DIMENSION: SCIENCE AND ENGINEERING PRACTICES

The practices describe behaviors that scientists and engineers 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 term ***practices*** are used instead of a term like "skills" to emphasize that engaging in scientific investigation requires not only skill but also knowledge that is specific to each practice. The 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. As you read over the practices, you'll notice that these are the things great teachers already do to teach students science concepts.

1. Asking questions (for science) and defining problems (for engineering)

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 the ideas of others.

2. 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.

3. 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.

4. 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 the analysis of proposed solutions more efficient and effective.

5. 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; statistically analyzing data; 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. Statistical methods are frequently used to identify significant patterns and establish correlational relationships.

6. Constructing explanations (for science) and designing solutions (for engineering)

The products of science are explanations and the 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.

7. 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.

8. 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.

Source: *A Framework for K-12 Science Education*

Video: https://www.teachingchannel.org/videos/science-engineering-practices-achieve

Video 'NASA's What is engineering?': https://www.youtube.com/watch?v=wE-z_TJyziI

DIMENSION: CROSSCUTTING CONCEPTS

The Louisiana Student Standards for Science are built upon the belief that there are *BIG* concepts that cut across the boundaries that separate the various disciplines of science. Crosscutting concepts have application across all domains of science: life, physical, earth and space, and environmental. They are the “big ideas” that connect all of the sciences and help to make sense of nature. As such, they are a way of linking the different domains of science. The crosscutting concepts include:

1. Patterns

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

2. Cause and effect

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.

3. Scale, proportion, and quantity

In thinking scientifically about systems and processes, it is essential to recognize that they vary in size (e.g., cells, whales, galaxies), in time span (e.g., nanoseconds, hours, millennia), in the amount of energy flowing through them (e.g., light bulbs, power grids, the sun), and in the relationships between the scales of these different quantities. The understanding of relative magnitude is only a starting point. As noted in Benchmarks for Science Literacy, “The large idea is that the way in which things work may change with scale. Different aspects of nature change at different rates with changes in scale, and so the relationships among them change, too”. Appropriate understanding of scale relationships is critical as well to engineering—no structure could be conceived, much less constructed, without the engineer’s precise sense of scale.

4. Systems and system models

The natural and designed world is complex; it is too large and complicated to investigate and comprehend all at once. Scientists and students learn to define small portions for the convenience of investigation. The units of investigations can be referred to as ‘systems.’ A system is an organized group of related objects or components that form a whole. Systems can consist, for example, of organisms, machines, fundamental particles, galaxies, ideas, and numbers. Systems have boundaries, parts, resources, flow, and feedback. Scientists and students develop models to study and understand complex systems.

5. Energy and matter

Energy and Matter are essential concepts in all disciplines of science and engineering, often in connection with systems. “The supply of energy and of each needed chemical element restricts a system’s operation—for example, without inputs of energy (sunlight) and matter (carbon dioxide and water), a plant cannot grow. Hence, it is very informative to track the transfers of matter and energy within, into, or out of any system under study.

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*. The shape and stability of structures of natural and designed objects are related to their function(s). The functioning of natural and built systems alike depends on the shapes and relationships of certain key parts as well as on the properties of the materials from which they are made. For example, understanding how a bicycle works is best addressed by examining the structures and their *functions* at the scale of, say, the frame, wheels, and pedals. However, building a lighter bicycle may require knowledge of the *properties* (such as rigidity and hardness) of the materials needed for specific parts of the bicycle. In that way, the builder can seek less dense materials with appropriate properties.

7. Stability and change

Stability denotes a condition in which some aspects of a system are unchanging, at least at the scale of observation. Stability means that a small disturbance will fade away—that is, the system will stay in, or return to, the stable condition. 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.

As one of the strands of three-dimensional learning, crosscutting concepts are not meant to be taught separately from the other two dimensions. Instead, they are meant to be interwoven throughout instruction. Teaching crosscutting concepts in the context of a curriculum's subject matter is key because they reinforce key ideas and provide a common vocabulary for science and engineering. It's also important to note that crosscutting concepts are essential for all students to learn, not only for high achievers who require extension activities. In the context of the Louisiana Student Standards for Science, crosscutting concepts help students make connections and build knowledge, benefiting every student regardless of their starting point.

Despite the fact that crosscutting concepts aren't new, the instructional philosophy for explicitly integrating them into three-dimensional learning is a new approach. By being more intentional in lesson planning and actively engaging with students during instruction, teachers can help students develop a coherent and scientifically-based view of the world.

Sources:

1. A Framework for K-12 Science Education

2. https://www.mentoringminds.com/learn/blog/a-close-look-at-the-ngss-crosscutting-concepts

Video: https://www.teachingchannel.org/videos/crosscutting-concepts-achieve

DIMENSION: DISCIPLINARY CORE IDEAS

Disciplinary Core Ideas describe the most essential ideas (content) in the major science disciplines. Disciplinary 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:

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

The continuing expansion of scientific knowledge makes it impossible to teach all the ideas related to a given discipline in exhaustive detail during the K-12 years. But given the cornucopia of information available today virtually at a touch - people live, after all, in an information age - an important role of science education is not to teach "all the fact" but rather prepare students with sufficient core knowledge so that they can later acquire additional information on their own. An education focused on a limited set of ideas and practices in science and engineering should enable students to evaluate and select reliable sources of scientific information, and allow them to continue their development well beyond their K-12 school years as science learners, users of scientific knowledge, and perhaps also as producers of such knowledge.

Rather than “learning” numerous disconnected ideas, the Louisiana Student Standards for Science focus on helping learners develop a useable understanding of fewer, powerful ideas that develop across K–12-science curriculum and can form conceptual tools that learners can use to make sense of the world. Disciplinary ideas are grouped in five ***domains***: the *physical sciences*; the *life sciences*; the *earth and space sciences*; and *environmental sciences*.

DIMENSION: DISCIPLINARY CORE IDEAS

Domain of Science	Descriptor
Physical Science (PS)	PS1: Matter and its interactions PS2: Motion and stability: Forces and Motions PS3: Energy PS4: Waves and their applications in technologies for information transfer
Life Science (LS)	LS1: From molecules to organism: Structures and processes LS2: Ecosystems: Interactions, energy, and dynamics LS3: Heredity: Inheritance and variation of traits LS4: Biological evolution: Unity and diversity
Earth and Space Science (ESS)	ESS1: Earth's place in the universe ESS2: Earth's systems ESS3: Earth and human activity
Engineering, Technology, & Applications of Science (ETS)	ETS1: Engineering Design ETS2: Links among engineering, technology, science, and society
Environmental (EVS) (high school only)	EVS1: Resources and resource management EVS2: Environmental awareness and protection EVS3: Personal responsibilities

Sources:

1. A Framework for K-12 Science Education

2. NSTA Website

Video: https://www.teachingchannel.org/videos/disciplinary-core-ideas-achieve