A FRAMEWORK FOR K-12 SCIENCE EDUCATION Practices, Crosscutting Concepts, and Core Ideas

INTRODUCTION

What is it?
A vision for education sciences and technology for students to become actively engaged and deepen their understanding and to encourage students to ask fundamental questions about the world.

Why is it needed?
15 years since last national scale effort
New understandings in science and learning

Who is it for?
Standards developers
Curriculum designers
State and district science administration
Science educators

Two major goals:
1. Educating all students in science and engineering in preparation to become citizens in a tech driven society
2. Providing foundational knowledge for future scientists, engineers and technologists

Achieving the vision:
• Learning is a developmental progression, building upon children’s curiosity about the world and establishing initial concepts about scientific investigation and results to answer their questions.
• Focusing on a limited number of core ideas rather than overwhelming the student with details that they have no interest in or understanding of. This leaves more room for individual growth and investigations.
• Knowledge and practice must be intertwined. The student needs content knowledge but also to be engaged in engineering design and scientific inquiry at the same time.

Defining the terms-
-“science” meaning the traditional natural sciences: physics, chemistry, biology, earth, space and environmental sciences.
-“engineering” meaning any engagement in a systematic practice of design to achieve solutions to a particular human problem.
-“technology” includes all types of human-made systems and processes

"AN IMPORTANT ROLE OF SCIENCE EDUCATION IS NOT TO TEACH ALL THE FACTS BUT RATHER TO PREPARE STUDENTS WITH SUFFICIENT CORE KNOWLEDGE SO THAT THEY CAN LATER ACQUIRE ADDITIONAL INFORMATION ON THEIR OWN."
FRAMEWORK PRINCIPLES

Children Are Born Investigators
Children’s ability to learn by observation and investigation begin at birth. Their early intuitions should be encouraged in grades K-5 by allowing engagement in scientific and engineering practices.

Focus on Core Ideas and Practices
Narrowing down to core scientific ideas will give students a better, broader understanding and help to develop meaning. Rather than rote memorization of terms and definitions, children will have an organized structure of the concepts needed in applied science and engineering practices to build upon in the future.

Understanding Develops Over Time
Learning progression happens over years, not weeks or months. Instruction should build upon core ideas introduced and practiced in the previous grade.

Science and Engineering Require Both Knowledge and Practice
Scientific knowledge is a product of collaborative, shared experiences stemming from communication and experimentation among scientists. Understanding is best achieved through analytical procedures as well as shared semantic information.

Connecting to Students’ Interests and Experiences
Personal interest and enthusiasm are critical to a child’s learning. Science should be posed in a way that sparks inquiry or curiosity and is relatable to their daily lives.

Promoting Equity
Opportunities for learning must be given to all students. This includes access to equipment, materials, space, support and teachers that motivate engagement.

FRAMEWORK STRUCTURE

- Dimension 1: Practices
- Dimension 2: Crosscutting Concepts
- Dimension 3: Core Ideas
**Dimension 1**

**Scientific and Engineering Practices**

**Organizing practices into both inquiry and design**

- **Investigating** — consider what needs to be measured, conduct an empirical inquiry, observe phenomena, plan experiments, methods of data collection, build instruments, engage in disciplined fieldwork and identify sources of uncertainty.
- **Evaluating** — argue, critique, analyze, identify weaknesses and limitations in the argument, refine and improve explanations or design.
- **Developing explanations and solutions** — draw from established theories and models and propose extensions to theory or create new models. Formulate hypotheses, propose solutions, imagine, reason, calculate, predict.

The goal of science is to provide single explanations of phenomena.
The goal of engineering is to address human wants and needs.

