, BC, Canada, or another city with many bridges.) For example, the jutting features of Vancouver would be difficult to access if it were not for the bridges that tie this region together.

Three basic types of bridges used in transportation are: beam and truss bridges, arch bridges and suspension bridges. To understand how bridges work, we must understand the forces that act on every bridge. Two major forces act on a bridge at any given time: compression and tension. Compression, or compressive force, is a force that acts to compress or shorten the thing it is acting on. Tension, or tensile force, is a force that acts to expand or lengthen the thing it is acting on. As a simple example, think of a spring. If we push both ends of the spring towards each other, we are compressing the spring. Thus, a force of compression is acting on it to shorten the spring. If we pull both ends of the spring away from each other, we are stretching the spring. Thus, a force of tension is acting on it to lengthen the spring. It is the purpose of the bridge design to handle these forces without breaking or failing in some manner.

Beam and Truss Bridges

Beam bridges are the simplest and least expensive type of bridge to build. The most simple beam bridges consist of a horizontal beam that is supported on each end by columns or piers. The weight of the beam and any additional load on the bridge is transferred directly to the piers. However, the beam itself must be able to support its own weight and loads between the piers. When a load pushes down on the beam, the top portion of the beam is pushed together by a compressive force while a tensile force stretches the lower portion. The farther apart the supports or piers, the weaker a beam bridge becomes. For larger beam bridges designed for heavy car and railroad traffic, the beams are substituted by simple trusses, or triangular units, which are more economical than solid beams. Engineers have used many different truss patterns in bridges. Therefore, most beam bridges rarely span more than 200 feet (61m), however, old truss bridges crossing major rivers are often as long as 500-600 feet (152-183m), not including end supports such as piers.

Arch Bridges

Arch bridges are the easiest type of bridge to recognize. They are one of the oldest types of bridges and have extraordinary natural strength. Instead of pushing straight down as beam bridges do, the weight of the arch bridge and any additional load on the bridge is carried outward along the curve of the arch to the supports at each end. These supports are called abutments. Abutments distribute the load from the bridge and keep the ends of the bridge from spreading out. The Romans were masters of the arch bridge. Many of their arch bridges used little or no mortar, or "glue," to hold the stones together. The goal of an arch bridge is to carry all loads in compression, without any tensile loads present. The stones in the structures stay together by the sheer force of their own weight and the compression transferred between them. The size of the arch, or the amount of curvature, has a major effect on the effectiveness of this type of bridge. Sometimes, in very large arch bridges, the arch is often reduced in size or flattened down, which results in significant tensile forces that must be factored into the design. Most modern arch bridges span between 100-1,500 feet (30-457m).

Suspension Bridges
Two categories of suspension bridges are: modern suspension bridges and cable-stayed bridges. Modern suspension bridges are characterized by an M-shaped cable pattern. Cables are strung over two towers and then anchored on both ends. The roadway is suspended from the cables by thinner cables or rods. The roadway's weight and any additional load are transferred to the cables, creating a tension force in the cables. The cables then transfer their force to the towers and anchors. Typical modern suspension bridges span distances from 2,000 to 7,000 feet (610-2,134m). Cable-stayed bridges are characterized by an A-shaped cable pattern. Cables are anchored directly to the towers and eliminate the need for an anchorage system. The same tensile and compressive forces are seen in a cable-stayed bridge as they are in a modern suspension bridge. Typical cable-stayed bridges span distances from 500 to 3,000 feet (152-914m), fast becoming the bridge of choice for medium length spans. Cable-stayed bridges also look cool!

Today, we are going to create simple models of each type of bridge that we just discussed to help us learn more about how the forces of tension and compression act on each one. We are also going to think about the situations when an engineer might decide to use each type of bridge when designing roadways.

