Table of Contents

Introduction

Since the release of the first draft of the AzSS, we have known that we would need to provide support in promoting the standards and helping science educators become familiar with and learn to navigate this exciting but complex document. Along the way MPS learned that even the simplest of resources, such as a one-page cheat sheet, can be extremely useful. Many of those tools are collected in this document, including:

- An "AzSS and Framework Snapshot" that gives a quick look at the practices, Crosscutting Concepts, Core Ideas, and Using Science of the AzSS as described in *A Framework for K-12 Science Education*.
- An "Inside the MPS Curricular Guide" graphic that explains all of the individual sections that appear on a sequence in the curricular guide.

There are also tables that describe various parts of the standard. For example, the standards describe what every student should be able to know and be able to do by the end of a particular grade or grade span. The expectations are outlined in the curricular documents and vertical progression documents:

- Standards
- Core Ideas
- Science and Engineering Practices
- Crosscutting Concepts
- Connections to the AzSS Using Science

While summative assessments (including district and state exams) focus on a particular combination of the Core Ideas, Science and Engineering Practices, Crosscutting Concepts, and Using Science, curriculum developers and classroom teachers have the freedom to mix and match these components in a wide variety of ways. It has been commonly stated from the standards department at the Arizona Department of Education that to master any standard, students will need to engage in multiple practices in a well-thought-out sequence of learning experiences. Please feel free to use this document in planning for instruction.

This document last updated October of 2020.

Acknowledgments

The development of the Arizona Science Standards involved the work and contributions over 100 educators and field experts across the state. The development of vertical progressions and other resources have been a combined effort of many national and state leaders who believe in rigorous standards that center around scientific literacy. MPS would like to thank any individual that has worked to make these standards accessible to Arizona students.

CHAPTER 1: BASICS OF THE AzSS

The Science and Engineering Practices

The Science and Engineering Practices describe both the behaviors that scientists engage in as they investigate and build models and theories about the natural world, and the key set of engineering practices that engineers use as they design and build models and systems. The National Research Council uses the term "practices" instead of a term like "skills" to emphasize that engaging in scientific investigation requires not only skill, but also knowledge specific to each practice. Part of the NRC's intent is to better explain and extend what is meant by "inquiry" in science and the range of cognitive, social, and physical practices that it requires. Although engineering design is similar to scientific inquiry, there are significant differences. For example, scientific inquiry involves the formulation of a question that can be answered through investigation, while engineering design involves the formulation of a problem that can be solved through design. Strengthening the engineering aspects of the Arizona Science Standards will clarify for students the relevance of science, technology, engineering, and mathematics (the four STEM fields) to everyday life.

Asking Questions and Defining Problems [Link]

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

Developing and Using Models [Link]

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

Planning and Carrying Out Investigations [Link]

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

Analyzing and Interpreting Data [Link]

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

Using Mathematics and Computational Thinking [Link]

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

Constructing Explanations and Designing Solutions [Link]

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

Engaging in Argument from Evidence [Link]

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

Obtaining, Evaluating, and Communicating Information [Link]

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

https://ngss.nsta.org/practicesfull.aspx

The Crosscutting Concepts

Crosscutting Concepts have application across all domains of science. As such, they are a way of linking the different domains of science. They include patterns; cause and effect; scale, proportion, and quantity; systems and system models; energy and matter; structure and function; and stability and change. The *Framework* emphasizes that these concepts need to be made explicit for students because they provide an organizational schema for interrelating knowledge from various science fields into a coherent and scientifically based view of the world.

1. Patterns [Link]

Observed patterns in nature guide organization and classification and prompt questions about relationships and their underlying causes.

2. Cause and Effect [Link]

Events have causes, sometimes simple, sometimes multifaceted. Deciphering causal relationships, and the mechanisms by which they are mediated, is a major activity of science and engineering.

3. Scale, Proportion, and Quantity [Link]

In considering phenomena, it is critical to recognize what is relevant at different size, time, and energy scales, and to recognize proportional relationships between different quantities as scales change.

4. Systems and System Models [Link]

A system is an organized group of related objects or components; models can be used for understanding and predicting the behavior of systems.

5. Energy and Matter [Link]

Tracking energy and matter flows into, out of, and within systems helps one understand their system's behavior.

6. Structure and Function [Link]

The way an object is shaped or structured determines many of its properties and functions.

7. Stability and Change [Link]

For both designed and natural systems, conditions that affect stability and factors that control rates of change are critical elements to consider and understand.

https://ngss.nsta.org/CrosscuttingConceptsFull.aspx

The Core Ideas

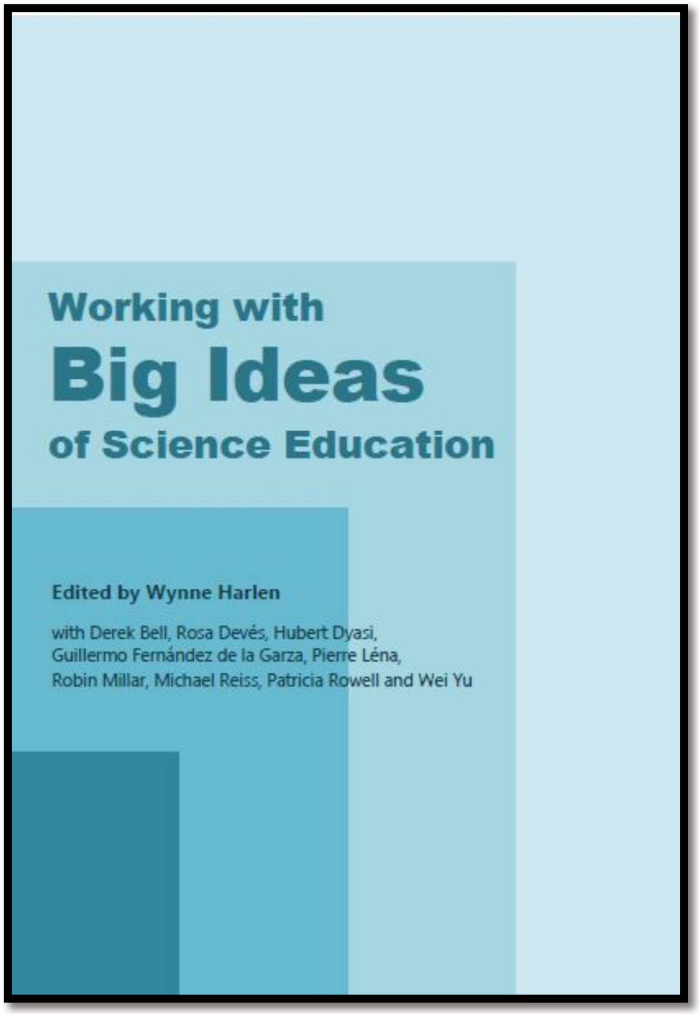
The Core Ideas have the power to focus K–12 science curriculum, instruction, and assessments on the most important aspects of science. To be considered core, the ideas should meet at least two of the following criteria and ideally all four:

- Have broad importance across multiple sciences or engineering disciplines or be a key organizing concept of a single discipline;
- Provide a key tool for understanding or investigating more complex ideas and solving problems;
- Relate to the interests and life experiences of students or be connected to societal or personal concerns that require scientific or technological knowledge;
- Be teachable and learnable over multiple grades at increasing levels of depth and sophistication.

Core Ideas are grouped in three domains: the physical sciences; the life sciences; and the earth and space sciences.

Core Ideas for Knowing Science	**Core Ideas for Using Science**
Physical Science **P1**: All matter in the Universe is made of very small particles. **P2:** Objects can affect other objects at a distance. **P3:** Changing the movement of an object requires a net force to be acting on it. **P4:** The total amount of energy in a closed system is always the same but can be transferred from one energy store to another during an event. **Earth and Space Science** **E1:** The composition of the Earth and its atmosphere and the natural and human processes occurring within them shape the Earth's surface and its climate. **E2:** The Earth and our solar system are a very small part of one of many galaxies within the Universe. **Life Science** **L1:** Organisms are organized on a cellular basis and have a finite life span. **L2:** Organisms require a supply of energy and materials for which they often depend on, or compete with, other organisms. **L3:** Genetic information is passed down from one generation of organisms to another. **L4:** The unity and diversity of organisms, living and extinct, is the result of evolution. ***Adapted from *Working with Big Ideas in Science Education***[2]	**U1:** Scientists explain phenomena using evidence obtained from observations and or scientific investigations. Evidence may lead to developing models and or theories to make sense of phenomena. As new evidence is discovered, models and theories can be revised. **U2:** The knowledge produced by science is used in engineering and technologies to solve problems and/or create products. **U3:** Applications of science often have both positive and negative ethical, social, economic, and/or political implications.

Free download of *Working with Big Ideas of Science Education*



Working with
Big Ideas
of Science Education

Edited by Wynne Harlen

with Derek Bell, Rosa Devés, Hubert Dyasi,
Guillermo Fernández de la Garza, Pierre Léna,
Robin Millar, Michael Reiss, Patricia Rowell and Wei Yu

Reference Tables: Three Dimensions of the Arizona Science Standards (AzSS)

Science and Engineering Practices (SEPs)

Asking Questions and Defining Problems

Science begins with a question about a phenomenon, and seeks to develop theories that can provide explanatory answers to such questions.

Engineering begins with a problem, need, or desire that suggests an engineering problem that needs to be solved. Engineers ask questions to define the engineering problem, determine criteria for a successful solution, and identify constraints.

Developing and Using Models

Science often involves the construction and use of a wide variety of models and simulations to help develop explanations about natural phenomena. Models make it possible to go beyond observables and imagine a world not yet seen. Models enable predictions of the form “if . . .then . . . therefore” to be made in order to test hypothetical explanations.

Engineering makes use of models and simulations to analyze existing systems so as to see where flaws might occur or to test possible solutions to a new problem.

Planning and Carrying Out Investigations

Scientific **investigation and the engineering design process** may be conducted in the field or the laboratory. Planning and carrying out a systematic investigation, which requires the identification of what is to be recorded and, if applicable, what are to be treated as the dependent and independent variables (control of variables).

Observations and data collected from such work are used to test existing theories and explanations or to revise and develop new ones.

Analyzing and Interpreting Data

Scientific **investigations** produce data that must be analyzed in order to derive meaning. Because data usually do not speak for themselves, scientists use a range of tools to identify the significant features and patterns in the data. Sources of error are identified and the degree of certainty calculated.

Engineers analyze data collected in the tests of their designs and investigations; this allows them to compare different solutions and determine how well each one meets specific design criteria—that is, which design best solves the problem within the given constraints.

Using Mathematics and Computational Thinking

In **science and engineering,** mathematics and computation are fundamental tools for representing physical variables and their relationships. Mathematical and computational approaches enable predictions of the behavior of physical systems, along with the testing of such predictions. Moreover, statistical techniques are invaluable for assessing the significance of patterns or correlations. Mathematical and computational representations of established relationships and principles are an integral part of engineering design.

Constructing Explanations and Designing Solutions

The goal of science is the construction of theories that can provide explanatory accounts of features of the world. Scientific explanations are explicit applications of theory to a specific situation or phenomenon, perhaps with the intermediary of a theory-based model for the system under study.

Engineering design, a systematic process for solving engineering problems, is based on scientific knowledge and models of the material world. Each proposed solution results from a process of balancing competing criteria of desired functions, technological feasibility, cost, safety, esthetics, and compliance with requirements.

Engaging in Argument from Evidence

In **science,** reasoning and argument are essential for identifying the strengths and weaknesses of a line of reasoning and for finding the best explanation for a natural phenomenon. Scientists and engineers use argumentation to listen to, compare and evaluate competing ideas and method based on merits.

In **engineering,** reasoning and argument are essential for finding the best possible solution to a problem. Engineers collaborate with their peers throughout the design process, with a critical stage being the selection of the most promising solution among a field of competing ideas.

Obtaining, Evaluating, and Communicating Information

Science cannot advance if scientists are unable to communicate their findings clearly and persuasively or to learn about the findings of others. Science requires the ability to derive meaning from scientific texts to evaluate the scientific validity of the information thus acquired, and to integrate that information.

Engineers need to be able to express their ideas, orally and in writing, with the use of tables, graphs, drawings, or models and by engaging in extended discussions with peers.

Crosscutting Concepts (CCCs)

Patterns. Observed patterns of forms and events guide organization and classification, and they prompt questions about relationships and the factors that influence them.

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

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.

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

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.

Structure and function. The way in which an object or living thing is shaped and its substructure determine many of its properties and functions

Stability and change. For natural and built systems alike, conditions of stability and determinants of rates of change or evolution of a system are critical elements of study.

Core Ideas for Knowing Science

Physical Science

P1: All matter in the Universe is made of very small particles.

P2: Objects can affect other objects at a distance.

P3: Changing the movement of an object requires a net force to be acting on it.

P4: The total amount of energy in a closed system is always the same but can be transferred from one energy store to another during an event.

Earth and Space Science

E1: The composition of the Earth and its atmosphere and the natural and human processes occurring within them shape the Earth's surface and its climate.

E2: The Earth and our solar system are a very small part of one of many galaxies within the Universe.

Life Science

L1: Organisms are organized on a cellular basis and have a finite life span.

L2: Organisms require a supply of energy and materials for which they often depend on, or compete with, other organisms.

L3: Genetic information is passed down from one generation of organisms to another.

L4: The unity and diversity of organisms, living and extinct, is the result of evolution.

Core Ideas for Using Science

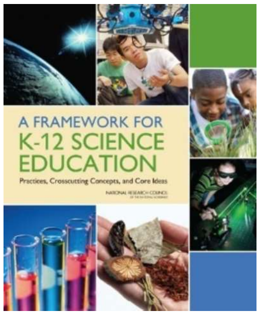
U1: Scientists explain phenomena using evidence obtained from observations and or scientific investigations. Evidence may lead to developing models and or theories to make sense of phenomena. As new evidence is discovered, models and theories can be revised.

U2: The knowledge produced by science is used in engineering and technologies to solve problems and/or create products.

U3: Applications of science often have both positive and negative ethical, social, economic, and/or political implications.

**Adapted from Working with Big Ideas in Science Education*[2]

Excerpts from A Framework for K-12 Science Education, Chapter 3


A FRAMEWORK FOR K-12 SCIENCE EDUCATION

Dimension 1: Scientific and Engineering Practices

From its inception, one of the principal goals of science education has been to cultivate students' scientific habits of mind, develop their capability to engage in scientific inquiry, and teach them how to reason in a scientific context [1, 2]. There has always been a tension, however, between the emphasis that should be placed on developing knowledge of the content of science and the emphasis placed on scientific practices. A narrow focus on content alone has the unfortunate consequence of leaving students with naive conceptions of the nature of scientific inquiry [3] and the impression that science is simply a body of isolated facts [4]. This chapter stresses the importance of developing students' knowledge of how science and engineering achieve their ends while also strengthening their competency with related practices. As previously noted, we use the term "practices," instead of a term such as "skills," to stress that engaging in scientific inquiry requires coordination both of knowledge and skill simultaneously. In the chapter's three major sections, we first articulate why the learning of Science and Engineering Practices is important for K-12 students and why these practices should reflect those of professional scientists and engineers. Second, we describe in detail eight practices we consider essential for learning science and engineering in grades K-12 (see Box 3-1). Finally, we conclude that acquiring skills in these practices supports a better understanding of how scientific knowledge is produced and how engineering solutions are developed. Such understanding will help students become more critical consumers of scientific information.

WHY PRACTICES?

Engaging in the practices of science helps students understand how scientific knowledge develops; such direct involvement gives them an appreciation of the wide range of approaches that are used to investigate, model, and explain the world. Engaging in the practices of engineering likewise helps students understand the work of engineers, as well as the links between engineering and science. Participation in these practices also helps students form an understanding of the Crosscutting Concepts and disciplinary ideas of science and engineering; moreover, it makes students' knowledge more meaningful and embeds it more deeply into their worldview. The actual doing of science or engineering can also pique students' curiosity, capture their interest, and motivate their continued study; the insights thus gained help them recognize that the work of scientists and engineers is a creative endeavor [5, 6]—one that has deeply affected the world they live in. Students may then recognize that science and engineering can contribute to meeting many of the major challenges that confront society today, such as generating sufficient energy, preventing and treating disease, maintaining supplies of fresh water and food, and addressing climate change. Any education that focuses predominantly on the detailed products of scientific labor—the facts of science—without developing an understanding of how those facts were established or that ignores the many important applications of science in the world misrepresents science and marginalizes the importance of engineering.

Practice 1: Asking Questions and Defining Problems

Questions are the engine that drive science and engineering. Science asks

- What exists and what happens?
- Why does it happen?
- How does one know? Engineering asks

- What can be done to address a particular human need or want? • How can the need be better specified?
- What tools and technologies are available, or could be developed, for addressing this need? Both science and engineering ask
- How does one communicate about phenomena, evidence, explanations, and design solutions?

Asking questions is essential to developing scientific habits of mind. Even for individuals who do not become scientists or engineers, the ability to ask well-defined questions is an important component of science literacy, helping to make them critical consumers of scientific knowledge. Scientific questions arise in a variety of ways. They can be driven by curiosity about the world (e.g., Why is the sky blue?). They can be inspired by a model's or theory's predictions or by attempts to extend or refine a model or theory (e.g., How does the particle model of matter explain the incompressibility of liquids?). Or they can result from the need to provide better solutions to a problem. For example, the question of why it is impossible to siphon water above a height of 32 feet led Evangelista Torricelli (17th-century inventor of the barometer) to his discoveries about the atmosphere and the identification of a vacuum. Questions are also important in engineering. Engineers must be able to ask probing questions in order to define an engineering problem. For example, they may ask: What is the need or desire that underlies the problem? What are the criteria (specifications) for a successful solution? What are the constraints? Other questions arise when generating possible solutions: Will this solution meet the design criteria? Can two or more ideas be combined to produce a better solution?

What are the possible trade-offs? And more questions arise when testing solutions: Which ideas should be tested? What evidence is needed to show which idea is optimal under the given constraints? The experience of learning science and engineering should therefore develop students' ability to ask—and indeed, encourage them to ask—well-formulated questions that can be investigated empirically. Students also need to recognize the distinction between questions that can be answered empirically and those that are answerable only in other domains of knowledge or human experience.

GOALS: By grade 12, students should be able to

- Ask questions about the natural and human-built worlds—for example: Why are there seasons? What do bees do? Why did that structure collapse? How is electric power generated?
- Distinguish a scientific question (e.g., Why do helium balloons rise?) from a nonscientific question (Which of these colored balloons is the prettiest?).
- Formulate and refine questions that can be answered empirically in a science classroom and use them to design an inquiry or construct a pragmatic solution.
- Ask probing questions that seek to identify the premises of an argument, request further elaboration, refine a research question or engineering problem, or challenge the interpretation of a data set—for example: How do you know? What evidence supports that argument?
- Note features, patterns, or contradictions in observations and ask questions about them.
- For engineering, ask questions about the need or desire to be met in order to define constraints and specifications for a solution.