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**Practices for K-12 Science Classrooms**

1. Asking questions (for science) and defining problems (for engineering)
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Constructing explanations (for science) and designing solutions (for engineering)
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating

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**Practice 1: Asking Questions and Defining Problems**

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?
Goals by grade 12, students should be able to:
  o Ask questions about the natural and human-built worlds
  o Distinguish a scientific question from a nonscientific question
  o Formulate and refine questions that can be answered empirically in a science classroom and use them to design
  o 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.
  o Note features, patterns, or contradictions in observations and ask questions about them.

Practice 2: Developing and Using Models

Scientists construct mental and conceptual models of phenomena. Building an understanding of models and their role in science helps students to construct and revise mental models of phenomena and lead to deeper understanding of science and enhanced scientific reasoning.

Engineering makes use of models to analyze existing systems 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 new designs. Modeling can begin in the earliest grades with pictures and physical scale models to more abstract representations in later grades. Modeling tools should be made available throughout the curriculum and students should feel comfortable in constructing models across grades.

Goals by grade 12:
  o Construct drawings or diagrams as representations of events or systems
  o Represent and explain phenomena with multiple types of models and move flexibly between model types.
  o Discuss the limitations and precision of a model and suggest ways in which the model might be improved.
  o Use computer simulations developed with simple simulation tools to evaluate aspects of the system not visible to the naked eye.
  o Make and use a model to test a design, or the 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
2. To develop and test theories and explanations of how the world works
Planning and designing investigations require the ability to design experimental or observational inquiries that address the question that needs answering appropriately. The goal is to measure the variable as accurately as possible and reduce sources of error.

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.

### Goals by grade 12:
- Formulate a question that can be investigated within the scope of the classroom, school laboratory or field with available resources and frame a hypothesis 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 the need for controls.
- Consider possible confounding variables or effects and ensure that the investigations design has controlled for them.

### Practice 4: Analyzing and Interpreting Data

Scientists and engineers rely on data to interpret results from models, very rarely using trial and error. Students need access to data, the ability to read charts and graphs and analyze variables and error accurately.

Students should begin recording observations such as pictures, word, or numbers, in elementary school. As they age, they should be able to interpret graphs and tables, also using computers and other digital tools. In middle school, students should be able to display, analyze and interpret data and explain why these techniques are needed. In high school, their investigations should be more complex, using x-y scatterplots and cross-tabulations to express relationships between variables. At all levels, students should understand the importance of this analysis to validate or improve a design or a solution.

### Goals by grade 12:
- 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.
- 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.
Practice 5: Using Mathematics and Computational Thinking

Mathematics and computational tools are central to science and engineering. They are the numerical representations of variables, the symbolic representation of relationships between physical entities and the prediction of outcomes.

Goals by grade 12:
- 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 to see if they “make sense.”
- Use grade-level appropriate understanding of mathematics and statistics in analyzing data.

Practice 6: Constructing Explanations and Designing Solutions

Students need opportunities to construct explanations and be encouraged to come up with ideas that explain what they have observed. Children are natural born engineers, using whatever they have to construct imaginative playhouses. Testing their designs and improving on them later is an important part of research and teaches children about variables in identifying problems.

Goals by grade 12:
- Construct their own explanations of phenomena using knowledge of scientific theory and linking it to models and evidence.
- Use primary or secondary scientific evidence and models to support or refute and explanatory account of a phenomenon.
- Offer causal explanations appropriate to their level of scientific knowledge.
- Identify gaps or weaknesses in explanatory accounts.
- 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.

Practice 7: Engaging in Argument from Evidence

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.
Students should construct their own arguments for observed data and learn to critique by asking questions about their findings. They should understand the formal means through which scientific ideas are evaluated today.

**Goals by grade 12:**
- 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.

**Practice 8: Obtaining, Evaluating and Communicating Information**

Communication is an important part of science and engineering as nothing could progress without the ability to communicate findings precisely and clearly. These communications take place in the form of journal articles, books, conferences, presentations and websites. Students should be able to distinguish methodological flaws, poor population selections, etc.