Procedure:
Before the Activity: Prepare the following materials for each group:

- For the beam bridge model, use a pen or marker to draw equally-distant parallel lines along the width (not the length) of the sponge (or eraser) (see Figure 1). If using a sponge, dampen it a bit so it is able to flex.
- For the arch bridge model, cut cardboard into strips.
- For the suspension bridge model, cut the string (or small-diameter rope) into three 2-foot (.6-m) lengths and one 4-foot (1.2-m) piece.
- For the cable-stayed bridge model, cut the larger-diameter rope into one piece 5-feet long and another piece 6-feet long.
- Make copies of the Bridge Types & Forces Worksheet, one per student.
- Divide the class into groups of two students each.

With the students”

1. Present to students the basic concepts of each bridge: beam, arch and both suspension bridges as described in the introduction section. Discuss the forces present in each bridge—compression and tension—and the differences in each. Hand out the worksheets for students to complete independently. After students have finished, review their answers to assure their understanding of the behavior of compressive and tensile forces in the different bridge types.

2. Have each team make a simple beam bridge (see Figure 1). Position two stacks of textbooks of approximately equal height (3-4 inches or 8-10 cm) so that the flat sponge (or eraser) can "span" them (make distance between the stacks about 1-2 inches or 2-5 cm). Rest the sponge on the two textbook stacks spanning the distance between them. Using a pen or pencil, place a downward force on the top of the sponge—just enough to cause the sponge to bend but not completely collapse.
    a. What happens to the parallel lines drawn on the top and bottom? (Answer: The lines on the top move closer together. The lines on the bottom move farther apart.)
    b. Where are the compressive forces located? (Answer: The compressive forces are located on the top.)
    c. Where are the tensile forces located? (Answer: The tensile forces are located on the bottom.)
3. Have each group make a simple arch bridge. Direct them to gently bend their cardboard strips so that they have a curved shape. Then, place the cardboard strip on a smooth flat surface (desktop or tile floor; not carpet) so that it resembles an arch. Using a pen or pencil, place a downward force on the top of the center of the arch. What happens to the arch? (Answer: Expect the arch to collapse because its ends move outward.) Next, place two stacks of textbooks ~5-6 inches (13-15 cm) apart. Place the cardboard strip in-between the two stacks with the curved shape resembling an arch bridge. Press down on the center of the arch
    a. Now what happens? (Answer: The arch should not collapse as easily.)
    b. What kind of force do the abutments (as represented by the textbooks) impose on the arch, pushing (compression) or pulling (tension)? (Answer: The abutments push back on the arch since the arch is pushing on the abutments.)
    c. Point out how the stacks of books act as abutments keeping the ends of the arch from spreading apart.
4. Have each group make a simple suspension bridge. First, tie one of the 2-foot (.6-m) long pieces of string (or small-diameter rope) around the middle of one ~1-inch (2.5-cm) thick textbook while it is laying flat on the table. Repeat this step with a second 2-foot long piece around a different textbook. Stand these two textbooks on end with the string at the top. Take the third piece of 2-foot string and tie each end to the string on the tops of the textbooks. Position the textbooks about 18 inches (.5 m) apart. Now, push down on the string that connects the two textbooks together. What happens? (Answer: Notice how the books fall inward relatively easily.)
5. Next, remove the strings from the two textbooks. Take the 4-foot (1.2-m) long piece and place a stack of textbooks on top of one end. Place another stack of textbooks on the other end. Using the same 1-inch (2.5-cm) thick textbooks as before, place them under the string standing on end. Try to position the distance between the two textbooks the same as before, 18 inches (.5m). Now, push down on the string between the two textbooks.
    a. What happens? (Answer: Expect the books to not fall as easily, even with increasing load.)
    b. Is the string (cable) in tension or compression? (Answer: The string is in tension; it can only support a tensile force.)
    c. Are the books (towers) in tension or compression? (Answer: The books are in compression.)
    d. Do the stacks of books (anchors) push or pull on the string (cable)? (Answer: The stacks of books pull on the string because the string is pulling on them.)
    e. Point out how the anchorages (textbook stacks) help to stabilize the bridge.
6. Have each group make a simple cable-stayed bridge. Have students stand up and hold their arms out horizontally to each side. Have them imagine their arms form a bridge and their head is a tower in the middle. In this position, their muscles are holding up their arms. Now, using the rope, have the students become cable-stayed bridges, Tie each end of the 5-foot (1.5-m) piece of rope around each elbow.