PROGRESSION

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

Practice 2: Developing and Using Models

Scientists construct mental and conceptual models of phenomena. Mental models are internal, personal, idiosyncratic, incomplete, unstable, and essentially functional. They serve the purpose of being a tool for thinking with, making predictions, and making sense of experience. Conceptual models, the focus of this section, are, in contrast, explicit representations that are in some ways analogous to the phenomena they represent. Conceptual models allow scientists and engineers to better visualize and understand a phenomenon under investigation or develop a possible solution to a design problem. Used in science and engineering as either structural, functional, or behavioral analogs, albeit simplified, conceptual models include diagrams, physical replicas, mathematical representations, analogies, and computer simulations. Although they do not correspond exactly to the more complicated entity being modeled, they do bring certain features into focus while minimizing or obscuring others. Because all models contain approximations and assumptions that limit the range of validity of their application and the precision of their predictive power, it is important to recognize their limitations. Conceptual models are in some senses the external articulation of the mental models that scientists hold and are strongly interrelated with mental models. Building an understanding of models and their role in science helps students to construct and revise mental models of phenomena. Better mental models, in turn, lead to a deeper understanding of science and enhanced scientific reasoning. Scientists use models (from here on, for the sake of simplicity, we use the term “models” to refer to conceptual models rather than mental models) to represent their current understanding of a system (or parts of a system) under study, to aid in the development of questions and explanations, and to communicate ideas to others [13]. Some of the models used by scientists are mathematical; for example, the ideal gas law is an equation derived from the model of a gas as a set of point masses engaged in perfectly elastic collisions with each other and the walls of the container—which is a simplified model based on the atomic theory of matter. For more complex systems, mathematical representations of physical systems are used to create computer simulations, which enable scientists to predict the behavior of otherwise intractable systems—for example, the effects of increasing atmospheric levels of carbon dioxide on agriculture in different regions of the world. Models can be evaluated and refined through an iterative cycle of comparing their predictions with the real world and then adjusting them, thereby potentially yielding insights into the phenomenon being modeled. Engineering makes use of models to analyze existing systems; this allows engineers to see where or under what conditions flaws might develop or to test possible solutions to a new problem. Engineers also use models to visualize a design and take it to a higher level of refinement, to communicate a design’s features to others, and as prototypes for testing design performance. Models, particularly modern computer simulations that encode relevant physical laws and properties of materials, can be especially helpful both in realizing and testing designs for structures, such as buildings, bridges, or aircraft, that are expensive to construct and that must survive extreme conditions that occur only on rare occasions. Other types of engineering problems also benefit from use of specialized computer-based simulations in their design and testing phases. But as in science, engineers who use models must be aware of their intrinsic limitations and test them against known situations to ensure that they are reliable.

GOALS: By grade 12, students should be able to

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

Practice 3: Planning and Carrying Out Investigations

Scientists and engineers investigate and observe the world with essentially two goals: (1) to systematically describe the world and (2) to develop and test theories and explanations of how the world works. In the first, careful observation and description often lead to identification of features that need to be explained or questions that need to be explored. The second goal requires investigations to test explanatory models of the world and their predictions and whether the inferences suggested by these models are supported by data. Planning and designing such investigations require the ability to design experimental or observational inquiries that are appropriate to answering the question being asked or testing a hypothesis that has been formed. This process begins by identifying the relevant variables and considering how they might be observed, measured, and controlled (constrained by the experimental design to take particular values). Planning for controls is an important part of the design of an investigation. In laboratory experiments, it is critical to decide which variables are to be treated as results or outputs and thus left to vary at will and which are to be treated as input conditions and hence controlled. In many cases, particularly in the case of field observations, such planning involves deciding what can be controlled and how to collect different samples of data under different conditions, even though not all conditions are under the direct control of the investigator. Decisions must also be made about what measurements should be taken, the level of accuracy required, and the kinds of instrumentation best suited to making such measurements. As in other forms of inquiry, the key issue is one of precision—the goal is to measure the variable as accurately as possible and reduce sources of error. The investigator must therefore decide what constitutes a sufficient level of precision and what techniques can be used to reduce both random and systematic error.

GOALS: By grade 12, students should be able to

- Formulate a question that can be investigated within the scope of the classroom, school laboratory, or field with available resources and, when appropriate, frame a hypothesis (that is, a possible explanation that predicts a particular and stable outcome) based on a model or theory.

- Decide what data are to be gathered, what tools are needed to do the gathering, and how measurements will be recorded.
- Decide how much data are needed to produce reliable measurements and consider any limitations on the precision of the data.
- Plan experimental or field-research procedures, identifying relevant independent and dependent variables and, when appropriate, the need for controls.
- Consider possible confounding variables or effects and ensure that the investigation's design has controlled for them.

PROGRESSION

Students need opportunities to design investigations so that they can learn the importance of such decisions as what to measure, what to keep constant, and how to select or construct data collection instruments that are appropriate to the needs of an inquiry. They also need experiences that help them recognize that the laboratory is not the sole domain for legitimate scientific inquiry and that, for many scientists (e.g., earth scientists, ethologists, ecologists), the "laboratory" is the natural world where experiments are conducted and data are collected in the field. In the elementary years, students' experiences should be structured to help them learn to define the features to be investigated, such as patterns that suggest causal relationships (e.g., What features of a ramp affect the speed of a given ball as it leaves the ramp?). The plan of the investigation, what trials to make and how to record information about them, then needs to be refined iteratively as students recognize from their experiences the limitations of their original plan. These investigations can be enriched and extended by linking them to engineering design projects—for example, how can students apply what they have learned about ramps to design a track that makes a ball travel a given distance, go around a loop, or stop on an uphill slope. From the earliest grades, students should have opportunities to carry out careful and systematic investigations, with appropriately supported prior experiences that develop their ability to observe and measure and to record data using appropriate tools and instruments. Students should have opportunities to plan and carry out several different kinds of investigations during their K-12 years. At all levels, they should engage in investigations that range from those structured by the teacher—in order to expose an issue or question that they would be unlikely to explore on their own (e.g., measuring specific properties of materials)—to those that emerge from students' own questions. As they become more sophisticated, students also should have opportunities not only to identify questions to be researched but also to decide what data are to be gathered, what variables should be controlled, what tools or instruments are needed to gather and record data in an appropriate format, and eventually to consider how to incorporate measurement error in analyzing data. Older students should be asked to develop a hypothesis that predicts a particular and stable outcome and to explain their reasoning and justify their choice. By high school, any hypothesis should be based on a well-developed model or theory. In addition, students should be able to recognize that it is not always possible to control variables and that other methods can be used in such cases—for example, looking for correlations (with the understanding that correlations do not necessarily imply causality).

Practice 4: Analyzing and Interpreting Data

Once collected, data must be presented in a form that can reveal any patterns and relationships and that allows results to be communicated to others. Because raw data as such have little meaning, a major practice of scientists is to organize and interpret data through tabulating, graphing, or statistical analysis. Such analysis can bring out the meaning of data—and their relevance—so that they may be used as evidence. Engineers, too, make decisions based on evidence that a given design will work; they rarely rely on trial and error. Engineers often analyze a design by creating a model or prototype and collecting extensive data on how it performs, including under extreme conditions. Analysis of this kind of data not only informs design decisions and enables the prediction or assessment of performance but also helps define or clarify problems, determine economic feasibility, evaluate alternatives, and investigate failures. Spreadsheets and databases provide useful ways of organizing data, especially large data sets. The identification of relationships in data is aided by a range of tools, including tables, graphs, and mathematics. Tables permit major features of a large body of data to be summarized in a conveniently accessible form, graphs offer a means of visually summarizing data, and mathematics is essential for expressing relationships between different variables in the data set (see Practice 5 for further discussion of mathematics). Modern computer-based visualization tools often allow data to be displayed in varied forms and thus for learners to engage interactively with data in their analyses. In addition, standard statistical techniques can help to reduce the effect of error in relating one variable to another. Students need opportunities to analyze large data sets and identify correlations. Increasingly, such data sets—involving temperature, pollution levels, and other scientific measurements—are available on the Internet. Moreover, information technology enables the capture of data beyond the classroom at all hours of the day. Such data sets extend the range of students' experiences and help to illuminate this important practice of analyzing and interpreting data.

GOALS: By grade 12, students should be able to

- Analyze data systematically, either to look for salient patterns or to test whether data are consistent with an initial hypothesis.
- Recognize when data are in conflict with expectations and consider what revisions in the initial model are needed.
- Use spreadsheets, databases, tables, charts, graphs, statistics, mathematics, and information and computer technology to collate, summarize, and display data and to explore relationships between variables, especially those representing input and output.
- Evaluate the strength of a conclusion that can be inferred from any data set, using appropriate grade-level mathematical and statistical techniques.
- Recognize patterns in data that suggest relationships worth investigating further. Distinguish between causal and correlational relationships.
- Collect data from physical models and analyze the performance of a design under a range of conditions.

PROGRESSION

At the elementary level, students need support to recognize the need to record observations—whether in drawings, words, or numbers—and to share them with others. As they engage in scientific inquiry more deeply, they should begin to collect categorical or numerical data for presentation in forms that facilitate interpretation, such as tables and graphs. When feasible, computers and other digital tools should be introduced as a means of enabling this practice. In middle school, students should have opportunities to learn standard techniques for displaying, analyzing, and interpreting data; such techniques include different types of graphs, the identification of outliers in the data set, and averaging to reduce the effects of measurement error. Students should also be asked to explain why these techniques are needed. As students progress through various science classes in high school and their investigations become more complex, they need to develop skill in additional techniques for displaying and analyzing data, such as x-y scatterplots or crosstabulations to express the relationship between two variables. Students should be helped to recognize that they may need to explore more than one way to display their data in order to identify and present significant features. They also need opportunities to use mathematics and statistics to analyze features of data such as covariation. Also at the high school level, students should have the opportunity to use a greater diversity of samples of scientific data and to use computers or other digital tools to support this kind of analysis. Students should be expected to use some of these same techniques in engineering as well. When they do so, it is important that they are made cognizant of the purpose of the exercise—that any data they collect and analyze are intended to help validate or improve a design or decide on an optimal solution.

Practice 5: Using Mathematics and Computational Thinking

Mathematics and computational tools are central to science and engineering. Mathematics enables the numerical representation of variables, the symbolic representation of relationships between physical entities, and the prediction of outcomes. Mathematics provides powerful models for describing and predicting such phenomena as atomic structure, gravitational forces, and quantum mechanics. Since the mid-20th century, computational theories, information and computer technologies, and algorithms have revolutionized virtually all scientific and engineering fields. These tools and strategies allow scientists and engineers to collect and analyze large data sets, search for distinctive patterns, and identify relationships and significant features in ways that were previously impossible. They also provide powerful new techniques for employing mathematics to model complex phenomena— for example, the circulation of carbon dioxide in the atmosphere and ocean. Mathematics and computation can be powerful tools when brought to bear in a scientific investigation. Mathematics serves pragmatic functions as a tool—both a communicative function, as one of the languages of science, and a structural function, which allows for logical deduction. Mathematics enables ideas to be expressed in a precise form and enables the identification of new ideas about the physical world. For example, the concept of the equivalence of mass and energy emerged from the mathematical analysis conducted by Einstein, based on the premises of special relativity. The contemporary understanding of electromagnetic waves emerged from Maxwell's mathematical analysis of the behavior of electric and magnetic fields. Modern theoretical physics is so heavily imbued with mathematics that it would make no sense to try to divide it into mathematical and nonmathematical parts. In much of modern science, predictions and inferences have a probabilistic nature, so understanding the mathematics of probability and of statistically derived inferences is an important part of understanding science. Computational tools enhance the power of mathematics by enabling calculations that cannot be carried out analytically. For example, they allow the development of simulations, which combine mathematical representations of multiple underlying phenomena to model the dynamics of a complex system. Computational methods are also potent tools for visually representing data, and they can show the results of calculations or simulations in ways that allow the exploration of patterns. Engineering, too, involves mathematical and computational skills. For example, structural engineers create mathematical models of bridge and building designs, based on physical laws, to test their performance, probe their structural limits, and assess whether they can be completed within acceptable budgets. Virtually any engineering design raises issues that require computation for their resolution. Although there are differences in how mathematics and computational thinking are applied in science and in engineering, mathematics often brings these two fields together by enabling engineers to apply the mathematical form of scientific theories and by enabling scientists to use powerful information technologies designed by engineers. Both kinds of professionals can thereby accomplish investigations and analyses and build complex models, which might otherwise be out of the question. Mathematics (including statistics) and computational tools are essential for data analysis, especially for large data sets. The abilities to view data from different perspectives and with different graphical representations, to test relationships between variables, and to explore the interplay of diverse external conditions all require mathematical skills that are enhanced and extended with computational skills.

GOALS: By grade 12, students should be able to

- Recognize dimensional quantities and use appropriate units in scientific applications of mathematical formulas and graphs.
- Express relationships and quantities in appropriate mathematical or algorithmic forms for scientific modeling and investigations.
- Recognize that computer simulations are built on mathematical models that incorporate underlying assumptions about the phenomena or systems being studied.
- Use simple test cases of mathematical expressions, computer programs, or simulations—that is, compare their outcomes with what is known about the real world—to see if they “make sense.”
- Use grade-level-appropriate understanding of mathematics and statistics in analyzing data.

PROGRESSION

Increasing students’ familiarity with the role of mathematics in science is central to developing a deeper understanding of how science works. As soon as students learn to count, they can begin using numbers to find or describe patterns in nature. At appropriate grade levels, they should learn to use such instruments as rulers, protractors, and thermometers for the measurement of variables that are best represented by a continuous numerical scale, to apply mathematics to interpolate values, and to identify features—such as maximum, minimum, range, average, and median—of simple data sets. A significant advance comes when relationships are expressed using equalities first in words and then in algebraic symbols—for example, shifting from distance traveled equals velocity multiplied by time elapsed to $s = vt$. Students should have opportunities to explore how such symbolic representations can be used to represent data, to predict outcomes, and eventually to derive further relationships using mathematics. Students should gain experience in using computers to record measurements taken with computer-connected probes or instruments, thereby recognizing how this process allows multiple measurements to be made rapidly and recurrently. Likewise, students should gain experience in using computer programs to transform their data between various tabular and graphical forms, thereby aiding in the identification of patterns. Students should thus be encouraged to explore the use of computers for data analysis, using simple data sets, at an early age. For example, they could use spreadsheets to record data and then perform simple and recurring calculations from those data, such as the calculation of average speed from measurements of positions at multiple times. Later work should introduce them to the use of mathematical relationships to build simple computer models, using appropriate supporting programs or information and computer technology tools. As students progress in their understanding of mathematics and computation, at every level the science classroom should be a place where these tools are progressively exploited.

Practice 6: Constructing Explanations and Designing Solutions

Because science seeks to enhance human understanding of the world, scientific theories are developed to provide explanations aimed at illuminating the nature of particular phenomena, predicting future events, or making inferences about past events. Science has developed explanatory theories, such as the germ theory of disease, the Big Bang theory of the origin of the universe, and Darwin’s theory of the evolution of species. Although their role is often misunderstood—the informal use of the word “theory,” after all, can mean a guess—scientific theories are constructs based on significant bodies of knowledge and evidence, are revised in light of new evidence, and must withstand significant scrutiny by the scientific community before they are widely accepted and applied. Theories are not mere guesses, and they are especially valued because they provide explanations for multiple instances. In science, the term “hypothesis” is also used differently than it is in everyday language. A scientific hypothesis is neither a scientific theory nor a guess; it is a plausible explanation for an observed phenomenon that can predict what will happen in a given situation. A hypothesis is made based on existing theoretical understanding relevant to the situation and often also on a specific model for the system in question. Scientific explanations are accounts that link scientific theory with specific observations or phenomena—for example, they explain observed relationships between variables and describe the mechanisms that support cause and effect inferences about them. Very often the theory is first represented by a specific model for the situation in question, and then a model-based explanation is developed. For example, if one understands the theory of how oxygen is obtained, transported, and utilized in the body, then a model of the circulatory system can be developed and used to explain why heart rate and breathing rate increase with exercise. Engaging students with standard scientific explanations of the world— helping them to gain an understanding of the major ideas that science has developed—is a central aspect of science education. Asking students to demonstrate their own understanding of the implications of a scientific idea by developing their own explanations of phenomena, whether based on observations they have made or models they have developed, engages them in an essential part of the process by which conceptual change can occur. Explanations in science are a natural for such pedagogical uses, given their inherent appeals to simplicity, analogy, and empirical data (which may even be in the form of a thought experiment) [26, 27]. And explanations are especially valuable for the classroom because of, rather than in spite of, the fact that there often are competing explanations offered for the same phenomenon—for example, the recent gradual rise in the mean surface temperature on Earth. Deciding on the best explanation is a matter of argument that is resolved by how well any given explanation fits with all available data, how much it simplifies what would seem to be complex, and whether it produces a sense of understanding. Because scientists achieve their own understanding by building theories and theory-based explanations with the aid of models and representations and by drawing on data and evidence, students should also develop some facility in constructing model- or evidence-based explanations. This is an essential step in building their own understanding of phenomena, in gaining greater appreciation of the explanatory power of the scientific theories that they are learning about in class, and in acquiring greater insight into how scientists operate. In engineering, the goal is a design rather than an explanation. The process of developing a design is iterative and systematic, as is the process of developing an explanation or a theory in science. Engineers' activities, however, have elements that are distinct from those of scientists. These elements include specifying constraints and criteria for desired qualities of the solution, developing a design plan, producing and testing models or prototypes, selecting among alternative design features to optimize the achievement of design criteria, and refining design ideas based on the performance of a prototype or simulation.

GOALS: By grade 12, students should be able to

- Construct their own explanations of phenomena using their knowledge of accepted scientific theory and linking it to models and evidence.
- Use primary or secondary scientific evidence and models to support or refute an explanatory account of a phenomenon.
- Offer causal explanations appropriate to their level of scientific knowledge.
- Identify gaps or weaknesses in explanatory accounts (their own or those of others).
- In their experience of engineering, students should have the opportunity to
- Solve design problems by appropriately applying their scientific knowledge.
- Undertake design projects, engaging in all steps of the design cycle and producing a plan that meets specific design criteria.
- Construct a device or implement a design solution.

- Evaluate and critique competing design solutions based on jointly developed and agreed-on design criteria.

PROGRESSION FOR EXPLANATION

Early in their science education, students need opportunities to engage in constructing and critiquing explanations. They should be encouraged to develop explanations of what they observe when conducting their own investigations and to evaluate their own and others' explanations for consistency with the evidence. For example, observations of the owl pellets they dissect should lead them to produce an explanation of owls' eating habits based on inferences made from what they find. As students' knowledge develops, they can begin to identify and isolate variables and incorporate the resulting observations into their explanations of phenomena. Using their measurements of how one factor does or does not affect another, they can develop causal accounts to explain what they observe. For example, in investigating the conditions under which plants grow fastest, they may notice that the plants die when kept in the dark and seek to develop an explanation for this finding. Although the explanation at this level may be as simple as "plants die in the dark because they need light in order to live and grow," it provides a basis for further questions and deeper understanding of how plants utilize light that can be developed in later grades. On the basis of comparison of their explanation with their observations, students can appreciate that an explanation such as "plants need light to grow" fails to explain why they die when no water is provided. They should be encouraged to revisit their initial ideas and produce more complete explanations that account for more of their observations. By the middle grades, students recognize that many of the explanations of science rely on models or representations of entities that are too small to see or too large to visualize. For example, explaining why the temperature of water does not increase beyond 100°C when heated requires students to envisage water as consisting of microscopic particles and that the energy provided by heating can allow fast-moving particles to escape despite the force of attraction holding the particles together. In the later stages of their education, students should also progress to using mathematics or simulations to construct an explanation for a phenomenon.