Students need sustained practice in retrieving scientific information from published sources. They should be familiar with how to read scientific texts and media reports. The earliest grades should teach careful descriptions of observations and clear statements of ideas with the ability to refine in response to questions. Written text is also an important part of understanding explicit instructions.

Students should write accounts of their work, using journals to record observations, thoughts, ideas and models. They should also produce results on posters or reports and have opportunities to engage in discussions about the research.

**Goals by grade 12:**
- Use tables, diagrams, and graphs 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 ideas and accomplishments.
- Engage in a critical reading of primary scientific literature or of media reports of science and discuss the validity and reliability of the data, hypotheses, and conclusions.
Pattern recognition depends on careful observation of similarities and differences, which is important for codifying relationships and organizing a multitude of objects into a limited number of groups.

Elementary aged children begin learning patterns in the natural world such as the sun and moon and the seasons of the year. This will progress to classifications and relations to the nature of microscopic and atomic-level structures in high school.

**Cause and Effect: Mechanism and Prediction**

One goal of instruction about cause and effect is to encourage students to see events in the world as having understandable causes. Another aspect understands variables that play a part of the causal relationship, whereas if one thing is not present, then the relationship cannot exist, and so on.

While studying patterns, children should begin to question what causes the patterns and relationships. Students should question the underlying causes and begin to explain the effects of relationships, arguing from evidence in high school and forming strategies about specific causes.

**Scale, Proportion, and Quantity**

Concepts that concern the very small or the very large require a sense of not only relative scale sizes but also of what concepts are meaningful at what scale. The ideas of ratio and proportionality as used in science can extend and challenge students’ mathematical understanding of these concepts. Recognition of different quantities is a key step in forming mathematical models that interpret scientific data. Understanding estimation across scales and contexts is important for making sense of data.

**Systems and System Models**

Scientists and engineers imagine boundaries around systems and then examine the system in detail while regarding all things around it as either forces acting on the system or flows of energy crossing over it. A good system model must specify not only the parts, or subsystems, but also how they interact with one another.
Students should organize their knowledge about systems by its component parts and interactions, as well as its inputs, outputs and processes. Models of systems should incorporate mathematical relationships among variables. They should also make invisible features explicit such as energy flow or matter transfers.

**Energy and Matter: Flows, Cycles, and Conservation**

The ability to examine, characterize, and model the transfers and cycles of matter and energy is a tool that students can use across virtually all areas of science and engineering. Studying the interactions between matter and energy supports students in developing increasingly sophisticated conceptions of their role in any system.

**Structure and Function**

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. 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.

**Stability and Change**

Understanding the feedback mechanisms that regulate a system's stability or that drives its instability provides insight into how the system may operate under various conditions. Any system has a range of conditions under which it can operate in a stable fashion, as well as conditions under which it cannot function. Stability is always a balance of competing effects. An understanding of dynamic equilibrium is crucial to understanding the major issues in any complex system. It is important for students to ask why things don’t change as much as it is why they do change.

“Through discussion and reflection, students can come to realize that scientific inquiry embodies a set of values. These values include respect for the importance of logical thinking, precision, open-mindedness, objectivity, skepticism, and a requirement for transparent research procedures and honest report of findings.”
1. Matter and Its Interactions
2. Motion and Stability: Forces and Interactions
3. Energy
4. Wave and Their Applications in Technologies for Information Transfer

**Matter and Its Interactions**
How can one explain the structure, properties, and interactions of matter?

**Structure and Properties of Matter**
How do particles combine to form the variety of matter one observes?

- **By end of grade 2:** Different kinds of matter exist in varied forms with multiple uses.
- **By end of grade 5:** Matter of any type can be subdivided into particles that are too small to see, but even the matter still exists and can be detected by other means.
- **By end of grade 8:** All substances are made from some 100 different types of atoms, which combine with one another in various ways.
- **By the end of grade 12:** Atomic substructures, the use of the periodic table of the elements including patterns and electron states, and rules of energy in regards to stable molecules.