Position the middles of the ropes on the tops of their heads. The rope acts as a cable-stay and holds up the elbows. Using the 6-foot (1.8-m) piece, repeat this process tying the ends around their wrists.

   a. Where do you feel a pushing or compression force? (Answer: The ropes are in tension due to the arm weight (the bridge) while their heads are in compression.)
   b. Notice how the load (arm weight) is transferred to the tower (heads).
   c. Step back and notice the pattern made by the strings going over their heads.\

7. Conclude the activity with one of the post-activity assessment activities described in the Assessment section. For example, have each team pick one type of bridge to design. Using their notes and activity worksheets, have them create a drawing of the bridge in an appropriate location. For example, a modern suspension bridge might cross a body of water that is 3,000 ft (914 m) in length.

Universal Supports	Targeted Supports
• **Layer 1:** Students will need to analyze different design solutions and determine a method for choosing the best one. Using the one that best meets the criteria and constraints of the specific problem.	• **Layer 2:** Some students may need further assistance in constructing an argument using valuable and reliable evidence and sources to support their design solution. Some students may need help to understand the criteria and constraints of their problem.

Common Misconceptions

- Choices among design solutions should be made on aesthetic preference rather than on meeting the criteria/constraints of a problem.
- The wants or needs of a local community will not change over time.
- Students may struggle to find which tool to use for evaluation.
- Students may also struggle to identify the base problem and then create an appropriate solution.

Culturally and Linguistically Responsive Instruction

Guiding Questions and Connections

The teacher could use these questions in science classroom discussions to bring out student’s thoughts, ideas and cultures:

Validate-Ask Students: What knowledge and experiences have you had that might help us as a class explain how to pick the best design solution?
Ex. Students can compare design solutions within the class and help each other to improve on each of their designs.

Affirm-Ask Students: What questions do we need to answer to test your ideas about how to determine the constraints of the problem?
Ex. Students will work together to peer-edit the constraints of their problems to create a more comprehensive design.

	Build and Bridge-Ask Students: Why does this phenomenon matter to you, to your community or others, and to scientists? Ex. The teacher can ask how science, engineering, and technology impact their lives?

Students who demonstrate understanding can:

MS-ETS1-3. **Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.**

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
Analyzing and Interpreting Data Analyzing data in 6–8 builds on K–5 experiences and progresses to extending quantitative analysis to investigations, distinguishing between correlation and causation, and basic statistical techniques of data and error analysis. • Analyze and interpret data to determine similarities and differences in findings.	**ETS1.B: Developing Possible Solutions** • There are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of a problem. • Sometimes parts of different solutions can be combined to create a solution that is better than any of its predecessors. **ETS1.C: Optimizing the Design Solution** • Although one design may not perform the best across all tests, identifying the characteristics of the design that performed the best in each test can provide useful information for the redesign process—that is, some of those characteristics may be incorporated into the new design.	

Connections to MS-ETS1.B: Developing Possible Solutions Problems include:
Physical Science: MS-PS1-6, MS-PS3-3, **Life Science:** MS-LS2-5
Connections to MS-ETS1.C: Optimizing the Design Solution include:
Physical Science: MS-PS1-6

Articulation of DCIs across grade-bands:
3-5.ETS1.A ; **3-5.ETS1.B** ; **3-5.ETS1.C** ; **HS.ETS1.B** ; **HS.ETS1.C**