PROGRESSION FOR DESIGN

In some ways, children are natural engineers. They spontaneously build sandcastles, dollhouses, and hamster enclosures, and they use a variety of tools and materials for their own playful purposes. Thus a common elementary school activity is to challenge children to use tools and materials provided in class to solve a specific challenge, such as constructing a bridge from paper and tape and testing it until failure occurs. Children's capabilities to design structures can then be enhanced by having them pay attention to points of failure and asking them to create and test redesigns of the bridge so that it is stronger. Furthermore, design activities should not be limited just to structural engineering but should also include projects that reflect other areas of engineering, such as the need to design a traffic pattern for the school parking lot or a layout for planting a school garden box. In middle school, it is especially beneficial to engage students in engineering design projects in which they are expected to apply what they have recently learned in science—for example, using their now-familiar concepts of ecology to solve problems related to a school garden. Middle school students should also have opportunities to plan and carry out full engineering design projects in which they define problems in terms of criteria and constraints, research the problem to deepen their relevant knowledge, generate and test possible solutions, and refine their solutions through redesign. At the high school level, students can undertake more complex engineering design projects related to major local, national or global issues. Increased emphasis should be placed on researching the nature of the given problems, on reviewing others' proposed solutions, on weighing the strengths and weaknesses of various alternatives, and on discerning possibly unanticipated effects.

Practice 7: Engaging in Argument from Evidence

Whether they concern new theories, proposed explanations of phenomena, novel solutions to technological problems, or fresh interpretations of old data, scientists and engineers use reasoning and argumentation to make their case. In science, the production of knowledge is dependent on a process of reasoning that requires a scientist to make a justified claim about the world. In response, other scientists attempt to identify the claim's weaknesses and limitations. Their arguments can be based on deductions from premises, on inductive generalizations of existing patterns, or on inferences about the best possible explanation. Argumentation is also needed to resolve questions involving, for example, the best experimental design, the most appropriate techniques of data analysis, or the best interpretation of a given data set. In short, science is replete with arguments that take place both informally, in lab meetings and symposia, and formally, in peer review. Historical case studies of the origin and development of a scientific idea show how a new idea is often difficult to accept and has to be argued for—archetypal examples are the Copernican idea that Earth travels around the sun and Darwin's ideas about the origin of species. Over time, ideas that survive critical examination even in the light of new data attain consensual acceptance in the community, and by this process of discourse and argument science maintains its objectivity and progress [28]. The knowledge and ability to detect "bad science" [29, 30] are requirements both for the scientist and the citizen. Scientists must make critical judgments about their own work and that of their peers, and the scientist and the citizen alike must make evaluative judgments about the validity of science-related media reports and their implications for people's own lives and society [30]. Becoming a critical consumer of science is fostered by opportunities to use critique and evaluation to judge the merits of any scientifically based argument. Possible solution to a problem. At an early design stage, competing ideas must be compared (and possibly combined) to achieve an initial design, and the choices are made through argumentation about the merits of the various ideas pertinent to the design goals. At a later stage in the design process, engineers test their potential solution, collect data, and modify their design in an iterative manner. The results of such efforts are often presented as evidence to argue about the strengths and weaknesses of a particular design. Although the forms of argumentation are similar, the criteria employed in engineering are often quite different from those of science. For example, engineers might use cost-benefit analysis, an analysis of risk, an appeal to aesthetics, or predictions about market reception to justify why one design is better than another—or why an entirely different course of action should be followed.

GOALS: By grade 12, students should be able to

- Construct a scientific argument showing how data support a claim.
- Identify possible weaknesses in scientific arguments, appropriate to the students' level of knowledge, and discuss them using reasoning and evidence.
- Identify flaws in their own arguments and modify and improve them in response to criticism.
- Recognize that the major features of scientific arguments are claims, data, and reasons and distinguish these elements in examples.
- Explain the nature of the controversy in the development of a given scientific idea, describe the debate that surrounded its inception, and indicate why one particular theory succeeded.
- Explain how claims to knowledge are judged by the scientific community today and articulate the merits and limitations of peer review and the need for independent replication of critical investigations. • Read media reports of science or technology in a critical manner so as to identify their strengths and weaknesses.

PROGRESSION

The study of science and engineering should produce a sense of the process of argument necessary for advancing and defending a new idea or an explanation of a phenomenon and the norms for conducting such arguments. In that spirit, students should argue for the explanations they construct, defend their interpretations of the associated data, and advocate for the designs they propose. Meanwhile, they should learn how to evaluate critically the scientific arguments of others and present counterarguments. Learning to argue scientifically offers students not only an opportunity to use their scientific knowledge in justifying an explanation and in identifying the weaknesses in others' arguments but also to build their own knowledge and understanding. Constructing and critiquing arguments are both a core process of science and one that supports science education, as research suggests that interaction with others is the most cognitively effective way of learning [31-33]. Young students can begin by constructing an argument for their own interpretation of the phenomena they observe and of any data they collect. They need instructional support to go beyond simply making claims—that is, to include reasons or references to evidence and to begin to distinguish evidence from opinion. As they grow in their ability to construct scientific arguments, students can draw on a wider range of reasons or evidence, so that their arguments become more sophisticated. In addition, they should be expected to discern what aspects of the evidence are potentially significant for supporting or refuting a particular argument. Students should begin learning to critique by asking questions about their own findings and those of others. Later, they should be expected to identify possible weaknesses in either data or an argument and explain why their criticism is justified. As they become more adept at arguing and critiquing, they should be introduced to the language needed to talk about argument, such as claim, reason, data, etc. Exploration of historical episodes in science can provide opportunities for students to identify the ideas, evidence, and arguments of professional scientists. In so doing, they should be encouraged to recognize the criteria used to judge claims for new knowledge and the formal means by which scientific ideas are evaluated today. In particular, they should see how the practice of peer review and independent verification of claimed experimental results help to maintain objectivity and trust in science.

Practice 8: Obtaining, Evaluating, and Communicating Information

Being literate in science and engineering requires the ability to read and understand their literatures [34]. Science and engineering are ways of knowing that are represented and communicated by words, diagrams, charts, graphs, images, symbols, and mathematics [35]. Reading, interpreting, and producing text* are fundamental practices of science in particular, and they constitute at least half of engineers' and scientists' total working time [36]. Even when students have developed grade-level-appropriate reading skills, reading in science is often challenging to students for three reasons. First, the jargon of science texts is essentially unfamiliar; together with their often extensive use of, for example, the passive voice and complex sentence structure, many find these texts inaccessible [37]. Second, science texts must be read so as to extract information accurately. Because the precise meaning of each word or clause may be important, such texts require a mode of reading that is quite different from reading a novel or even a newspaper. Third, science texts are multimodal [38], using a mix of words, diagrams, charts, symbols, and mathematics to communicate. Thus understanding science texts requires much more than simply knowing the meanings of technical terms. Communicating in written or spoken form is another fundamental practice of science; it requires scientists to describe observations precisely, clarify their thinking, and justify their arguments. Because writing is one of the primary means of communicating in the scientific community, learning how to produce scientific texts is as essential to developing an understanding of science as learning how to draw is to appreciating the skill of the visual artist. Indeed, the new Common Core State Standards for English Language Arts & Literacy in History/Social Studies, Science, and Technical Subjects

[39] recognize that reading and writing skills are essential to science; the formal inclusion in this framework of this science practice reinforces and expands on that view. Science simply cannot advance if scientists are unable to communicate their findings clearly and persuasively. Communication occurs in a variety of formal venues, including peer-reviewed journals, books, conference presentations, and carefully constructed websites; it occurs as well through informal means, such as discussions, email messages, phone calls, and blogs. New technologies have extended communicative practices, enabling multidisciplinary collaborations across the globe that place even more emphasis on reading and writing. Increasingly, too, scientists are required to engage in dialogues with lay audiences about their work, which requires especially good communication skills. Being a critical consumer of science and the products of engineering, whether as a lay citizen or a practicing scientist or an engineer, also requires the ability to read or view reports about science in the press or on the Internet and to recognize the salient science, identify sources of error and methodological flaws, and distinguish observations from inferences, arguments from explanations, and claims from evidence. All of these are constructs learned from engaging in a critical discourse around texts. Engineering proceeds in a similar manner because engineers need to communicate ideas and find and exchange information—for example, about new techniques or new uses of existing tools and materials. As in science, engineering communication involves not just written and spoken language; many engineering ideas are best communicated through sketches, diagrams, graphs, models, and products. Also in wide use are handbooks, specific to particular engineering fields, that provide detailed information, often in tabular form, on how best to formulate design solutions to commonly encountered engineering tasks. Knowing how to seek and use such informational resources is an important part of the engineer's skill set.

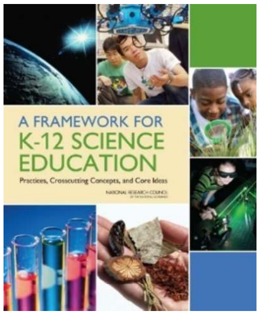
GOALS: By grade 12, students should be able to

- Use words, tables, diagrams, and graphs (whether in hard copy or electronically), as well as mathematical expressions, to communicate their understanding or to ask questions about a system under study.
- Read scientific and engineering text, including tables, diagrams, and graphs, commensurate with their scientific knowledge and explain the key ideas being communicated.
- Recognize the major features of scientific and engineering writing and speaking and be able to produce written and illustrated text or oral presentations that communicate their own ideas and accomplishments.
- Engage in a critical reading of primary scientific literature (adapted for classroom use) or of media reports of science and discuss the validity and reliability of the data, hypotheses, and conclusions.

PROGRESSION

Any education in science and engineering needs to develop students' ability to read and produce domain-specific text. As such, every science or engineering lesson is in part a language lesson, particularly reading and producing the genres of texts that are intrinsic to science and engineering. Students need sustained practice and support to develop the ability to extract the meaning of scientific text from books, media reports, and other forms of scientific communication because the form of this text is initially unfamiliar— expository rather than narrative, often linguistically dense, and reliant on precise logical flows. Students should be able to interpret meaning from text, to produce text in which written language and diagrams are used to express scientific ideas, and to engage in extended discussion about those ideas. From the very start of their science education, students should be asked to engage in the communication of science, especially regarding the investigations they are conducting and the observations they are making. Careful description of observations and clear statement of ideas, with the ability to both refine a statement in response to questions and to ask questions of others to achieve clarification of what is being said begin at the earliest grades. Beginning in upper elementary and middle school, the ability to interpret written materials becomes more important. Early work on reading science texts should also include explicit instruction and practice in interpreting tables, diagrams, and charts and coordinating information conveyed by them with information in written text. Throughout their science education, students are continually introduced to new terms, and the meanings of those terms can be learned only through opportunities to use and apply them in their specific contexts. Not only must students learn technical terms but also more general academic language, such as “analyze” or “correlation,” which are not part of most students’ everyday vocabulary and thus need specific elaboration if they are to make sense of scientific text. It follows that to master the reading of scientific material, students need opportunities to engage with such text and to identify its major features; they cannot be expected simply to apply reading skills learned elsewhere to master this unfamiliar genre effectively. Students should write accounts of their work, using journals to record observations, thoughts, ideas, and models. They should be encouraged to create diagrams and to represent data and observations with plots and tables, as well as with written text, in these journals. They should also begin to produce reports or posters that present their work to others. As students begin to read and write more texts, the particular genres of scientific text—a report of an investigation, an explanation with supporting argumentation, an experimental procedure—will need to be introduced and their purpose explored. Furthermore, students should have opportunities to engage in discussion about observations and explanations and to make oral presentations of their results and conclusions as well as to engage in appropriate discourse with other students by asking questions and discussing issues raised in such presentations. Because the spoken language of such discussions and presentations is as far from their everyday language as scientific text is from a novel, the development both of written and spoken scientific explanation/argumentation needs to proceed in parallel. In high school, these practices should be further developed by providing students with more complex texts and a wider range of text materials, such as technical reports or scientific literature on the Internet. Moreover, students need opportunities to read and discuss general media reports with a critical eye and to read appropriate samples of adapted primary literature [40] to begin seeing how science is communicated by science practitioners. In engineering, students likewise need opportunities to communicate ideas using appropriate combinations of sketches, models, and language. They should also create drawings to test concepts and communicate detailed plans; explain and critique models of various sorts, including scale models and prototypes; and present the results of simulations, not only regarding the planning and development stages but also to make compelling presentations of their ultimate solutions.

The study of science and engineering should produce a sense of the process of argument necessary for advancing and defending a new idea or an explanation of a phenomenon and the norms for conducting such arguments. In that spirit, students should argue for the explanations they construct, defend their interpretations of the associated data, and advocate for the designs they propose. Meanwhile, they should learn how to evaluate critically the scientific arguments of others and present counterarguments. Learning to argue scientifically offers students not only an opportunity to use their scientific knowledge in justifying an explanation and in identifying the weaknesses in others’ arguments but also to build their own knowledge and understanding. Constructing and critiquing arguments are both a core process of science and one that supports science education, as research suggests that interaction with others is the most cognitively effective way of learning [31-33]. Young students can begin by constructing an argument for their own interpretation of the phenomena they observe and of any data they collect. They need instructional support to go beyond simply making claims—that is, to include reasons or references to evidence and to begin to distinguish evidence from opinion. As they grow in their ability to construct scientific arguments, students can draw on a wider range of reasons or evidence, so that their arguments become more sophisticated. In addition, they should be expected to discern what aspects of the evidence are potentially significant for supporting or refuting a particular argument. Students should begin learning to critique by asking questions about their own findings and those of others. Later, they should be expected to identify possible weaknesses in either data or an argument and explain why their criticism is justified. As they become more adept at arguing and critiquing, they should be introduced to the language needed to talk about argument, such as claim, reason, data, etc. Exploration of historical episodes in science can provide opportunities for students to identify the ideas, evidence, and arguments of professional scientists. In so doing, they should be encouraged to recognize the criteria used to judge claims for new knowledge and the formal means by which scientific ideas are evaluated today. In particular, they should see how the practice of peer review and independent verification of claimed experimental results help to maintain objectivity and trust in science.



Dimension 2: Crosscutting Concepts

Although Crosscutting Concepts are fundamental to an understanding of science and engineering, students have often been expected to build such knowledge without any explicit instructional support. Hence the purpose of highlighting them as Dimension 2 of the framework is to elevate their role in the development of standards, curricula, instruction, and assessments. These concepts should become common and familiar touchstones across the disciplines and grade levels. Explicit reference to the concepts, as well as their emergence in multiple disciplinary contexts, can help students develop a cumulative, coherent, and usable understanding of science and engineering. Although we do not specify grade band endpoints for the Crosscutting Concepts, we do lay out a hypothetical progression for each. Like all learning in science, students' facility with addressing these concepts and related topics at any particular grade level depends on their prior experience and instruction. The research base on learning and teaching the Crosscutting Concepts is limited. For this reason, the progressions we describe should be treated as hypotheses that require further empirical investigation.

1. **Patterns:** Observed patterns of forms and events guide organization and classification, and they prompt questions about relationships and the factors that influence them.

   PROGRESSION

   Human beings are good at recognizing patterns; indeed, young children begin to recognize patterns in their own lives well before coming to school. They observe, for example, that the sun and the moon follow different patterns of appearance in the sky. Once they are students, it is important for them to develop ways to recognize, classify, and record patterns in the phenomena they observe. For example, elementary students can describe and predict the patterns in the seasons of the year; they can observe and record patterns in the similarities and differences between parents and their offspring. Similarly, they can investigate the characteristics that allow classification of animal types (e.g., mammals, fish, insects), of plants (e.g., trees, shrubs, grasses), or of materials (e.g., wood, rock, metal, plastic). These classifications will become more detailed and closer to scientific classifications in the upper elementary grades, when students should also begin to analyze patterns in rates of change—for example, the growth rates of plants under different conditions. By middle school, students can begin to relate patterns to the nature of microscopic and atomic-level structure—for example, they may note that chemical molecules contain particular ratios of different atoms. By high school, students should recognize that different patterns may be observed at each of the scales at which a system is studied. Thus classifications used at one scale may fail or need revision when information from smaller or larger scales is introduced (e.g., classifications based on DNA comparisons versus those based on visible characteristics).

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

PROGRESSION

In the earliest grades, as students begin to look for and analyze patterns—whether in their observations of the world or in the relationships between different quantities in data (e.g., the sizes of plants over time)—they can also begin to consider what might be causing these patterns and relationships and design tests that gather more evidence to support or refute their ideas. By the upper elementary grades, students should have developed the habit of routinely asking about cause-and effect relationships in the systems they are studying, particularly when something occurs that is, for them, unexpected. The questions “How did that happen?” or “Why did that happen?” should move toward “What mechanisms caused that to happen?” and “What conditions were critical for that to happen?” In middle and high school, argumentation starting from students’ own explanations of cause and effect can help them appreciate standard scientific theories that explain the causal mechanisms in the systems under study. Strategies for this type of instruction include asking students to argue from evidence when attributing an observed phenomenon to a specific cause. For example, students exploring why the population of a given species is shrinking will look for evidence in the ecosystem of factors that lead to food shortages, over predation, or other factors in the habitat related to survival; they will provide an argument for how these and other observed changes affect the species of interest.

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.

PROGRESSION

The concept of scale builds from the early grades as an essential element of understanding phenomena. Young children can begin understanding scale with objects, space, and time related to their world and with explicit scale models and maps. They may discuss relative scales—the biggest and smallest, hottest and coolest, fastest and slowest—without reference to particular units of measurement. Typically, units of measurement are first introduced in the context of length, in which students can recognize the need for a common unit of measure—even develop their own before being introduced to standard units—through appropriately constructed experiences. Engineering design activities involving scale diagrams and models can support students in developing facility with this important concept. Once students become familiar with measurements of length, they can expand their understanding of scale and of the need for units that express quantities of weight, time, temperature, and other variables. They can also develop an understanding of estimation across scales and contexts, which is important for making sense of data. As students become more sophisticated, the use of estimation can help them not only to develop a sense of the size and time scales relevant to various objects, systems, and processes but also to consider whether a numerical result sounds reasonable. Students acquire the ability as well to move back and forth between models at various scales, depending on the question being considered. They should develop a sense of the powers-of-10 scales and what phenomena correspond to what scale, from the size of the nucleus of an atom to the size of the galaxy and beyond. Well-designed instruction is needed if students are to assign meaning to the types of ratios and proportional relationships they encounter in science. Thus the ability to recognize mathematical relationships between quantities should begin developing in the early grades with students’ representations of counting (e.g., leaves on a branch), comparisons of amounts (e.g., of flowers on different plants), measurements (e.g., the height of a plant), and the ordering of quantities such as number, length, and weight. Students can then explore more sophisticated mathematical representations, such as the use of graphs to represent data collected. The interpretation of these graphs may be, for example, that a plant gets bigger as time passes or that the hours of daylight decrease and increase across the months. As students deepen their understanding of algebraic thinking, they should be able to apply it to examine their scientific data to predict the effect of a change in one variable on another, for example, or to appreciate the difference between linear growth and exponential growth. As their thinking advances, so too should their ability to recognize and apply more complex mathematical and statistical relationships in science. A sense of numerical quantity is an important part of the general "numeracy" (mathematics literacy) that is needed to interpret such relationships.