**Chemical Reactions**
How do substances combine or change (react) to make new substances?
How does one characterize and explain these reactions and make predictions about them?

- **By end of grade 2:** Heating or cooling a substance may cause changes that can be observed. Sometimes the changes are reversible, sometimes they are not.
- **By end of grade 5:** When two or more different substances are mixed, a new substance with different properties may be formed yet the total weight of the substances does not change.
- **By end of grade 8:** Substances react chemically in characteristic ways. Some chemical reactions release energy, others do store energy.
- **By end of grade 12:** Chemical processes, their rates, and whether or not energy is stored or released can be understood in terms of the collisions of molecules and the rearrangements of atoms into new molecules, with consequent changes in total binding energy that are matched by changes in kinetic energy. Chemical processes and properties of materials underlie many important biological and geophysical phenomena.
Nuclear Processes

What forces hold nuclei together and mediate nuclear processes?

By end of grade 8: Nuclear fusion can result in the merging of two nuclei to form a larger one, along with the release of significantly more energy per atom than any chemical process. The elements found on Earth and throughout the universe (other than hydrogen and helium, which are primordial) were formed in the stars or supernovas by fusion processes.

By end of grade 12: Nuclear processes, including fusion, fission, and radioactive decays of unstable nuclei, involve changes in nuclear binding energies. Strong and weak nuclear interactions determine nuclear stability and processes. Nuclear lifetimes allow radiometric dating to be used to determine the ages of rocks and other materials from the isotope ratios present.

Motion and Stability: Forces and Interactions

How can one explain and predict interactions between objects and within systems of objects?

Forces and Motion

How can one predict an object’s continued motion, changes in motion, or stability?

By end of grade 2: An object sliding on a surface or sitting on a slope experiences a pull due to friction on the object due to the surface that opposes the object’s motion.

By end of grade 5: Each force acts on one particular object and has both a strength and a direction. The patterns of an object’s motion in various situations can be observed and measured; when past motion exhibits a regular pattern, future motion can be predicted from it.

By end of grade 8: For any pair of interacting objects, the force exerted by the first object on the second object is equal in strength to the force that the second object exerts on the first but in the opposite direction.

By end of grade 12: If a system interacts with objects outside itself, the total momentum of the system can change; however, any such change is balanced by changes in the momentum of objects outside the system.

Types of Interactions

What underlying forces explain the variety of interactions observed?

By end of grade 2: When objects touch or collide, they push on one another and can change motion or shape.

By end of grade 5: Objects in contact exert forces on each other. Electric, magnetic, and gravitational forces between a pair of objects do not require that the objects be in contact.

By end of grade 8: Electric and magnetic forces can be attractive or repulsive, and their sizes depend on the magnitudes of the charges, currents, or magnetic strengths involved and on the distances between the interacting objects. Forces that act at a distance can be explained by force fields that extend through space and can be mapped by their effect on a test object.
**By end of grade 12:** Newton’s law of universal gravitation and Coulomb’s law provide the mathematical models to describe and predict the effects of gravitational and electrostatic forces between distant objects.

**Stability and Instability in Physical Systems**

Why are some physical systems more stable than others?

**By end of grade 2:** Whether an object stays still or moves often depends on the effects of multiple pushes and pulls on it.

**By end of grade 5:** Examining how the forces on and within the system change as it moves can help to explain the system’s patterns of change. Conditions and properties of the objects within a system affect how fast or slowly a process occurs.

**By end of grade 8:** Many systems, both natural and engineered, rely on feedback mechanisms to maintain stability, but they can function only within a limited range of conditions.

**By end of grade 12:** Systems may evolve in unpredictable ways when the outcome depends sensitively on the starting condition and the starting condition cannot be specified precisely enough to distinguish between different possible outcomes.

**Energy**

How is energy transferred and conserved?

**Definitions of Energy**

What is energy?