Common Core State Standards Connections:
ELA/Literacy -

RST.6-8.1 Cite specific textual evidence to support analysis of science and technical texts. *(MS-ETS1-3)*
RST.6-8.7 Integrate quantitative or technical information expressed in words in a text with a version of that information expressed visually (e.g., in a flowchart, diagram, model, graph, or table). *(MS-ETS1-3)*
RST.6-8.9 Compare and contrast the information gained from experiments, simulations, video, or multimedia sources with that gained from reading a text on the same topic. (MS-ETS1-3)

Mathematics -

MP.2 Reason abstractly and quantitatively. *(MS-ETS1-3)*
7.EE.3 Solve multi-step real-life and mathematical problems posed with positive and negative rational numbers in any form (whole numbers, fractions, and decimals), using tools strategically. Apply properties of operations to calculate with numbers in any form; convert between forms as appropriate; and assess the reasonableness of answers using mental computation and estimation strategies. *(MS-ETS1-3)*

Grade	*NGSS Discipline*
MS	**Engineering and Technology 1.3**
ETS1-3	**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.* • Pollution (air or water) • - Water conservation • - Oil spills • - Air quality • - Endangered species • - Bioengineering scenarios • - Sustainable design, including green buildings and hazard resilient buildings/structures

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.

One of your teachers has a problem. You've noticed that anytime their coffee gets cold (below 130 degrees fahrenheit) during the first period, they stop drinking it and become very cranky. You're tasked to design something that can warm up your teacher's coffee using chemical reactions before it get too cold! Whatever you build needs to be safe enough to work inside the classroom and it needs to fit on the teacher's desk.

1. Draw a model of a device that uses a chemical reaction to keep your teacher's coffee hot.

Leave a space for student response.

2. What would be the best way to test how well a solution to this problem works?

Universal Supports

- **Layer 1:** Students will need to analyze different design solutions to see what best fits the criteria and constraints of the problem. Students will then work together to decide what factors they can combine and eliminate in their solution to ensure the best product.

Targeted Supports

- **Layer 2:** Some students may need further assistance on analyzing, interpreting data, and identifying strengths and weaknesses in the design.

Common Misconceptions

- Students may be hesitant or unwilling to change or alter their designs.
- A failed model provides no value to the design process.
- Failure points in a design solution cannot be fixed via ad hoc amendments.
- Failure points found via simulations of prototype functioning do not represent failure points of the actual prototype
- -A problem only has one true solution.
- -A problem cannot be solved.
- -A solution can be perfect, with no limitations or drawbacks.
- -Everyone will benefit from the best solution.

Culturally and Linguistically Responsive Instruction

Guiding Questions and Connections

The teacher could use these questions in science classroom discussions to bring out student's thoughts, ideas and cultures:

Validate-Ask Students: What knowledge and experiences have you had that might help us as a class explain why certain solutions work and others do not?

	Ex. Students can share experiences of when they created something that worked and something that did not and work to identify what factors made it successful or not. **Affirm-**Ask Students: What questions do we need to answer to test your ideas about what factors influence the outcome of a design solution and how to ensure the solution is the best it can be? Ex. Students will add to their prior knowledge and their generated list of factors to determine how to combine the best parts of each solution into one super solution. **Build and Bridge-**Ask Students: Why does this phenomenon matter to you, to your community or others, and to scientists? Ex. The teacher can ask how science, engineering, and technology impact their lives?

Students who demonstrate understanding can:

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

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

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

Connections to MS-ETS1.B: Developing Possible Solutions Problems include:
Physical Science: MS-PS1-6, MS-PS3-3, **Life Science:** MS-LS2-5
Connections to MS-ETS1.C: Optimizing the Design Solution include:
Physical Science: MS-PS1-6

Articulation of DCIs across grade-bands:
3-5.ETS1.B ; **3-5.ETS1.C** ; **HS.ETS1.B** ; **HS.ETS1.C**