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

PROGRESSION

As science instruction progresses, so too should students' ability to analyze and model more complex systems and to use a broader variety of representations to explicate what they model. Their thinking about systems in terms of component parts and their interactions, as well as in terms of inputs, outputs, and processes, gives students a way to organize their knowledge of a system, to generate questions that can lead to enhanced understanding, to test aspects of their model of the system, and, eventually, to refine their model. Starting in the earliest grades, students should be asked to express their thinking with drawings or diagrams and with written or oral descriptions. They should describe objects or organisms in terms of their parts and the roles those parts play in the functioning of the object or organism, and they should note relationships between the parts. Students should also be asked to create plans— for example, to draw or write a set of instructions for building something—that another child can follow. Such experiences help them develop the concept of a model of a system and realize the importance of representing one's ideas so that others can understand and use them. As students progress, their models should move beyond simple renderings or maps and begin to incorporate and make explicit the invisible features of a system, such as interactions, energy flows, or matter transfers. Mathematical ideas, such as ratios and simple graphs, should be seen as tools for making more definitive models; eventually, students' models should incorporate a range of mathematical relationships among variables (at a level appropriate for grade-level mathematics) and some analysis of the patterns of those relationships. By high school, students should also be able to identify the assumptions and approximations that have been built into a model and discuss how they limit the precision and reliability of its predictions. Instruction should also include discussion of the interactions within a system. As understanding deepens, students can move from a vague notion of interaction as one thing affecting another to more explicit realizations of a system's physical, chemical, biological, and social interactions and of their relative importance for the question at hand. Students' ideas about the interactions in a system and the explication of such interactions in their models should become more sophisticated in parallel with their understanding of the microscopic world (atoms, molecules, biological cells, microbes) and with their ability to interpret and use more complex mathematical relationships. Modeling is also a tool that students can use in gauging their own knowledge and clarifying their questions about a system. Student-developed models may reveal problems or progress in their conceptions of the system, just as scientists' models do. Teaching students to explicitly craft and present their models in diagrams, words, and, eventually, in mathematical relationships serves three purposes. It supports them in clarifying their ideas and explanations and in considering any inherent contradictions; it allows other students the opportunity to critique and suggest revisions for the model; and it offers the teacher insights into those aspects of each student's understanding that are well founded and those that could benefit from further instructional attention. Likewise in engineering projects, developing systems thinking and system models supports critical steps in developing, sharing, testing, and refining design ideas.

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.

   PROGRESSION

   The Core Ideas of matter and energy and their development across the grade bands are spelled out in detail in Chapter 5. What is added in this crosscutting discussion is recognition that an understanding of these Core Ideas can be informative in examining systems in life science, earth and space science, and engineering contexts. Young children are likely to have difficulty studying the concept of energy in depth—everyday language surrounding energy contains many shortcuts that lead to misunderstandings. For this reason, the concept is not developed at all in K-2 and only very generally in grades 3-5. Instead, the elementary grades focus on recognition of conservation of matter and of the flow of matter into, out of, and within systems under study. The role of energy transfers in conjunction with these flows is not introduced until the middle grades and only fully developed by high school. Clearly, incorrect beliefs—such as the perception that food or fuel is a form of energy—would lead to elementary grade students' misunderstanding of the nature of energy. Hence, although the necessity for food or fuel can be discussed, the language of energy needs to be used with care so as not to further establish such misconceptions. By middle school, a more precise idea of energy—for example, the understanding that food or fuel undergoes a chemical reaction with oxygen that releases stored energy—can emerge. The common misconceptions can be addressed with targeted instructional interventions (including student-led investigations), and appropriate terminology can be used in discussing energy across the disciplines. Matter transfers are less fraught in this respect, but the idea of atoms is not introduced with any specificity until middle school. Thus, at the level of grades 3-5, matter flows and cycles can be tracked only in terms of the weight of the substances before and after a process occurs, such as sugar dissolving in water. Mass/ weight distinctions and the idea of atoms and their conservation (except in nuclear processes) are taught in grades 6-8, with nuclear substructure and the related conservation laws for nuclear processes introduced in grades 9-12.

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.

   PROGRESSION

   Exploration of the relationship between structure and function can begin in the early grades through investigations of accessible and visible systems in the natural and human-built world. For example, children explore how shape and stability are related for a variety of structures (e.g., a bridge's diagonal brace) or purposes (e.g., different animals get their food using different parts of their bodies). As children move through the elementary grades, they progress to understanding the relationships of structure and mechanical function (e.g., wheels and axles, gears). For upper-elementary students, the concept of matter having a substructure at a scale too small to see is related to properties of materials; for example, a model of a gas as a collection of moving particles (not further defined) may be related to observed properties of gases. Upper-elementary students can also examine more complex structures, such as subsystems of the human body, and consider the relationship of the shapes of the parts to their functions. By the middle grades, students begin to visualize, model, and apply their understanding of structure and function to more complex or less easily observable systems and processes (e.g., the structure of water and salt molecules and solubility, Earth's plate tectonics). For students in the middle grades, the concept of matter having a submicroscopic structure is related to properties of materials; for example, a model based on atoms and/or molecules and their motions may be used to explain the properties of solids, liquids, and gases or the evaporation and condensation of water. As students develop their understanding of the relationships between structure and function, they should begin to apply this knowledge when investigating phenomena that are unfamiliar to them. They recognize that often the first step in deciphering how a system works is to examine in detail what it is made of and the shapes of its parts. In building something—say, a mechanical system— they likewise apply relationships of structure and function as critical elements of successful designs.

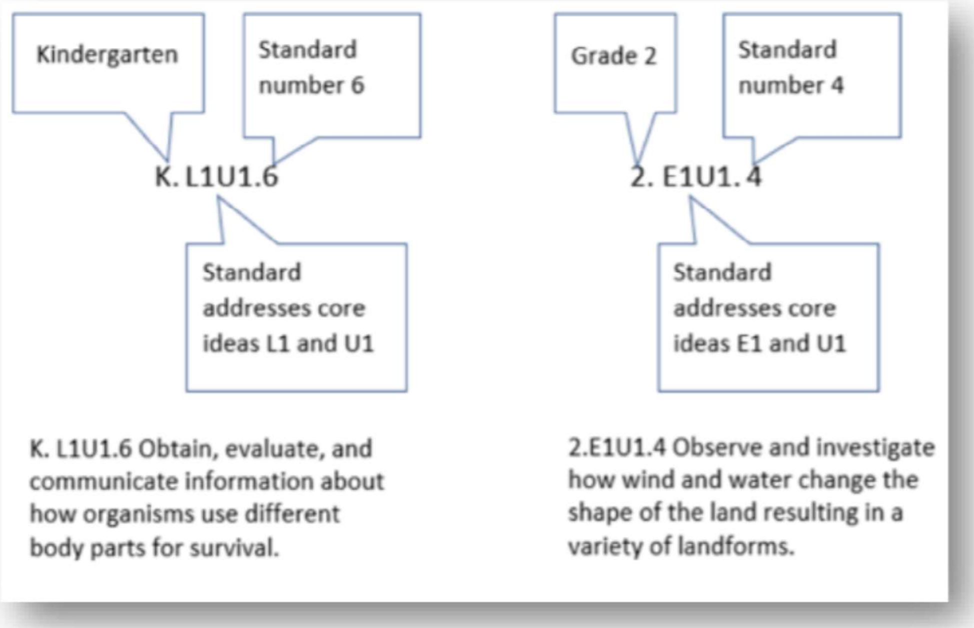
7. **Stability and Change:** For natural and built systems alike, conditions of stability and determinants of rates of change or evolution of a system are critical elements of study

   PROGRESSION

   Even very young children begin to explore stability (as they build objects with blocks or climb on a wall) and change (as they note their own growth or that of a plant). The role of instruction in the early grades is to help students to develop some language for these concepts and apply it appropriately across multiple examples, so that they can ask such questions as "What could I change to make this balance better?" or "How fast did the plants grow?" One of the goals of discussion of stability and change in the elementary grades should

A Look at the Arizona Science Standards (AzSS)

Each standard represents the intersection of Core Ideas for knowing science and using science. This intersection stresses that content in physical science, Earth and space science, and life science is not learned independently from ideas about the nature of science, applications of science, or the social implications of using science. The coding of the standard captures this intersection. Students engage in multiple practices as they gather information to solve problems, answer their questions, reason about how the data provide evidence to support their understanding, and then communicate their understanding of phenomena, applications, or social implications. They use the Crosscutting Concepts to support their understanding of patterns, cause and effect relationships, and systems thinking as they make sense of phenomena. The standard number at the end of the code is designed for recording purposes and does not imply instructional sequence or importance. The images below are examples and descriptions of coding of the K-8 Standards, which remain similar in high school.



K. L1U1.6 Obtain, evaluate, and communicate information about how organisms use different body parts for survival.

2.E1U1.4 Observe and investigate how wind and water change the shape of the land resulting in a variety of landforms.

The *2018 Arizona Science Standards* (AzSS) differ from prior science standards in that they integrate their dimensions (Science and Engineering Practices, Core Ideas, and Crosscutting Concepts) into a single standard document and have intentional connections between standards across all disciplines. The system architecture *Draft Tool Template* of the AzSS for MPS highlights the standard as well as each of the three integral dimensions and connections to other grade bands and subjects. The architecture involves a table with three main sections:

Architecture of the Arizona Science Standards

What is Assessed (The Standard)	**3D Foundations Box**	**Evidence of Learning Specifications Box (EoLS)**
A standard describes what students should be able to do at the end of instruction and incorporates a science and engineering practice and core idea. Standards are not instructional strategies or objectives for a lesson. Instead, they are intended to guide the development of assessments and are what a student needs to know, understand, and be able to do by the end of each grade. Standards build across grade levels in a progression of increasing understanding and through a range of cognitive demand levels.	The 3-dimensions foundation box contains the learning goals that students should achieve. It is critical that science educators consider the foundations box an essential component when reading the AzSS and developing curricula. There are four main parts of the foundation box: core ideas, science and engineering practices, crosscutting concepts, and using science, all of which are derived from A Framework for Science Education and Working with Big Ideas of Science Education. During instruction, teachers will need to have students use multiple practices to help students understand the core ideas. Most groupings of standards emphasize only a few practices or crosscutting concepts; however, all are emphasized within a grade band. The foundation box also contains the AzSS using science that connect scientific principles, theories, and models; engineering and technological applications; and societal implications to the content knowledge to support scientific understanding.	The evidence of learning specification box uses the standards and 3D foundations to develop EoLS, which describe what qualifies as evidence for students' proficiency. High quality assessment practices are critical to the success of the AzSS. The Evidence of Learning Specifications represent learning at the nexus of the 3-dimensions of the AzSS.

Inside the Mesa Public Schools (MPS) Curricular Guide

Navigating the Science Curriculum Guide

Core Ideas for the Unit
Core Ideas as described below that will appear in the unit.

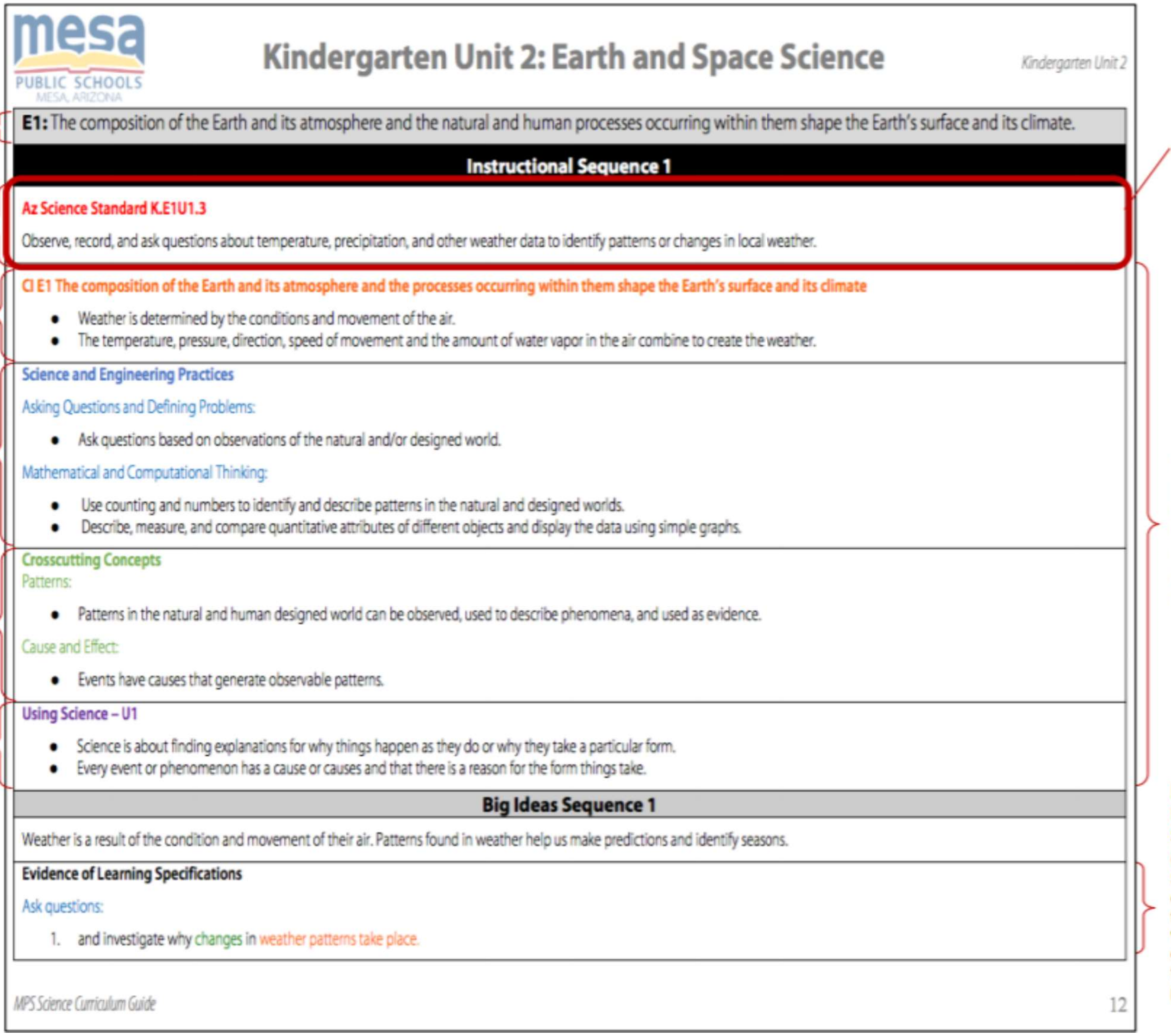
What is Assessed
A collection of one or more standards describing what students should be able to do at the end of instruction

Core Ideas
Concepts in science that have broad importance within and across disciplines as well as relevance in people's lives

Science & Engineering Practices
Skills and knowledge that scientists and engineers engage in to either understand the world or solve a problem

Crosscutting Concepts
Ideas that are not specific to one discipline but cut across all disciplines

Using Science
Concepts that connect scientific principles, theories, and models; engineering and technological applications; and societal implications to the content knowledge to support scientific understanding.



Kindergarten Unit 2: Earth and Space Science

Kindergarten Unit 2

E1: The composition of the Earth and its atmosphere and the natural and human processes occurring within them shape the Earth's surface and its climate.

Instructional Sequence 1

Az Science Standard K.E1U1.3

Observe, record, and ask questions about temperature, precipitation, and other weather data to identify patterns or changes in local weather.

CI E1 The composition of the Earth and its atmosphere and the processes occurring within them shape the Earth's surface and its climate

- Weather is determined by the conditions and movement of the air.
- The temperature, pressure, direction, speed of movement and the amount of water vapor in the air combine to create the weather.

Science and Engineering Practices

Asking Questions and Defining Problems:

- Ask questions based on observations of the natural and/or designed world.

Mathematical and Computational Thinking:

- Use counting and numbers to identify and describe patterns in the natural and designed worlds.
- Describe, measure, and compare quantitative attributes of different objects and display the data using simple graphs.

Crosscutting Concepts

Patterns:

- Patterns in the natural and human designed world can be observed, used to describe phenomena, and used as evidence.

Cause and Effect:

- Events have causes that generate observable patterns.

Using Science – U1

- Science is about finding explanations for why things happen as they do or why they take a particular form.
- Every event or phenomenon has a cause or causes and that there is a reason for the form things take.

Big Ideas Sequence 1

Weather is a result of the condition and movement of their air. Patterns found in weather help us make predictions and identify seasons.

Evidence of Learning Specifications

Ask questions:

1. and investigate why changes in weather patterns take place.

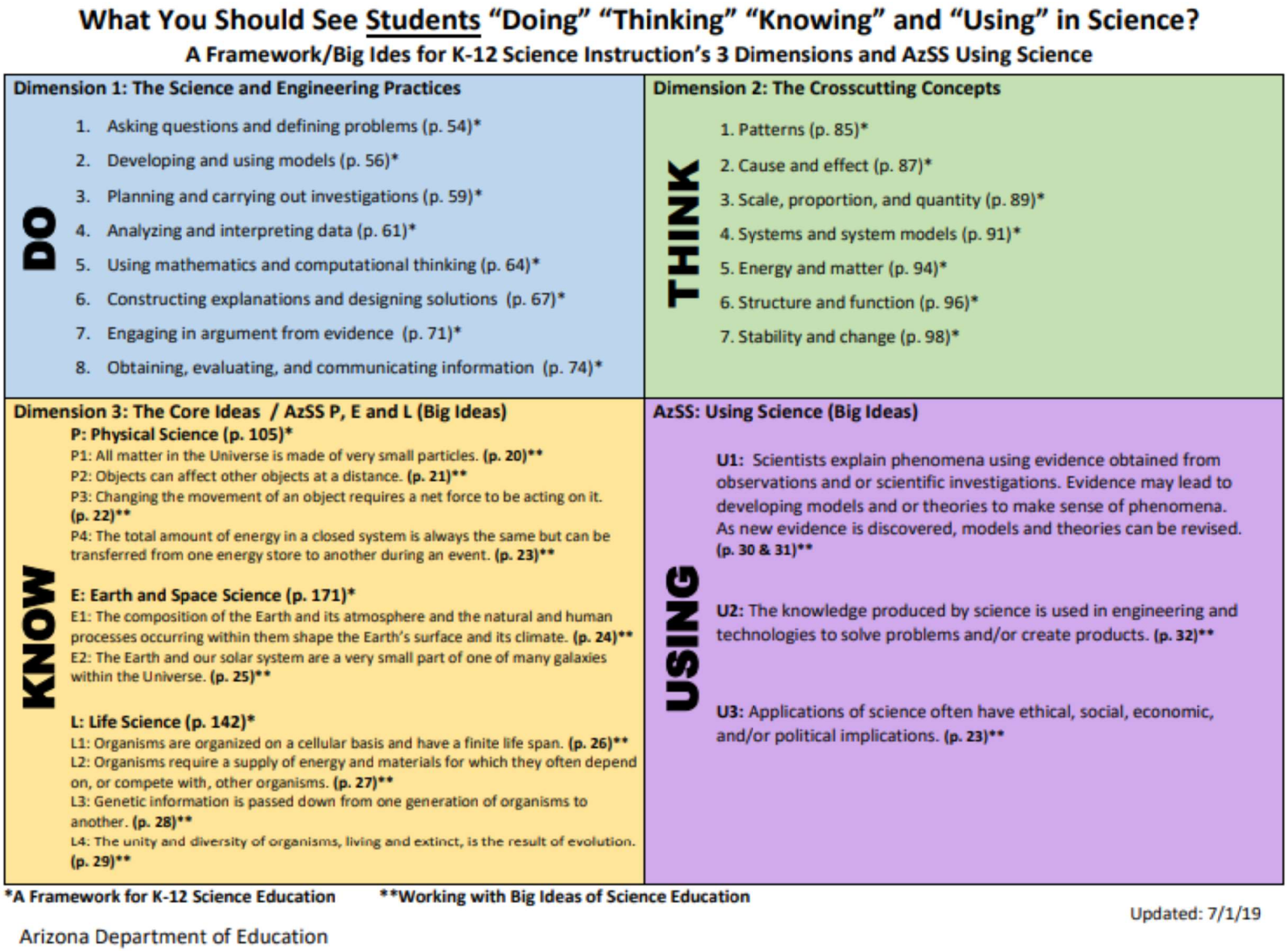
MPS Science Curriculum Guide 12

Standard
A statement that Combines Science and Engineering Practices and Core Ideas to describe how students can show what they have learned

3D Foundations
The Practices, Core Ideas, and Crosscutting Concepts from *A Framework for K-12 Science Education* that were used to form the standards

Evidence of Learning Specifications (EoLS)
Standards and the 3-dimensions are used to develop EoLS, which describe what qualifies as evidence for students' proficiency.