**By end of grade 5:** The faster a given object is moving, the more energy it possesses. Energy can be moved from place to place by moving objects or through sound, light, or electric currents.

**By end of grade 8:** The relationship between the temperature and the total energy of a system depends on the types, states, and amounts of matter present.

**By end of grade 12:** Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system. Knowledge of the terms “mechanical energy,” “chemical energy,” and “electrical energy.”

**Conservation of Energy and Energy Transfer**

What is meant by conservation of energy?

How is energy transferred between objects or systems?

**By end of grade 2:** Sunlight warms Earth’s surface.

**By end of grade 5:** Energy is present whenever there are moving objects, sound light, or heat.

**By end of grade 8:** When the motion energy of an object changes, there is inevitably some other change in energy at the same time.
By end of grade 12: Conservation of energy means that the total change of energy in any system is always equal to the total energy transferred into or out of the system.

**Relationship between Energy and Forces**

How are forces related to energy?

By end of grade 2: A bigger push or pull makes things go faster.
By end of grade 5: When objects collide, the contact forces transfer energy so as to change the objects’ motions.
By end of grade 8: When two objects interact, each one exerts a force on the other that can cause energy to be transferred to or from the object.
By end of grade 12: Force fields contain energy and can transmit energy across space from one object to another.

**Energy in Chemical Processes and Everyday Life**

How do food and fuel provide energy?
If energy is conserved, why do people say it is produced or used?

By end of grade 2: When two objects rub against each other, this interaction is called friction. Friction between two surfaces can warm one or both of them. There are ways to reduce the friction between two subjects.
By end of grade 5: The energy released by burning fuel or digesting food was once energy from the sun that was captured by plants in the chemical process that forms plant matter.
By end of grade 8: The chemical reaction by which plants produce complex food molecules (sugars) requires an energy input to occur. In this reaction, carbon dioxide and water combine to form carbon-based organic molecules and release oxygen.
By end of grade 12: Nuclear fusion processes in the center of the sun release the energy that ultimately reaches Earth as radiation. The main way that solar energy is captured and stored on Earth is through the complex chemical process known as photosynthesis. Although energy cannot be destroyed, it can be converted to less useful forms.

**Waves and Their Application in Technologies for Information Transfer**

How are waves used to transfer energy and information?

**Wave Properties**
What are the characteristic properties and behaviors of waves?

By end of grade 2: Waves can be made in water by disturbing the surface. Sound can make matter vibrate, and vibrating matter can make sound.
By end of grade 5: Waves of the same type can differ in amplitude and wavelength. Earthquakes cause seismic waves, which are waves of motion in Earth’s crust.
By end of grade 8: A simple wave has a repeating pattern with a specific wavelength, frequency and amplitude. A sound wave needs a medium through which it is transmitted. Geologists use seismic waves and their reflection at interfaces between layers to probe structures deep in the planet.
By end of grade 12: The wavelength and frequency of a wave are related to one another by the speed of travel of the wave, which depends on the type of wave and the medium through which it is passing. Combining waves of different frequencies can make a wide variety of patterns and thereby encode and transmit information. The phenomenon of resonance is used in speech and in the design of all musical instruments.

Electromagnetic Radiation
What is light?
How can one explain the varied effects that involve light?
What other forms of electromagnetic radiation are there?

By end of grade 2: Objects can only be seen when light is available to illuminate them. Some materials allow light to pass through them, others allow only some light through and others block all the light and create a dark shadow on any surface beyond them.
By end of grade 5: A great deal of light travels through space to Earth from the sun and from distant stars. An object can be seen when light reflected from its surface enters the eyes; the color people see depends on the color of the available light sources as well as the properties of the surface.
By end of grade 8: When light shines on an object, it is reflected, absorbed, or transmitted through the object, depending on the object’s material and the frequency of the light.
By end of grade 12: Electromagnetic radiation can be modeled as a wave of changing electric and magnetic fields or as particles called photons. All electromagnetic radiation travels through a vacuum at the same speed, called the speed of light. Atoms of each element emit and absorb characteristic frequencies of light, and nuclear transitions have distinctive gamma ray wavelengths.