Common Core State Standards Connections:
ELA/Literacy -
SL.8.5 Integrate multimedia and visual displays into presentations to clarify information, strengthen claims and evidence, and add interest. *(MS-ETS1-4)*
Mathematics -
MP.2 Reason abstractly and quantitatively. *(MS-ETS1-4)*
7.SP Develop a probability model and use it to find probabilities of events. Compare probabilities from a model to observed frequencies; if the agreement is not good, explain possible sources of the discrepancy. *(MS-ETS1-4)*

Grade	*NGSS Discipline*
MS	**Engineering and Technology 1.4**
ETS1-4	**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.* ● Pollution ● - Resource conservation ● - Air and water quality ● - Environmental accidents ● - Endangered species ● - Habitat and/or biodiversity loss due to development ● - Bioengineering scenarios ● - Sustainable design ● - Hazard-resistant design **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.

Extreme Biosuits: Link Here
This module's essential challenge focuses on biosuit construction. Biosuits, such as spacesuits and hazmat suits, protect scientists and engineers when they work in extreme environments.

Throughout the module, students design a biosuit that must address biological necessities and assure that its user can survive multiple environments while completing key tasks. As students design and build a model biosuit, they develop an understanding of human response to stimuli and the transfer of thermal energy. Students use the science ideas developed in the module to inform and justify their design decisions. Students build heavily on their understanding of engineering and the engineering design process through their work developing, testing, optimizing, and presenting their design solutions.

DAY 1: What is a Biosuit?

Students are introduced to the design problem to develop biosuits capable of protecting scientists and engineers in extreme environments, while allowing them to do their work comfortably. Download

DAY 2: Where the Scientist or Engineer Works

Students research their assigned environment and career, and create models to show the impact their environment may have on a human body. Download

DAY 3: What If a Scientist or Engineer Does Not Wear a Biosuit?

Students investigate what might happen to their scientist or engineer if he or she does not wear a biosuit in their environment. To do so, students conduct an experiment in which they monitor heart rate, breathing rate, blood pressure, skin response, and eye response to cold water. Download

DAYS 4 & 5: Materials We Can Use to Develop a Biosuit

Students link the ideas of human response to stimuli to thermal energy transfer. Students then select biosuit materials that minimize the transfer of thermal energy. Students make material tradeoffs based on budgetary constraints and design criteria. Download

DAYS 6, 7 & 8: How to Build Our Biosuit Models

Students participate in a *critical friends tuning protocol* to give and receive feedback on their biosuit designs and budget. Students reflect on the peer feedback and then redesign their model to optimize its performance. On Days 7 and 8, students construct their biosuit models and prepare a presentation to show how each feature of their biosuit meets all of the criteria for their task assignment and environmental conditions. Download

DAYS 9 & 10: Biosuit Testing, Presentation, and Reflection

Students present their research, test their biosuit model, and suggest design optimizations based on performance test results. Download

Universal Supports	Targeted Supports
• **Layer 1:** Students will need to test their design solutions and modify them as needed. They will continue this process until their design meets all criteria determined by testing. Students will also have to design and conduct investigations to test their solutions.	• **Layer 2:** Some students may need further assistance on developing models of their design solution and determining ways to test those models.

Common Misconceptions

- The design process only needs to occur one time.
- The design process is linear, it only goes step by step.
- Once you modify a solution, you are done.

Culturally and Linguistically Responsive Instruction

Guiding Questions and Connections

The teacher could use these questions in science classroom discussions to bring out student's thoughts, ideas and cultures:

Validate-Ask Students: What knowledge and experiences have you had that might help us as a class explain what's happening in the Engineering Process?
Ex. Students can discuss times they have engineered something and express what process they used.
Affirm-Ask Students: What questions do we need to answer to test your ideas about what testing and modification can be used on a specific design solution?
Ex. Students will help each other to create and test a complete design process.
Build and Bridge-Ask Students: Why does this phenomenon matter to you, to your community or others, and to scientists?
Ex. The teacher can ask how science, engineering, and technology impact their lives?

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.