AzSS, Framework, and Big Ideas Snapshot



What You Should See Students “Doing” “Thinking” “Knowing” and “Using” in Science?

A Framework/Big Ides for K-12 Science Instruction’s 3 Dimensions and AzSS Using Science

Dimension 1: The Science and Engineering Practices

DO

1. Asking questions and defining problems (p. 54)*
2. Developing and using models (p. 56)*
3. Planning and carrying out investigations (p. 59)*
4. Analyzing and interpreting data (p. 61)*
5. Using mathematics and computational thinking (p. 64)*
6. Constructing explanations and designing solutions (p. 67)*
7. Engaging in argument from evidence (p. 71)*
8. Obtaining, evaluating, and communicating information (p. 74)*

Dimension 2: The Crosscutting Concepts

THINK

1. Patterns (p. 85)*
2. Cause and effect (p. 87)*
3. Scale, proportion, and quantity (p. 89)*
4. Systems and system models (p. 91)*
5. Energy and matter (p. 94)*
6. Structure and function (p. 96)*
7. Stability and change (p. 98)*

Dimension 3: The Core Ideas / AzSS P, E and L (Big Ideas)

KNOW

P: Physical Science (p. 105)*

P1: All matter in the Universe is made of very small particles. **(p. 20)****
P2: Objects can affect other objects at a distance. **(p. 21)****
P3: Changing the movement of an object requires a net force to be acting on it. **(p. 22)****
P4: The total amount of energy in a closed system is always the same but can be transferred from one energy store to another during an event. **(p. 23)****

E: Earth and Space Science (p. 171)*

E1: The composition of the Earth and its atmosphere and the natural and human processes occurring within them shape the Earth’s surface and its climate. **(p. 24)****
E2: The Earth and our solar system are a very small part of one of many galaxies within the Universe. **(p. 25)****

L: Life Science (p. 142)*

L1: Organisms are organized on a cellular basis and have a finite life span. **(p. 26)****
L2: Organisms require a supply of energy and materials for which they often depend on, or compete with, other organisms. **(p. 27)****
L3: Genetic information is passed down from one generation of organisms to another. **(p. 28)****
L4: The unity and diversity of organisms, living and extinct, is the result of evolution. **(p. 29)****

AzSS: Using Science (Big Ideas)

USING

U1: Scientists explain phenomena using evidence obtained from observations and or scientific investigations. Evidence may lead to developing models and or theories to make sense of phenomena. As new evidence is discovered, models and theories can be revised. **(p. 30 & 31)****

U2: The knowledge produced by science is used in engineering and technologies to solve problems and/or create products. **(p. 32)****

U3: Applications of science often have ethical, social, economic, and/or political implications. **(p. 23)****

***A Framework for K-12 Science Education** ****Working with Big Ideas of Science Education**

Updated: 7/1/19

Arizona Department of Education

AzSS as Interpreted by MPS - Organized by Topic

Level		Life Science	Earth and Space Science	Physical Science
Elementary School	K	Living Things	Weather Sun, Moon, and Stars	The Senses (Light and Sound Waves)
	1	Animals and Plants	Natural Resources	Light and Sound Forces
	2	Organisms and Energy	Wind and Water The Environment The Earth, Sun, and Moon	Matter
	3	Survival Structures	Sun Energy	Light and Sound (Waves)
	4	Survival or Extinction	Earth Systems	Magnets and Electricity
	5	Genetics, Traits, and Adaptations	Gravity in Space	Matter Force and Motion
Middle School	6	Ecosystems	Movement in the Solar System Solar Radiation	Energy and Matter
	7	Cells: Structure and Function Body Systems	Earth Systems	Forces at a Distance Newton's Laws
	8	Inheritance and Variation of Traits	Life Over Geologic Time	Energy & Transfer
High School Essential Standards		Matter and Energy in Organisms Homeostasis and Cell Function Growth, Development, and Reproduction of Organisms Matter and Energy in Ecosystems Ecosystems and Populations Natural Selection and Population Change Inheritable Traits	Earth's Systems: Climate Earth's Systems: Processes Space Systems and Formation Gravity's Role in Universal Movement	Matter and Energy in Systems Application of Motion in Systems

AzSS: Organized by Core Idea of Knowing Science

Arizona State Science Standards
Distribution of Core Ideas in Know Science across Grade Levels

Knowing Science	Knowing Science	K	1	2	3	4	5	6	7	8	HS
P1 Physical Science	All matter in the Universe is made of very small particles.			■			■	■		■	■
P2: Physical Science	Objects can affect other objects at a distance.	■	■		■	■	■	■	■		■
P3: Physical Science	Changing the movement of an object requires a net force to be acting on it.		■				■		■		■
P4: Physical Science	The total amount of energy in a closed system is always the same but can be transferred from one energy store to another during an event.		■	■	■	■	■	■		■	■

Knowing Science	Knowing Science	K	1	2	3	4	5	6	7	8	HS
E1 Earth & Space Science	The composition of the Earth and its atmosphere and the natural and human processes occurring within them shape the Earth's surface and its climate.	■	■	■	■	■		■	■	■	■
E2: Earth & Space Science	The Earth and our solar system are a very small part of one of many galaxies within the Universe.	■		■			■	■			■

Knowing Science	Knowing Science	K	1	2	3	4	5	6	7	8	HS
L1 Life Science	Organisms are organized on a cellular basis and have a finite life span.	■	■		■				■		■
L2: Life Science	Organisms require a supply of energy and materials for which they often depend on, or compete with, other organisms.	■	■	■	■			■	■		■
L3: Life Science	Genetic information is passed down from one generation of organisms to another.		■				■			■	■
L4: Life Science	The unity and diversity of organisms, living and extinct, is the result of evolution.		■			■	■			■	■

The Core Ideas for knowing and using science came from a resource document called *Working with Big Ideas of Science Education*. The purpose of this publication is to update the discussion and conclusions about the essential understanding in science that all students should acquire during their K-12 education. Science education also needs to take account of changes in the work place that require ability to link science with engineering, technology, and mathematics (STEM); the urgent need for attention to major global issues such as the adverse impacts of climate change; the positive and negative influences of student assessment and the growing contribution of neurosciences to the understanding of learning. All of these add to the reasons for the development of *Big Ideas* to provide a framework for decisions about science education. You can review the Core Ideas of knowing and using science to the *Big Ideas* outlined in *Working with Big Ideas of Science Education.*

Working with Big Ideas of Science Education and AzSS Comparison

Working wih Big Ideas of Science Education	Az Core Ideas of Knowing and Using Science
1. All matter in the Universe is made of very small particles	P1: All matter in the Universe is made of very small particles
2. Objects can affect other objects at a distance	P2: Objects can affect other objects at a distance
3. Changing the movement of an object requires a net force to be acting on it	P3: Changing the movement of an object requires a net force to be acting on it.
4. The total amount of energy in the Universe is always the same but can transferred from one energy store to another during an event	P4: The total amount of energy in a closed system is always the same but can be transferred from one energy store to another during an event.
5. The composition of the Earth and its atmosphere and the processes occurring within them shape the Earth's surface and its climate	E1: The composition of the Earth and its atmosphere and the natural and human processes occurring within them shape the Earth's surface and its climate.
6. Our solar system is a very small part of one of billions of galaxies in the Universe	E2: The Earth and our solar system are a very small part of one of many galaxies within the Universe.
7. Organisms are organized on a cellular basis and have a finite life span	L1: Organisms are organized on a cellular basis and have a finite life span.
8. Organisms require a supply of energy and materials for which they often depend on, or compete with, other organisms	L2: Organisms require a supply of energy and materials for which they often depend on, or compete with, other organisms.
9. Genetic information is passed down from one generation of organisms to another	L3: Genetic information is passed down from one generation of organisms to another.
10. The diversity of organisms, living and extinct, is the result of evolution	L4: The unity and diversity of organisms, living and extinct, is the result of evolution.
11. Science is about finding the cause or causes of phenomena in the natural world	U1: Scientists explain phenomena using evidence obtained from observations and or scientific investigations. Evidence may lead to developing models and or theories to make sense of phenomena. As new evidence is discovered, models and theories can be revised.
12. Scientific explanations, theories and models are those that best fit the evidence available at a particular time	
13. The knowledge produced by science is used in engineering and technologies to create products	U2: The knowledge produced by science is used in engineering and technologies to solve problems and/or create products.
14. Applications of science often have ethical, social, economic and political implications	U3: Applications of science often have both positive and negative ethical, social, economic, and/or political implications.

Science and Engineering Practices Vertical Progression

K-12 Science and Engineering Practices Progression Matrix of Elements

For use with Arizona Science Standards for Mesa Public Schools

Science and Engineering Practices	K–2 Condensed Practices	3–5 Condensed Practices	6–8 Condensed Practices	9–12 Condensed Practices
Asking Questions and Defining Problems A practice of science is to ask and refine questions that lead to descriptions and explanations of how the natural and designed world works and which can be empirically tested. Engineering questions clarify problems to determine criteria for successful solutions and identify constraints to solve problems about the designed world. Both scientists and engineers also ask questions to clarify ideas.	Asking questions and defining problems in grades K–2 builds on prior experiences and progresses to simple descriptive questions that can be tested. ▪ Ask questions based on observations of the natural and/or designed world. ▪ Define a simple problem that can be solved through the development of a new or improved object or tool.	Asking questions and defining problems in grades 3–5 builds from grades K–2 experiences and progresses to specifying qualitative relationships. ▪ Identify scientific (testable) and non-scientific (non-testable) questions. ▪ Ask questions based on careful observations of phenomena and information. ▪ Ask questions to clarify ideas or request evidence. ▪ Ask questions that relate one variable to another variable. ▪ Ask questions to clarify the constraints of solutions to a problem. ▪ Use prior knowledge to describe problems that can be solved. ▪ Define a simple design problem that can be solved through the development of an object, tool or process and includes several criteria for success and constraints on materials, time, or cost. ▪ Formulate questions that can be investigated and predict reasonable outcomes based on patterns such as cause and effect relationships.	Asking questions and defining problems in grades 6–8 builds from grades K–5 experiences and progresses to formulating and refining empirically testable models that support explanations of phenomena or solutions to problems. ▪ Ask questions that arise from careful observation of phenomena, models, or unexpected results. ▪ Ask questions to clarify or identify evidence and the premise(s) of an argument. ▪ Ask questions to determine relationships between independent and dependent variables. ▪ Ask questions that challenge the interpretation of a data set. ▪ Ask questions to clarify and refine a model, an explanation, or an engineering problem. ▪ 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. ▪ Formulate a question that can be investigated within the scope of the classroom, school laboratory, or field with available resources and, when appropriate, frame a hypothesis (a possible explanation that predicts a particular and stable outcome) based on a model or theory.	Asking questions and defining problems in grades 9–12 builds from grades K–8 experiences and progresses to formulating, refining, and evaluating empirically testable questions and design solutions using models and simulations. ▪ Ask questions that arise from careful observation of phenomena, models, theory, or unexpected results. ▪ Ask questions that require relevant empirical evidence to answer. ▪ Ask questions to determine relationships, including quantitative relationships, between independent and dependent variables. ▪ Ask and evaluate questions that challenge the premise of an argument, the interpretation of a data set, or the suitability of a design. ▪ Define a design problem that involves the development of a process or system with interacting components and criteria and constraints that may include social, technical and/or environmental considerations

Science and Engineering Practices	K–2 Condensed Practices	3–5 Condensed Practices	6–8 Condensed Practices	9–12 Condensed Practices
Developing and Using Models A practice of both science and engineering is to use and construct models as helpful tools for representing ideas and explanations. These tools include diagrams, drawings, physical replicas, mathematical representations, analogies, and computer simulations. Modeling tools are used to develop questions, predictions and explanations; analyze and identify flaws in systems; and communicate ideas. Models are used to build and revise scientific explanations and proposed engineered systems. Measurements and observations are used to revise models and designs.	Modeling in K–2 builds on prior experiences and progresses to include identifying, using, and developing models that represent concrete events or design solutions. - Distinguish between a model and the actual object, process, and/or events the model represents. - Compare models to identify common features and differences. - Develop and/or use models (i.e., diagrams, drawings, physical replicas, dioramas, dramatizations, or storyboards) that represent amounts, relationships, relative scales (bigger, smaller), and/or patterns in the natural and designed worlds. - Develop a simple model that represents a proposed object or tool.	Modeling in 3–5 builds on K–2 models and progresses to building and revising simple models and using models to represent events and design solutions. - Develop and revise models collaboratively to measure and explain frequent and regular events. - Develop a model using an analogy, example, or abstract representation to describe a scientific principle or design solution. - Use simple models to describe or support explanations for phenomena and test cause and effect relationships or interactions concerning the functioning of a natural or designed system. - Identify limitations of models. - Develop a diagram or simple physical prototype to convey a proposed object, tool or process. - Use a simple model to test cause and effect relationships concerning the functioning of a proposed object, tool or process.	Modeling in 6–8 builds on K–5 and progresses to developing, using, and revising models to support explanations, describe, test, and predict more abstract phenomena and design systems. - Use and/or develop models to predict, describe, support explanations, and/or collect data to test ideas about phenomena in natural or designed systems, including those representing inputs and outputs, and those at unobservable scales. - Develop models to describe unobservable mechanisms. - Modify models—based on their limitations—to increase detail or clarity, or to explore what will happen if a component is changed. - Use and develop models of simple systems with uncertain and less predictable factors. - Develop a model that allows for manipulation and testing of a proposed object, tool, process or system. - Evaluate limitations of a model for a proposed object or tool.	Modeling in 9–12 builds on K–8 and progresses to using, synthesizing, and developing models to predict and explain relationships between systems and their components in the natural and designed world. - Use multiple types of models to represent and support explanations of phenomena, and move flexibly between model types based on merits and limitations. - Develop, revise, and use models to predict and support explanations of relationships between systems or between components of a system. - Use models (including mathematical and computational) to generate data to support explanations and predict phenomena, analyze systems, and solve problems. - Design a test of a model to ascertain its reliability. - Develop a complex model that allows for manipulation and testing of a proposed process or system. - Evaluate merits and limitations of two different models of the same proposed tool, process, or system in order to select or revise a model that best fits the evidence or design criteria.

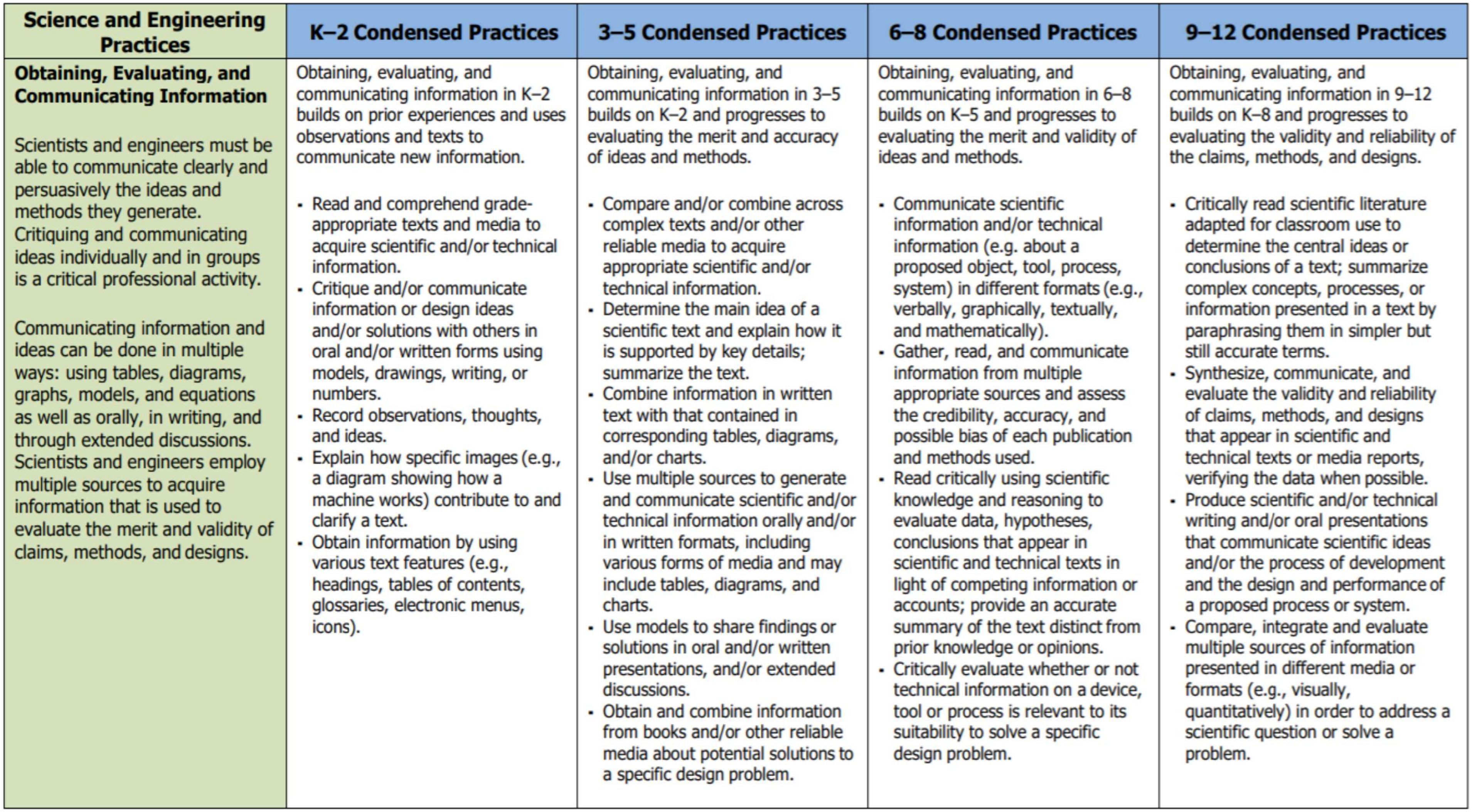
Science and Engineering Practices	K–2 Condensed Practices	3–5 Condensed Practices	6–8 Condensed Practices	9–12 Condensed Practices
Planning and Carrying Out Investigations Scientists and engineers plan and carry out investigations in the field or laboratory, working collaboratively as well as individually. Their investigations are systematic and require clarifying what counts as data and identifying variables or parameters. Engineering investigations identify the effectiveness, efficiency, and durability of designs under different conditions.	Planning and carrying out investigations to answer questions or test solutions to problems in K–2 builds on prior experiences and progresses to simple investigations, based on fair tests, which provide data to support explanations or design solutions. - With guidance, design and conduct investigations in collaboration with peers. - Design and conduct investigations collaboratively. - Evaluate different ways of observing and/or measuring an attribute of interest. - Make direct or indirect observations and/or measurements to collect data, which can be used to make comparisons. - Identify questions and make predictions based on prior experiences. - Make direct or indirect observations and/or measurements of a proposed object or tool or solution to determine if it solves a problem or meets a goal.	Planning and carrying out investigations to answer questions or test solutions to problems in 3–5 builds on K–2 experiences and progresses to include investigations that control variables and provide evidence to support explanations or design solutions. - Design and conduct investigations collaboratively, using fair tests in which variables are controlled and the number of trials considered. - Evaluate appropriate methods and tools for collecting data. - Make observations and/or measurements, collect appropriate data, and identify patterns that provide evidence for an explanation of a phenomenon or test a design solution. - Make measurements of two different models of the same proposed object, tool or process to determine which better meets criteria for success.	Planning and carrying out investigations to answer questions or test solutions to problems in 6–8 builds on K–5 experiences and progresses to include investigations that use multiple variables and provide evidence to support explanations or design solutions. - Conduct an investigation and evaluate and revise the experimental design to ensure that the data generated can meet the goals of the experiment. - Design an investigation individually and collaboratively, and in the design: identify independent and dependent variables and controls, what tools are needed to do the gathering, how measurements will be recorded, and how much data are needed to support their claim. - Evaluate the accuracy of various methods for collecting data. - Collect data and generate evidence to answer scientific questions or test design solutions under a range of conditions. - Collect data about the performance of a proposed object, tool, process or system under a range of conditions.	Planning and carrying out investigations to answer questions or test solutions to problems in 9–12 builds on K–8 experiences and progresses to include investigations that build, test, and revise conceptual, mathematical, physical, and empirical models. - Design an investigation individually and collaboratively and test designs as part of building and revising models, supporting explanations for phenomena, or testing solutions to problems. Consider possible confounding variables or effects and evaluate the investigation's design to ensure variables are controlled. - Design and conduct an investigation individually and collaboratively, 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. - Select appropriate tools to collect, record, analyze, and evaluate data. - Design and conduct investigations and test design solutions in a safe and ethical manner including considerations of environmental, social, and personal impacts. - Manipulate variables and collect data about a complex model of a proposed process or system to identify failure points or improve performance relative to criteria for success or other variables. - Use investigations to gather evidence to support explanations or concepts.

Science and Engineering Practices	K–2 Condensed Practices	3–5 Condensed Practices	6–8 Condensed Practices	9–12 Condensed Practices
Analyzing and Interpreting Data Scientific investigations produce data that must be analyzed in order to derive meaning. Because data patterns and trends are not always obvious, scientists use a range of tools—including tabulation, graphical interpretation, visualization, and statistical analysis—to identify the significant features and patterns in the data. Scientists identify sources of error in the investigations and calculate the degree of certainty in the results. Modern technology makes the collection of large data sets much easier, providing secondary sources for analysis. Engineering investigations include analysis of data collected in the tests of designs. This allows comparison of different solutions and determines how well each meets specific design criteria—that is, which design best solves the problem within given constraints. Like scientists, engineers require a range of tools to identify patterns within data and interpret the results. Advances in science make analysis of proposed solutions more efficient and effective.	Analyzing data in K–2 builds on prior experiences and progresses to collecting, recording, and sharing observations. - Use and share pictures, drawings, and/or writings of observations. - Use observations to describe patterns and/or relationships in the natural and designed worlds in order to answer scientific questions and solve problems. - Make measurements of length to quantify data. - Analyze data from tests of an object or tool to determine if a proposed object or tool functions as intended.	Analyzing data in 3–5 builds on K–2 and progresses to introducing quantitative approaches to collecting data and conducting multiple trials of qualitative observations. - Display data in tables and graphs, using digital tools when feasible, to reveal patterns that indicate relationships. - Use data to evaluate claims about cause and effect. - Compare data collected by different groups in order to discuss similarities and differences in their findings. - Use data to evaluate and refine design solutions. - Interpret data to make sense of and explain phenomena, using logical reasoning, mathematics, and/or computation. - Analyze data to refine a problem statement or the design of a proposed object, tool or process.	Analyzing data in 6–8 builds on K–5 and progresses to extending quantitative analysis to investigations, distinguishing between correlation and causation, and basic statistical techniques of data and error analysis. - Apply concepts of statistics and probability (including mean, median, mode, and variability) to analyze and characterize data, using digital tools when feasible. - Construct, analyze, and interpret graphical displays of data to identify linear and nonlinear relationships. - Consider limitations of data analysis (e.g., measurement error), and seek to improve precision and accuracy of data with better technological tools and methods (e.g., multiple trials). - Analyze and interpret data in order to determine similarities and differences in findings. - Distinguish between causal and correlational relationships. - Use graphical displays (e.g., maps) of large data sets to identify temporal and spatial relationships. - Analyze data to define an optimal operational range for a proposed object, tool, process or system that best meets criteria for success.	Analyzing data in 9–12 builds on K–8 and progresses to introducing more detailed statistical analysis, the comparison of data sets for consistency, and the use of models to generate and analyze data. - Use tools, technologies, and/or models (e.g., computational, mathematical) to generate and analyze data in order to make valid and reliable scientific claims or determine an optimal design solution. - Consider limitations (e.g., measurement error, sample selection) when analyzing and interpreting data. - Apply concepts of statistics and probability (including determining function fits to data, slope, intercept, and correlation coefficient for linear fits) to scientific and engineering questions and problems, using digital tools when feasible. - Compare and contrast various types of data sets (e.g., self-generated, archival) to examine consistency of measurements and observations. - Analyze data to identify design features or characteristics of the components of a proposed process or system to optimize it relative to criteria for success. - Evaluate the impact of new data on a working explanation of a proposed process or system.

Science and Engineering Practices	K–2 Condensed Practices	3–5 Condensed Practices	6–8 Condensed Practices	9–12 Condensed Practices
Using Mathematics and Computational Thinking In both science and engineering, mathematics and computation are fundamental tools for representing physical variables and their relationships. They are used for a range of tasks such as constructing simulations; solving equations exactly or approximately; and recognizing, expressing, and applying quantitative relationships. Mathematical and computational approaches enable scientists and engineers to predict the behavior of systems and test the validity of such predictions.	Mathematical and computational thinking at the K–2 level builds on prior experience and progresses to recognizing that mathematics can be used to describe the natural and designed world · Decide when to use qualitative vs. quantitative data. · Use counting and numbers to identify and describe patterns in the natural and designed worlds. · Describe, measure, and compare quantitative attributes of different objects and display the data using simple graphs. · Use quantitative data to compare two alternative solutions to a problem.	Mathematical and computational thinking at the 3–5 level builds on K–2 and progresses to extending quantitative measurements to a variety of physical properties and using computation and mathematics to compare alternative design solutions. · Use mathematical thinking and/or computational outcomes to compare alternative solutions to an engineering problem. · Organize simple data sets to reveal patterns that suggest relationships. · Describe, measure, estimate, and graph quantities such as area, volume, weight, and time to address scientific and engineering questions and problems. · Decide if qualitative or quantitative data is best to determine whether a proposed object or tool meets criteria for success.	Mathematical and computational thinking at the 6–8 level builds on K–5 and progresses to identifying patterns in large data sets and using mathematical concepts to support explanations and arguments. · Use digital tools (e.g., computers) to analyze very large data sets for patterns and trends. · Create algorithms (a series of ordered steps) to solve a problem. · Apply concepts of ratio, rate, percent, basic operations, and simple algebra to scientific and engineering questions and problems. · Use mathematical arguments to describe and support scientific conclusions and design solutions. · Use digital tools, mathematical concepts, and arguments to test and compare proposed solutions to an engineering design problem.	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 or algorithmic representations of phenomena or design solutions to describe and support claims and explanations, and create computational models or simulations. · Apply techniques of algebra and functions to represent and solve scientific and engineering problems. · Use simple limit cases to test mathematical expressions, computer programs, algorithms, or simulations of a process or system to see if a model "makes sense" by comparing the outcomes with what is known about the real world. · Create a simple computational model or simulation of a designed device, process, or system.

Science and Engineering Practices	K–2 Condensed Practices	3–5 Condensed Practices	6–8 Condensed Practices	9–12 Condensed Practices
Constructing Explanations and Designing Solutions *The end-products of science are explanations and the end-products of engineering are solutions.* The goal of science is the construction of theories that provide explanatory accounts of the world. A theory becomes accepted when it has multiple lines of empirical evidence and greater explanatory power of phenomena than previous theories. The goal of engineering design is to find a systematic solution to problems that is based on scientific knowledge and models of the material world. Each proposed solution results from a process of balancing competing criteria of desired functions, technical feasibility, cost, safety, aesthetics, and compliance with legal requirements. The optimal choice depends on how well the proposed solutions meet criteria and constraints.	Constructing explanations and designing solutions in K–2 builds on prior experiences and progresses to the use of evidence or ideas in constructing explanations and designing solutions. • Use information from direct or indirect observations to construct explanations. • Use tools and materials provided to design a device or solution to a specific problem. • Distinguish between opinions and evidence in one's own explanations. • Generate and compare multiple solutions to a problem.	Constructing explanations and designing solutions in 3–5 builds on prior experiences in K–2 and progresses to the use of evidence in constructing multiple explanations and designing multiple solutions. • Construct explanations of observed quantitative relationships (e.g., the distribution of plants in the back yard). • Use evidence (e.g., measurements, observations, patterns) to construct a scientific explanation or design a solution to a problem. • Identify the evidence that supports particular points in an explanation. • Distinguish among facts, reasoned judgment based on research findings, and speculation in an explanation. • Apply scientific knowledge to solve design problems. • Generate and compare multiple solutions to a problem based on how well they meet the criteria and constraints of the problem.	Constructing explanations and designing solutions in 6–8 builds on K–5 experiences and progresses to include constructing explanations and designing solutions supported by multiple sources of evidence consistent with scientific knowledge, principles, and theories. • Construct explanations for either qualitative or quantitative relationships between variables. • Apply scientific reasoning to show why the data are adequate for the explanation or conclusion. • Base explanations on evidence obtained from sources (including their own experiments) and the assumption that natural laws operate today as they did in the past and will continue to do so in the future. • Undertake design projects, engaging in the design cycle, to construct and implement a solution that meets specific design criteria and constraints. • Apply scientific knowledge and evidence to explain real-world phenomena, examples, or events. • Construct explanations from models or representations. • Apply scientific knowledge to design, construct, and test a design of an object, tool, process or system. • Optimize performance of a design by prioritizing criteria, making tradeoffs, testing, revising, and re-testing.	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 knowledge, principles, and theories. • Make quantitative and qualitative claims regarding the relationship between dependent and independent variables. • Apply scientific reasoning, theory, and models to link evidence to claims to assess the extent to which the reasoning and data support the explanation or conclusion. • Construct and revise explanations based on evidence obtained from a variety of sources (e.g., scientific principles, models, theories, simulations) and peer review. • Base causal explanations on valid and reliable empirical evidence from multiple sources and the assumption that natural laws operate today as they did in the past and will continue to do so in the future. • Apply scientific knowledge and evidence to explain phenomena and solve design problems, taking into account possible unanticipated effects. • Design, evaluate, and refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations.

Science and Engineering Practices	K–2 Condensed Practices	3–5 Condensed Practices	6–8 Condensed Practices	9–12 Condensed Practices
Engaging in Argument from Evidence *Argumentation is the process by which explanations and solutions are reached.* In science and engineering, reasoning and argument based on evidence are essential to identifying the best explanation for a natural phenomenon or the best solution to a design problem. Scientists and engineers use argumentation to listen to, compare, and evaluate competing ideas and methods based on merits. Scientists and engineers engage in argumentation when investigating a phenomenon, testing a design solution, resolving questions about measurements, building data models, and using evidence to identify strengths and weaknesses of claims.	Engaging in argument from evidence in K–2 builds on prior experiences and progresses to comparing ideas and representations about the natural and designed world. • Identify arguments that are supported by evidence. • Listen actively to others' explanations and arguments and ask questions for clarification. • Make a claim about the effectiveness of an object, tool, or solution that is based on relevant evidence.	Engaging in argument from evidence in 3–5 builds from K–2 experiences and progresses to critiquing the scientific explanations or solutions proposed by peers by citing relevant evidence about the natural and designed world. • Construct and/or support scientific arguments with evidence, data, and/or a model. • Compare and refine arguments based on the strengths and weaknesses of the evidence presented. • Respectfully provide and receive critiques on scientific arguments with peers by citing relevant evidence and posing specific questions. • Make a claim about the merit of a solution to a problem by citing relevant evidence about how it meets the criteria and constraints of the problem.	Engaging in argument from evidence in 6–8 builds from 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. • Construct, use, and present oral and written arguments supported by empirical evidence and scientific reasoning to support or refute an explanation for a phenomenon or a solution to a problem. • Evaluate competing design solutions based on jointly developed and agreed-upon design criteria. • Respectfully provide and receive critiques on scientific arguments by citing relevant evidence and posing and responding to questions that elicit pertinent elaboration and detail. • Compare two arguments on the same topic and analyze whether they emphasize similar or different evidence and/or interpretations of facts. • Make an oral or written argument that supports or refutes the advertised performance of a device, process, or system, based on empirical evidence concerning whether or not the technology meets relevant criteria and constraints.	Engaging in argument from evidence in 9–12 builds from K–8 experiences and progresses to using appropriate and sufficient evidence and scientific reasoning to defend and critique claims and explanations about the natural and designed world. Arguments may also come from current scientific or historical episodes in science. • Critique and evaluate competing arguments, models, and/or design solutions in light of new evidence, limitations (e.g., trade-offs), constraints, and ethical issues. • Evaluate the claims, evidence, and reasoning behind currently accepted explanations or solutions to determine the merits of arguments. • Construct a counter-argument that is based on data and evidence that challenges another proposed argument. • Make and defend a claim about the natural world or the effectiveness of a design solution that reflects scientific knowledge, and student-generated evidence. • Evaluate a claim for a design solution to a real-world problem based on scientific knowledge, empirical evidence, and logical arguments regarding relevant factors (e.g. economic, societal, environmental, ethical considerations).



Science and Engineering Practices	K–2 Condensed Practices	3–5 Condensed Practices	6–8 Condensed Practices	9–12 Condensed Practices
Obtaining, Evaluating, and Communicating Information Scientists and engineers must be able to communicate clearly and persuasively the ideas and methods they generate. Critiquing and communicating ideas individually and in groups is a critical professional activity. Communicating information and ideas can be done in multiple ways: using tables, diagrams, graphs, models, and equations as well as orally, in writing, and through extended discussions. Scientists and engineers employ multiple sources to acquire information that is used to evaluate the merit and validity of claims, methods, and designs.	Obtaining, evaluating, and communicating information in K–2 builds on prior experiences and uses observations and texts to communicate new information. - Read and comprehend grade-appropriate texts and media to acquire scientific and/or technical information. - Critique and/or communicate information or design ideas and/or solutions with others in oral and/or written forms using models, drawings, writing, or numbers. - Record observations, thoughts, and ideas. - Explain how specific images (e.g., a diagram showing how a machine works) contribute to and clarify a text. - Obtain information by using various text features (e.g., headings, tables of contents, glossaries, electronic menus, icons).	Obtaining, evaluating, and communicating information in 3–5 builds on K–2 and progresses to evaluating the merit and accuracy of ideas and methods. - Compare and/or combine across complex texts and/or other reliable media to acquire appropriate scientific and/or technical information. - Determine the main idea of a scientific text and explain how it is supported by key details; summarize the text. - Combine information in written text with that contained in corresponding tables, diagrams, and/or charts. - Use multiple sources to generate and communicate scientific and/or technical information orally and/or in written formats, including various forms of media and may include tables, diagrams, and charts. - Use models to share findings or solutions in oral and/or written presentations, and/or extended discussions. - Obtain and combine information from books and/or other reliable media about potential solutions to a specific design problem.	Obtaining, evaluating, and communicating information in 6–8 builds on K–5 and progresses to evaluating the merit and validity of ideas and methods. - Communicate scientific information and/or technical information (e.g. about a proposed object, tool, process, system) in different formats (e.g., verbally, graphically, textually, and mathematically). - Gather, read, and communicate information from multiple appropriate sources and assess the credibility, accuracy, and possible bias of each publication and methods used. - Read critically using scientific knowledge and reasoning to evaluate data, hypotheses, conclusions that appear in scientific and technical texts in light of competing information or accounts; provide an accurate summary of the text distinct from prior knowledge or opinions. - Critically evaluate whether or not technical information on a device, tool or process is relevant to its suitability to solve a specific design problem.	Obtaining, evaluating, and communicating information in 9–12 builds on K–8 and progresses to evaluating the validity and reliability of the claims, methods, and designs. - Critically read scientific literature adapted for classroom use to determine the central ideas or conclusions of a text; summarize complex concepts, processes, or information presented in a text by paraphrasing them in simpler but still accurate terms. - Synthesize, communicate, and evaluate the validity and reliability of claims, methods, and designs that appear in scientific and technical texts or media reports, verifying the data when possible. - Produce scientific and/or technical writing and/or oral presentations that communicate scientific ideas and/or the process of development and the design and performance of a proposed process or system. - Compare, integrate and evaluate multiple sources of information presented in different media or formats (e.g., visually, quantitatively) in order to address a scientific question or solve a problem.

azed.gov

Crosscutting Concepts Vertical Progression

K-12 Crosscutting Concepts Progression Matrix of Elements

For use with Arizona Science Standards for Mesa Public Schools

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

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

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

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

3. Scale, Proportion, and Quantity – In considering phenomena, it is critical to recognize what is relevant at different size, time, and energy scales, and to recognize proportional relationships between different quantities as scales change.

K-2 Crosscutting Statements	3-5 Crosscutting Statements	6-8 Crosscutting Statements	9-12 Crosscutting Statements
▪ Relative scales allow objects and events to be compared and described (e.g., bigger and smaller; hotter and colder; faster and slower). ▪ Standard units are used to measure length.	▪ Natural objects and/or observable phenomena exist from the very small to the immensely large or from very short to very long time periods. ▪ Standard units are used to measure and describe physical quantities such as weight, time, temperature, and volume.	▪ Time, space, and energy phenomena can be observed at various scales using models to study systems that are too large or too small. ▪ The observed function of natural and designed systems may change with scale. ▪ Proportional relationships (e.g., speed as the ratio of distance traveled to time taken) among different types of quantities provide information about the magnitude of properties and processes. ▪ Scientific relationships can be represented through the use of algebraic expressions and equations. ▪ Phenomena that can be observed at one scale may not be observable at another scale.	▪ The significance of a phenomenon is dependent on the scale, proportion, and quantity at which it occurs. ▪ Some systems can only be studied indirectly as they are too small, too large, too fast, or too slow to observe directly. ▪ Patterns observable at one scale may not be observable or exist at other scales. ▪ Using the concept of orders of magnitude allows one to understand how a model at one scale relates to a model at another scale. ▪ Algebraic thinking is used to examine scientific data and predict the effect of a change in one variable on another (e.g., linear growth vs. exponential growth).

4. Systems and System Models – A system is an organized group of related objects or components; models can be used for understanding and predicting the behavior of systems.

K-2 Crosscutting Statements	3-5 Crosscutting Statements	6-8 Crosscutting Statements	9-12 Crosscutting Statements
▪ Objects and organisms can be described in terms of their parts. ▪ Systems in the natural and designed world have parts that work together.	▪ A system is a group of related parts that make up a whole and can carry out functions its individual parts cannot. ▪ A system can be described in terms of its components and their interactions.	▪ Systems may interact with other systems; they may have sub-systems and be a part of larger complex systems. ▪ Models can be used to represent systems and their interactions—such as inputs, processes and outputs—and energy, matter, and information flows within systems. ▪ Models are limited in that they only represent certain aspects of the system under study.	▪ Systems can be designed to do specific tasks. ▪ When investigating or describing a system, the boundaries and initial conditions of the system need to be defined and their inputs and outputs analyzed and described using models. ▪ Models (e.g., physical, mathematical, computer models) can be used to simulate systems and interactions—including energy, matter, and information flows—within and between systems at different scales. ▪ Models can be used to predict the behavior of a system, but these predictions have limited precision and reliability due to the assumptions and approximations inherent in models.

5. Energy and Matter: Flows, Cycles, and Conservation – Tracking energy and matter flows, into, out of, and within systems helps one understand their system's behavior.

K-2 Crosscutting Statements	3-5 Crosscutting Statements	6-8 Crosscutting Statements	9-12 Crosscutting Statements
▪ Objects may break into smaller pieces, be put together into larger pieces, or change shapes.	▪ Matter is made of particles. ▪ Matter flows and cycles can be tracked in terms of the weight of the substances before and after a process occurs. The total weight of the substances does not change. This is what is meant by conservation of matter. Matter is transported into, out of, and within systems. ▪ Energy can be transferred in various ways and between objects.	▪ Matter is conserved because atoms are conserved in physical and chemical processes. ▪ Within a natural or designed system, the transfer of energy drives the motion and/or cycling of matter. ▪ Energy may take different forms (e.g. energy in fields, thermal energy, energy of motion). ▪ The transfer of energy can be tracked as energy flows through a designed or natural system.	▪ The total amount of energy and matter in closed systems is conserved. ▪ 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. ▪ Energy cannot be created or destroyed—only moves between one place and another place, between objects and/or fields, or between systems. ▪ Energy drives the cycling of matter within and between systems. ▪ In nuclear processes, atoms are not conserved, but the total number of protons plus neutrons is conserved.

6. Structure and Function – The way an object is shaped or structured determines many of its properties and functions.

K-2 Crosscutting Statements	3-5 Crosscutting Statements	6-8 Crosscutting Statements	9-12 Crosscutting Statements
▪ The shape and stability of structures of natural and designed objects are related to their function(s).	▪ Different materials have different substructures, which can sometimes be observed. ▪ Substructures have shapes and parts that serve functions.	▪ Complex and microscopic structures and systems can be visualized, modeled, and used to describe how their function depends on the shapes, composition, and relationships among its parts; therefore, complex natural and designed structures/systems can be analyzed to determine how they function. ▪ Structures can be designed to serve particular functions by taking into account properties of different materials, and how materials can be shaped and used.	▪ Investigating or designing new systems or structures requires a detailed examination of the properties of different materials, the structures of different components, and connections of components to reveal its function and/or solve a problem. ▪ The functions and properties of natural and designed objects and systems can be inferred from their overall structure, the way their components are shaped and used, and the molecular substructures of its various materials.

7. Stability and Change – For both designed and natural systems, conditions that affect stability and factors that control rates of change are critical elements to consider and understand.

K-2 Crosscutting Statements	3-5 Crosscutting Statements	6-8 Crosscutting Statements	9-12 Crosscutting Statements
▪ Some things stay the same while other things change. ▪ Things may change slowly or rapidly.	▪ Change is measured in terms of differences over time and may occur at different rates. ▪ Some systems appear stable, but over long periods of time will eventually change.	▪ Explanations of stability and change in natural or designed systems can be constructed by examining the changes over time and forces at different scales, including the atomic scale. ▪ Small changes in one part of a system might cause large changes in another part. ▪ Stability might be disturbed either by sudden events or gradual changes that accumulate over time. ▪ Systems in dynamic equilibrium are stable due to a balance of feedback mechanisms.	▪ Much of science deals with constructing explanations of how things change and how they remain stable. ▪ Change and rates of change can be quantified and modeled over very short or very long periods of time. Some system changes are irreversible. ▪ Feedback (negative or positive) can stabilize or destabilize a system. ▪ Systems can be designed for greater or lesser stability.

azed.gov

Using Science Vertical Progression

K-12 Using Science Progression Matrix of Elements

For use with Arizona Science Standards for Mesa Public Schools

U1: Scientists explain phenomena using evidence obtained from observations and or scientific investigations. Evidence may lead to developing models and or theories to make sense of phenomena. As new evidence is discovered, models and theories can be revised.			
K-2	***3-5***	***6-8***	***9-12***
U1 in grades K–2 builds on prior experiences and progresses to simple descriptive explanations of the nature of science. • Science is about finding explanations for why things happen as they do or why they take a particular form • Every event or phenomenon has a cause or causes and that there is a reason for the form things take. • An explanation is not a guess; there has to be some basis for it. • Careful observation, including measurement where possible, can suggest what may be happening. • Everyone can ask questions about things in the natural world and can do something to find answers that help explain what is happening	*U1 in grades 3-5 builds on prior experiences* from grades K-2 *and progresses* to deeper understanding of the nature of science • Science is about finding explanations for why things happen as they do or why they take a particular form • There can figure out various ways of finding out what makes things work or why they happen. • Careful observation, including accurate measurement where possible, can suggest what may be happening. • It is important to see that other things stay the same so that the result can only be the effect of changing one thing. • In science explanations are sought through some kind of systematic inquiry that involves • Collecting data by observing or measuring features of the objects being studied or using data from other sources.	*U1 in grades 6-8 builds on prior experiences* from grades 3-5 *and progresses* to deeper understanding of the nature of science. • Careful and systematic observations and accurate descriptions of what is observed are fundamental to scientific investigation. • What people expect to happen can influence what they observe, so it is good practice for observations to be made by several people independently and for results to be reported clearly enough to be checked by others.	*U1 in grades 9-12 builds on prior experiences* from grades 6-8 *and progresses* to deeper understanding of the nature of science. • Where factors cannot be experimentally manipulated, as in the case of the movement of planets in the solar system, a phenomenon can be investigated by observing systematically on several occasions and over a period of time. • Looking for patterns in the data may reveal that there is a correlation between factors – as one factor changes, so does another in a regular way. • A correlation may be used to propose a hypothesis, which can be used to make predictions, even though it may involve aspects that cannot be directly observed or changed.

U1			
K-2	**3-5**	**6-8**	**9-12**
	• Whether or not an effective explanation can be obtained depends on what data are collected and this is usually guided by having some theory or hypothesis about what might be happening.	• Different kinds of natural phenomena are explained in different ways. In some cases, a possible explanation (hypothesis) indicates the variable factor thought to cause a phenomenon. To test a hypothesis, it is used to predict what will happen when the variable identified as a possible cause is changed and then see if what happens fits the prediction. If the outcome agrees with the prediction, and no other changes are found to produce the same result, then the factor is accepted as being the cause that explains the observation. • To help in the process of explaining observations and what makes things happen, scientists create models to represent what they think may be happening. • Sometimes these are physical models, such as an orrery – a model of the solar system where various objects are used to represent the Sun, Moon, Earth and other planets – or a ball and stick model of how atoms are thought to be arranged in a substance.	• A correlation cannot usually be taken as conclusive evidence that change in one factor is the cause of the change in the other. Finding that one thing is the cause of an effect is not the same as explaining the mechanism by which the effect is brought about. • Phenomena that occurred in the past, such as rock changes or species evolution, can also be submitted to the process of hypothesis testing. • It is the coherence of all hypotheses consistent with all known facts and scientific principles which provides the best possible explanation. • Models provide ways of explaining phenomena in terms of relationships between parts of a system. They are developed through an iterative process of comparing what they predict with what is found in the real world. • Scientific explanations account for specific events or phenomena in terms of a theory or model. • Explanations do not emerge self-evidently from data but are created in a process that often involves intuition, imagination and informed hypothesis.

U1			
K-2	**3-5**	**6-8**	**9-12**
		• Other models are theoretical, more abstract, such as in representing light as a wave motion, or representing relationships as mathematical formulae. • Computer-based models enable phenomena to be simulated and variables easily changed to investigate their effect. • Others (models) are more tentative and are likely to be changed in future. • There may be more than one possible model and the evidence of which works best is not conclusive; and in other cases, we do not yet have a satisfactory explanatory model.	• A scientific theory is a well substantiated explanation of some aspect of the natural world, based on a body of facts that have been repeatedly confirmed through observation and experiment and so become well established. • If new data do not fit current ideas, then the ideas have to be changed or replaced by alternative ideas. • Although there is greater confidence in ideas or models that leads to predictions that are repeatedly and reliably confirmed by evidence – and so become regarded as facts – an explanation or theory can never be proved ‘correct’ because there is always the possibility of further data conflicting with it or because a new theory is found that also provides a good explanation.

U2: The knowledge produced by science is used in engineering and technologies to solve problems and/or create products.

K-2	3-5	6-8	9-12
U2 in grades K–2 builds on prior experiences and progresses to students to simply understand the knowledge produced by science is used in engineering and technologies to create products. • Technologies have been created by people to provide the things they need or can use, such as food, tools, clothes, somewhere to live and ways of communicating. • Materials have been changed so that they can be used for certain purposes.	*U2 in grades 3-5 builds on prior experiences from K-2 and progresses to students understanding the knowledge produced by science is used in engineering and technologies to create products.* • Technologies are developed using engineering, which involves identifying problems and using ideas of science and other ideas to design and develop the best possible solution. • There are always different ways of approaching problems, so various possibilities need to be tried out. • In order to decide which is the best solution it is necessary to be clear about what the result is intended to be and so how success is to be judged.	*U2 in grades 6-8 builds on prior experiences and progresses to students understanding the knowledge produced by science is used in engineering and technologies to create products.* • Designing a solution to a problem generally involves making a drawing or model. • Physical, mathematical or computer models enable the effect of changes in materials or design to be tested and the solution improved. • There are usually many factors to be considered in optimizing a solution, such as cost, availability of materials and impact on users and on the environment, which may constrain choices.	*U2 in grades 9-12 builds on prior experiences from 6-8 and progresses to students understanding the knowledge produced by science is used in engineering and technologies to create products.* • Science, engineering and technology are closely inter-connected. The application of science in making new materials is an example of how scientific knowledge has led advances in technology and provided engineers with a wider choice in designing constructions. • Technological advances have helped scientific developments by improving instruments for observation and measuring, automating processes that might otherwise be too dangerous or time consuming to undertake, and particularly through the provision of computers. • Technology aids scientific advances which in turn can be used in designing and making things for people to use. • Often in the past technological products have been developed empirically in advance of scientific ideas.

U2			
K-2	**3-5**	**6-8**	**9-12**
			• The application of science in designing and making new tools and machines has made mass production possible so more people have access to a range of commodities. • There are disadvantages as well as advantages to some technological products. • Although the use of some artificial materials may mean less demand on scarce natural ones, many new materials do not degrade as do natural materials, presenting a waste disposal problem when discarded. • Some technological devices such as mobile telephones and computers use metals that exist in the Earth only in small quantities and could soon be used up. • Scientists and engineers need to collaborate in understanding the problem and in finding solutions.

U3: Applications of science often have both positive and negative ethical, social, economic, and/or political implications.			
K-2	**3-5**	**6-8**	**9-12**
U3 in grades K–2 builds on prior experiences and progresses to students to simply realizing science has implications. • Understanding the natural world can often be applied to change or make things to help solve human problems.	*U3 in grades 3-5 builds on prior experiences in K-2 and progresses to students to simply realizing science has implications.* • Understanding the natural world can often be applied to change or make things to help solve human problems. • Technological solutions have improved the lives and health of many people in countries across the world. • Technology use materials from the natural world which may be in short supply or may be detrimental to the environment.	*U3 in grades 6-8 builds on prior experiences in 3-5 and progresses to students to simply realizing science has implications.* • There are generally both positive and negative consequences of the applications of science. Some negative impacts can be anticipated but others emerge from experience. • Some negative impacts can be anticipated but others emerge from experience. • Clean water, adequate food and improved medicines have increased human life expectancy but at the same time the resulting population growth has increased demands on resources and on space on the Earth’s surface for increased food production, housing and disposal of waste. This has often been detrimental to those in developing countries and resulted in the destruction of habitats of other living things, causing some to become extinct. • There are many examples of how technological and engineering advances have unintended consequences.	*U3 in grades 9-12 builds on prior experiences in 6-8 and progresses to students to simply realizing science has implications.* • All innovations consume resources of some kind, including financial resources, so decisions have to be made when there are competing demands. These decisions, whether at governmental, local or individual level, should be informed by understanding of the scientific concepts and the technological principles involved. • When designing a new system or product engineers have to take account of ethical values, political and economic realities as well as science and technology. • Scientific understanding can help to identify implications of certain applications but decisions about whether certain actions should be taken will require ethical and moral judgements which are not provided by knowledge of science.

U3			
K-2	**3-5**	**6-8**	**9-12**
		• Improved ease and speed of transport, particularly by air, burns fuel that produces carbon dioxide, one of several gases in the atmosphere that keep the Earth warm through the greenhouse effect. Increase in these gases in the atmosphere raises the Earth's temperature. Even a small increase in temperature of the Earth can have widespread effects through changes in the polar ice, sea levels and weather patterns. • If the detrimental effects are known, the trade-off between the advantages and the disadvantages of the application of science needs careful consideration.	• There is an important difference between the understanding that science provides about, for example, the need to preserve biodiversity, the factors leading to climate change and the adverse effects of harmful substances and lifestyles, and the actions that may or may not be taken in relation to these issues. • Opinions may vary about what action to take but arguments based on scientific evidence should not be a matter of opinion.

K-12 Core Ideas in Science Progression Matrix

Physical Science	P1: All matter in the Universe is made of very small particles.
2.P1U1.1	**Plan and carry out an investigation** to determine that matter has mass, takes up space, and is recognized by its observable properties; use the collected evidence to **develop and support an explanation**.
2.P1U1.2	**Plan and carry out investigations** to gather evidence to support an explanation on how heating or cooling can cause a phase change in matter.
5.P1U1.1	**Analyze and interpret data** to explain that matter of any type can be subdivided into particles too small to see and, in a closed system, if properties change or chemical reactions occur, the amount of matter stays the same.
5.P1U1.2	**Plan and carry out investigations** to demonstrate that some substances combine to form new substances with different properties and others can be mixed without taking on new properties.
6.P1U1.1	**Analyze and interpret data** to show that changes in states of matter are caused by different rates of movement of atoms in solids, liquids, and gases (Kinetic Theory).
6.P1U1.2	**Plan and carry out an investigation** to demonstrate that variations in temperature and/or pressure affect changes in state of matter.
6.P1U1.3	**Develop and use models** to represent that matter is made up of smaller particles called atoms.
8.P1U1.1	**Develop and use a model** to demonstrate that atoms and molecules can be combined or rearranged in chemical reactions to form new compounds with the total number of each type of atom conserved.
8.P1U1.2	**Obtain and evaluate information** regarding how scientists identify substances based on unique physical and chemical properties.
Essential HS.P1U1.1	**Develop and use models** to explain the relationship of the structure of atoms to patterns and properties observed within the Periodic Table and describe how these models are revised with new evidence.
Plus HS+C.P1U1.1	**Develop and use models** to demonstrate how changes in the number of subatomic particles (protons, neutrons, electrons) affect the identity, stability, and properties of the element.
Plus HS+C.P1U1.2	**Obtain, evaluate, and communicate** the qualitative evidence supporting claims about how atoms absorb and emit energy in the form of electromagnetic radiation.
Plus HS+C.P1U1.3	**Analyze and interpret data** to develop and support an explanation for the relationships between kinetic molecular theory and gas laws.
Essential HS.P1U1.2	**Develop and use models** for the transfer or sharing of electrons to predict the formation of ions, molecules, and compounds in both natural and synthetic processes.
Essential HS.P1U1.3	**Ask questions, plan, and carry out investigations** to explore the cause and effect relationship between reaction rate factors.
Plus HS+C.P1U1.4	**Develop and use models** to predict and explain forces within and between molecules.
Plus HS+C.P1U1.5	**Plan and carry out investigations** to test predictions of the outcomes of various reactions, based on patterns of physical and chemical properties.
Plus HS+C.P1U1.6	**Construct an explanation, design a solution, or refine the design** of a chemical system in equilibrium to maximize production.

Plus HS+C.P1U1.7	**Use mathematics and computational thinking** to determine stoichiometric relationships between reactants and products in chemical reactions.
Essential HS.P1U3.4	**Obtain, evaluate, and communicate information** about how the use of chemistry related technologies have had positive and negative ethical, social, economic, and/or political implications.
Plus HS+C.P1U3.8	**Engage in argument from evidence** regarding the ethical, social, economic, and/or political benefits and liabilities of fission, fusion, and radioactive decay.

Physical Science	**P2: Objects can affect other objects at a distance.**
K.P2U1.1	**Investigate** how senses can detect light, sound, and vibrations even when they come from far away; use the collected evidence to **develop and support an explanation.**
K.P2U2.2	**Design and evaluate** a tool that helps people extend their senses.
1.P2U1.1	**Plan and carry out investigations** demonstrating the effect of placing objects made with different materials in the path of a beam of light and **predict** how objects with similar properties will affect the beam of light.
1.P2U1.2	**Use models** to provide evidence that vibrating matter creates sound and sound can make matter vibrate.
3.P2U1.1	**Ask questions and investigate** the relationship between light, objects, and the human eye.
3.P2U1.2	**Plan and carry out an investigation** to explore how sound waves affect objects at varying distances.
4.P2U1.3	**Develop and use a model** to demonstrate magnetic forces.
5.P2U1.3	**Construct an explanation** using evidence to demonstrate that objects can affect other objects even when they are not touching.
6.P2U1.4	**Develop and use a model** to predict how forces act on objects at a distance.
7.P2U1.1	**Collect and analyze data** demonstrating how electromagnetic forces can be attractive or repulsive and can vary in strength.
7.P2U1.2	**Develop and use a model** to predict how forces act on objects at a distance.
Essential HS.P2U1.5	**Construct an explanation** for a field's strength and influence on an object (electric, gravitational, magnetic).
Plus HS+Phy.P2U1.1	**Plan and carry out investigations** to design, build, and refine a device that works within given constraints to demonstrate that an electric current can produce a magnetic field and that a changing magnetic field can produce an electric current.

Physical Science	**P3: Changing the movement of an object requires a net force to be acting on it.**
1.P3U1.3	**Plan and carry out investigations** which demonstrate how equal forces can balance objects and how unequal forces can push, pull, or twist objects, making them change their speed, direction, or shape.
5.P3U1.4	**Obtain, analyze, and communicate evidence** of the effects that balanced and unbalanced forces have on the motion of objects.
5.P3U2.5	**Define problems** and **design solutions** pertaining to force and motion.
7.P3U1.3	**Plan and carry out an investigation** that can support an **evidence-based explanation** of how objects on Earth are affected by gravitational force.
7.P3U1.4	**Use** non-algebraic **mathematics and computational thinking** to explain Newton's laws of motion.
Essential HS.P3U1.6	**Collect, analyze and interpret data** regarding the change in motion of an object or system in one dimension, to construct an explanation using Newton's Laws.

Plus HS+Phy.P3U1.2	**Develop and use** mathematical **models** of Newton's law of gravitation and Coulomb's law to describe and predict the gravitational and electrostatic forces between objects.
Plus HS+Phy.P3U1.3	**Develop a** mathematical **model**, using Newton's laws, to predict the motion of an object or system in **two dimensions** (projectile and circular motion).
Plus HS+Phy.P3U1.4	**Engage in argument from evidence** regarding the claim that the total momentum of a system is conserved when there is no net force on the system.
Essential HS.P3U2.7	**Use mathematics and computational thinking** to explain how Newton's laws are used in engineering and technologies to create products to serve human ends.
Plus HS+Phy.P3U2.5	**Design, evaluate,** and refine a device that minimizes or maximizes the force on a macroscopic object during a collision.

Physical Science	**P4: The total amount of energy in a closed system is always the same but can be transferred from one energy store to another during an event.**
1.P4U2.4	**Design and evaluate** ways to increase or reduce heat from friction between two objects.
2.P4U1.3	**Obtain, evaluate and communicate** information about ways heat energy can cause change in objects or materials.
3.P4U1.3	**Develop and use models** to describe how light and sound waves transfer energy.
4.P4U1.1	**Develop and use a model** to demonstrate how a system transfers energy from one object to another even when the objects are not touching.
4.P4U1.2	**Develop and use a model** that explains how energy is moved from place to place through electric currents.
4.P4U3.4	**Engage in argument from evidence** on the use and impact of renewable and nonrenewable resources to generate electricity.
5.P4U1.6	**Analyze and interpret data** to determine how and where energy is transferred when objects move.
6.P4U2.5	**Analyze** how humans use technology to store (potential) and/or use (kinetic) energy.
8.P4U1.3	**Construct an explanation** on how energy can be transferred from one energy store to another.
8.P4U1.4	**Develop and use mathematical models to explain** wave characteristics and interactions.
8.P4U2.5	**Develop a solution** to increase efficiency when transferring energy from one source to another.
Essential HS.P4U1.8	**Engage in argument from evidence** that the net change of energy in a system is always equal to the total energy exchanged between the system and the surroundings.
Essential HS.P4U3.9	**Engage in argument from evidence** regarding the ethical, social, economic, and/or political benefits and liabilities of energy usage and transfer.
Plus HS+Phy.P4U1.6	**Analyze and interpret data** to quantitatively describe changes in energy within a system and/or energy flows in and out of a system.
Plus HS+Phy.P4U2.7	**Design, evaluate**, and refine a device that works within given constraints to transfer energy within a system.
Plus HS+Phy.P4U1.8	**Use mathematics and computational thinking** to explain the relationships between power, current, voltage, and resistance.
Essential HS.P4U1.10	**Construct an explanation** about the relationships among the frequency, wavelength, and speed of waves traveling in various media, and their applications to modern technology.

Earth & Space Science	E1: The composition of the Earth and its atmosphere and the natural and human processes occurring within them shape the Earth's surface and its climate.
K.E1U1.3	**Observe, record, and ask questions** about temperature, precipitation, and other weather data to identify patterns or changes in local weather.
K.E1U1.4	**Observe, describe, ask questions, and predict** seasonal weather patterns; and how those patterns impact plants and animals (including humans).
1.E1U1.5	**Obtain, evaluate, and communicate information** about the properties of Earth materials and **investigate** how humans use natural resources in everyday life.
2.E1U1.4	**Observe and investigate** how wind and water change the shape of the land resulting in a variety of landforms.
2.E1U1.5	**Develop and use models** to represent that water can exist in different states and is found in oceans, glaciers, lakes, rivers, ponds, and the atmosphere.
2.E1U2.6	**Analyze patterns** in weather conditions of various regions of the world and **design, test, and refine solutions** to protect humans from severe weather conditions.
2.E1U3.7	**Construct an argument from evidence** regarding positive and negative changes in water and land systems that impact humans and the environment.
3.E1U1.4	**Construct an explanation** describing how the Sun is the primary source of energy impacting Earth systems.
4.E1U1.5	**Use models** to explain seismic waves and their effect on the Earth.
4.E1U1.6	**Plan and carry out an investigation** to explore and explain the interactions between Earth's major systems and the impact on Earth's surface materials and processes.
4.E1U1.7	**Develop and/or revise a model** using various rock types, fossils location, and landforms to show evidence that Earth's surface has changed over time.
4.E1U1.8	**Collect, analyze, and interpret data** to explain weather and climate patterns.
4.E1U3.9	**Construct and support an evidence-based argument** about the availability of water and its impact on life.
4.E1U2.10	**Define problem(s) and design solution(s)** to minimize the effects of natural hazards.
6.E1U1.6	**Investigate and construct an explanation** demonstrating that radiation from the Sun provides energy and is absorbed to warm the Earth's surface and atmosphere.
7.E1U1.5	**Construct a model** that shows the cycling of matter and flow of energy in the atmosphere, hydrosphere, and geosphere.
7.E1U1.6	**Construct a model** to explain how the distribution of fossils and rocks, continental shapes, and seafloor structures provides evidence of the past plate motions.
7.E1U2.7	**Analyze and interpret data to construct an explanation** for how advances in technology has improved weather prediction.
8.E1U1.6	**Analyze and interpret data** about the Earth's geological column to **communicate** relative ages of rock layers and fossils.
8.E1U3.7	**Obtain, evaluate, and communicate** information about data and historical patterns to predict natural hazards and other geological events**.**
8.E1U3.8	**Construct and support an argument** about how human consumption of limited resources impacts the biosphere.
Essential HS.E1U1.11	**Analyze and interpret data** to determine how energy from the Sun affects weather patterns and climate.
Plus HS+E.E1U1.1	**Construct an explanation** based on evidence for how the Sun's energy transfers between Earth's systems.
Plus HS+E.E1U1.2	**Develop and use models** to describe how variations in the flow of energy into and out of Earth's systems result in changes in climate.

Plus HS+E.E1U1.3	**Analyze** geoscience **data** and the results from global climate models to make evidence-based predictions of current rate and scale of global or regional climate changes.
Essential HS.E1U1.12	**Develop and use models** of the Earth that explains the role of energy and matter in Earth's constantly changing internal and external systems (geosphere, hydrosphere, atmosphere, biosphere).
Plus HS+E.E1U1.4	**Analyze and interpret** geoscience **data** to make the claim that dynamic interactions with Earth's surface can create feedbacks that cause changes to other Earth systems.
Plus HS+E.E1U1.5	**Obtain, evaluate, and communicate information** on the effect of water on Earth's materials, surface processes, and groundwater systems.
Essential HS.E1U1.13	**Evaluate explanations** and theories about the role of energy and matter in geologic changes over time.
Plus HS+E.E1U1.6	**Obtain, evaluate, and communicate information** of the theory of plate tectonics to explain the differences in age, structure, and composition of Earth's crust.
Plus HS+E.E1U1.7	**Engage in argument from evidence** of ancient Earth materials, meteorites, and other planetary surfaces to explain Earth's formation and early history.
Plus HS+E.E1U1.8	**Develop and use models** to illustrate how Earth's internal and surface processes operate over time to form, modify, and recycle continental and ocean floor features.
Essential HS.E1U3.14	**Engage in argument from evidence** about the availability of natural resources, occurrence of natural hazards, changes in climate, and human activity and how they influence each other.
Plus HS+E.E1U3.9	**Construct an explanation, based on evidence,** for how the availability of natural resources, occurrence of natural hazards, and changes in climate have influenced human activity.
Plus HS+E.E1U3.10	**Ask questions, define problems, and evaluate a solution** to a complex problem, based on prioritized criteria and tradeoffs, that account for a range of constraints, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts.
Plus HS+E.E1U3.11	**Develop and use a quantitative model** to illustrate the relationship among Earth systems and the degree to which those relationships are being modified due to human activity.

Earth & Space Science	**E2: The Earth and our solar system are a very small part of one of many galaxies within the Universe.**
K.E2U1.5	**Observe and ask questions** about patterns of the motion of the sun, moon, and stars in the sky.
2.E2U1.8	**Observe and explain** the Sun's position at different times during a twenty-four-hour period and changes in the apparent shape of the Moon from one night to another.
5.E2U1.7	**Develop, revise, and use models** based on evidence to **construct explanations** about the movement of the Earth and Moon within our solar system.
5.E2U1.8	**Obtain, analyze, and communicate evidence** to support an explanation that the gravitational force of Earth on objects is directed toward the planet's center.
6.E2U1.7	Use ratios and proportions to **analyze and interpret data** related to scale, properties, and relationships among objects in our solar system.
6.E2U1.8	**Develop and use models** to explain how constellations and other night sky patterns appear to move due to Earth's rotation and revolution.
6.E2U1.9	**Develop and use models to construct an explanation** of how eclipses, moon phases, and tides occur within the Sun-Earth-Moon system.

6.E2U1.10	**Use a model** to show how the tilt of Earth's axis causes variations in the length of the day and gives rise to seasons.
Essential **HS.E2U1.15**	**Construct an explanation** based on evidence to illustrate the role of nuclear fusion in the life cycle of a star.
Plus **HS+E.E2U1.12**	**Obtain, evaluate, and communicate scientific information** about the way stars, throughout their stellar stages, produce elements and energy
Essential **HS.E2U1.16**	**Construct an explanation** of how gravitational forces impact the evolution of planetary motion, structure, surfaces, atmospheres, moons, and rings.
Plus **HS+E.E2U1.13**	**Analyze and interpret data** showing how gravitational forces are influenced by mass, and the distance between objects.
Plus **HS+E.E2U1.14**	**Use mathematics and computational thinking** to explain the movement of planets and objects in the solar system.
Essential **HS.E2U1.17**	**Construct an explanation** of the origin, expansion, and scale of the universe based on astronomical evidence.
Plus **HS+E.E2U1.15**	**Obtain, evaluate, and communicate** information on how the nebular theory explains solar system formation with distinct regions characterized by different types of planetary and other bodies.
Plus **HS+E.E2U1.16**	**Obtain, evaluate, and communicate** information about patterns of size and scale of our solar system, our galaxy, and the universe.
Plus **HS+E.E2U2.17**	**Obtain, evaluate, and communicate** the impact of technology on human understanding of the formation, scale, and composition of the universe.

Life Science	**L1: Organisms are organized on a cellular basis and have a finite life span.**
K.L1U1.6	**Obtain, evaluate, and communicate** information about how organisms use different body parts for survival.
K.L1U1.7	**Observe, ask questions and explain** how specialized structures found on a variety of plants and animals (including humans) help them sense and respond to their environment.
1.L1U1.6	**Observe, describe, and predict** life cycles of animals and plants.
3.L1U1.5	**Develop and use models** to explain that plants and animals (including humans) have internal and external structures that serve various functions that aid in growth, survival, behavior, and reproduction.
7.L1U1.8	**Obtain, evaluate, and communicate information** to provide evidence that all living things are made of cells, cells come from existing cells, and cells are the basic structural and functional unit of all living things.
7.L1U1.9	**Construct an explanation** to demonstrate the relationship between major cell structures and cell functions (plant and animal).
7.L1U1.10	**Develop and use a model** to explain how cells, tissues, and organ systems maintain life (animals).
7.L1U1.11	**Construct an explanation** for how organisms maintain internal stability and evaluate the effect of the external factors on organisms' internal stability.
Essential **HS.L1U1.20**	**Ask questions and/or make predictions** based on observations and evidence to demonstrate how cellular organization, structure, and function allow organisms to maintain homeostasis.
Plus **HS+B.L1U1.4**	**Develop and use models** to explain the interdependency and interactions between cellular organelles.

Plus **HS+B.L1U1.5**	**Analyze and interpret data** that demonstrates the relationship between cellular function and the diversity of protein functions.
Plus **HS+B.L1U1.6**	**Develop and use models** to show how transport mechanisms function in cells.
Plus **HS+B.L1U1.7**	**Develop and use models** to illustrate the hierarchical organization of interacting systems that provide specific functions within multicellular organisms (plant and animal).
Essential **HS.L1U1.22**	**Construct an explanation** for how cellular division (mitosis) is the process by which organisms grow and maintain complex, interconnected systems.
Essential **HS.L1U3.23**	**Obtain, evaluate, and communicate** the ethical, social, economic and/or political implications of the detection and treatment of abnormal cell function.
Plus **HS+B.L1U1.9**	**Develop and use a model** to **communicate** how a cell copies genetic information to make new cells during asexual reproduction (mitosis).

Life Science	**L2: Organisms require a supply of energy and materials for which they often depend on, or compete with, other organisms.**
K.L2U1.8	**Observe, ask questions, and explain** the differences between the characteristics of living and non-living things.
1.L2U2.7	**Develop and use models** about how living things use resources to grow and survive; **design and evaluate** habitats for organisms using earth materials.
1.L2U1.8	**Construct an explanation** describing how organisms obtain resources from the environment including materials that are used again by other organisms.
2.L2U1.9	**Obtain, analyze, and communicate evidence** that organisms need a source of energy, air, water, and certain temperature conditions to survive.
2.L2U1.10	**Develop a model** representing how life on Earth depends on energy from the Sun and energy from other organisms.
3.L2U1.6	**Plan and carry out investigations** to demonstrate ways plants and animals react to stimuli.
3.L2U1.7	**Develop and use system models** to describe the flow of energy from the Sun to and among living organisms.
3.L2U1.8	**Construct an argument from evidence** that organisms are interdependent.
6.L2U3.11	**Use evidence** to **construct an argument** regarding the impact of human activities on the environment and how they positively and negatively affect the competition for energy and resources in ecosystems.
6.L2U3.12	**Engage in argument from evidence** to support a claim about the factors that cause species to change and how humans can impact those factors.
6.L2U1.13	**Develop and use models** to demonstrate the interdependence of organisms and their environment including biotic and abiotic factors.
6.L2U1.14	**Construct a model** that shows the cycling of matter and flow of energy in ecosystems.
7.L2U1.12	**Construct an explanation** for how some plant cells convert light energy into food energy.
Essential **HS.L2U3.18**	**Obtain, evaluate, and communicate** about the positive and negative ethical, social, economic, and political implications of human activity on the biodiversity of an ecosystem.
Plus **HS+B.L2U1.1**	**Develop a model** showing the relationship between limiting factors and carrying capacity, and use the model to make predictions on how environmental changes impact biodiversity.
Essential **HS.L2U1.19**	**Develop and use models** that show how changes in the transfer of matter and energy within an ecosystem and interactions between species may affect organisms and their environment.

Plus HS+B.L2U1.3	**Use mathematics and computational thinking** to support claims for the cycling of matter and flow of energy through trophic levels in an ecosystem.
Essential HS.L2U1.21	**Obtain, evaluate, and communicate data** showing the relationship of photosynthesis and cellular respiration; flow of energy and cycling of matter.
Plus HS+B.L2U1.8	**Develop and use models** to **develop a scientific explanation** that illustrates how photosynthesis transforms light energy into stored chemical energy and how cellular respiration breaks down macromolecules for use in metabolic processes.

Life Science	**L3: Genetic information is passed down from one generation of organisms to another.**
1.L3U1.9	**Obtain, evaluate, and communicate information** to **support an evidence-based explanation** that plants and animals produce offspring of the same kind, but offspring are generally not identical to each other or their parents.
5.L3U1.9	**Obtain, evaluate, and communicate information** about patterns between the offspring of plants, and the offspring of animals (including humans); **construct an explanation** of how genetic information is passed from one generation to the next.
5.L3U1.10	**Construct an explanation** based on evidence that the changes in an environment can affect the development of the traits in a population of organisms.
8.L3U1.9	**Construct an explanation** of how genetic variations occur in offspring through the inheritance of traits or through mutations.
8.L3U3.10	**Communicate** how advancements in technology have furthered the field of genetic research and use **evidence to support an argument** about the positive and negative effects of genetic research on human lives.
Essential HS.L3U1.24	**Construct an explanation** of how the process of sexual reproduction contributes to genetic variation.
Essential HS.L3U1.25	**Obtain, evaluate, and communicate information** about the causes and implications of DNA mutation.
Essential HS.L3U3.26	**Engage in argument from evidence** regarding the ethical, social, economic, and/or political implications of a current genetic technology.
Plus HS+B.L3U1.10	**Use mathematics and computational thinking** to explain the variation that occurs through meiosis and calculate the distribution of expressed traits in a population.
Plus HS+B.L3U1.11	**Construct an explanation** for how the structure of DNA and RNA determine the structure of proteins that perform essential life functions.
Plus HS+B.L3U1.12	**Analyze and interpret data** on how mutations can lead to increased genetic variation in a population.

Life Science	**L4: The unity and diversity of organisms, living and extinct, is the result of evolution.**
1.L4U1.10	**Develop a model** to describe how animals and plants are classified into groups and subgroups according to their similarities.
1.L4U3.11	**Ask questions** and explain how factors can cause species to go extinct.
4.L4U1.11	**Analyze and interpret** environmental **data** to demonstrate that species either adapt and survive, or go extinct over time.
5.L4U3.11	**Obtain, evaluate, and communicate evidence** about how natural and human-caused changes to habitats or climate can impact populations.
5.L4U3.12	**Construct an argument based on evidence** that inherited characteristics can be affected by behavior and/or environmental conditions.

8.L4U1.11	**Develop and use a model** to explain how natural selection may lead to increases and decreases of specific traits in populations over time.
8.L4U1.12	**Gather and communicate evidence** on how the process of natural selection provides an explanation of how new species can evolve.
Plus **HS+B.L4U1.2**	**Engage in argument from evidence** that changes in environmental conditions or human interventions may change species diversity in an ecosystem.
Essential **HS.L4U1.27**	**Obtain, evaluate, and communicate** evidence that describes how changes in frequency of inherited traits in a population can lead to biological diversity.
Essential **HS.L4U1.28**	**Gather, evaluate, and communicate** multiple lines of empirical evidence to explain the mechanisms of biological evolution.
Plus **HS+B.L4U1.13**	**Obtain, evaluate, and communicate** multiple lines of empirical evidence to explain the change in genetic composition of a population over successive generations.
Plus **HS+B.L4U1.14**	**Construct an explanation** based on scientific evidence that the process of natural selection can lead to adaption.