Information Technologies and Instrumentation
How are instruments that transmit and detect waves used to extend human senses?

By end of grade 2: People use their senses to learn about the world around them. People also use a variety of devices to communicate across long distances.
By end of grade 5: The design of instruments such as eyeglasses or telescopes is based on understanding how the path of light bends at the surface of a lens. Digitized information can be stored for future recovery or transmitted over long distances without significant degradation.
By end of grade 8: Many modern communication devices use digitized signals (sent as wave pulses) as a more reliable way to encode and transmit information.
By end of grade 12: Multiple technologies based on the understanding of waves and their interactions with matter are part of everyday experiences in the modern world.

**Dimension 3**

**Disciplinary Core Ideas - Life Sciences**

1. From Molecules to Organisms: Structures and Processes
2. Ecosystems: Interactions, Energy, and Dynamics
3. Heredity: Inheritance and Variation of Traits
4. Biological Evolution: Unity and Diversity

**From Molecules to Organisms: Structures and Processes**

*How do organisms live, grow, respond to their environment, and reproduce?*

**Structure and Function**

*How do the structures of organisms enable life’s functions?*

By end of grade 2: All organisms have external parts that help them to survive, grow, and reproduce.

By end of grade 5: Plants and animals have both internal and external structures that serve various functions in growth, survival, behavior and reproduction.

By end of grade 8: All living things are made up of cells, which is the smallest unit that can be said to be alive. An organism may be multicellular or unicellular. Within cells, special structures are responsible for particular functions.

By end of grade 12: All cells contain genetic material in the form of DNA molecules. Multicellular organisms have a hierarchical structural organization, in which any one system is made up of numerous parts and is itself a component of the next level.

**Growth and Development of Organisms**

*How do organisms grow and develop?*

By end of grade 2: Plants and animals have predictable characteristics at different stages of development.

By end of grade 5: Reproduction is essential to the continued existence of every kind of organism.

By end of grade 8: Organisms reproduce, either sexually or asexually, and transfer their genetic information to their offspring.

By end of grade 12: Terms such as mitosis and differentiation, as well as meiosis in regards to development and growth of individual cells should be understood.

**Organization for Matter and Energy Flow in Organisms**

*How do organisms obtain and use the matter and energy they need to live and grow?*
By end of grade 2: All animals need food in order to live and grow. They obtain their food from plants or other animals. Plants need water and light to live and grow.

By end of grade 5: Anaerobic life, such as bacteria in the gut, function without air. Food provides animals with materials their bodies need for repair and growth and is digested to release the energy they need for body warmth and motion. Plants acquire material for growth chiefly from air and water.

By the end of grade 8: Plants, algae, and many microorganisms use the energy from light to make sugars from carbon dioxide from the atmosphere and water through the process of photosynthesis, which also releases oxygen.

By the end of grade 12: The process of photosynthesis converts light energy to stored chemical energy by converting carbon dioxide plus water into sugars plus released oxygen. Cellular respiration releases the energy needed to maintain body temperature despite ongoing energy loss to the surrounding environment.

Information Processing
How do organisms detect, process, and use information about the environment?

By end of grade 2: Animals have body parts that capture and convey different kinds of information needed for growth and survival.

By end of grade 5: Different sense receptors are specialized for particular kinds of information, which may then be processed and integrated by an animal’s brain. Some responses to information are instinctive.

By end of grade 8: Each sense receptor responds to different inputs (electromagnetic, mechanical, chemical) transmitting them as signals that travel along nerve cells to the brain. The brain then processes these signals into behaviors and memories.

By end of grade 12: The integrated functioning of all parts of the brain is important for successful interpretation of inputs and generation of behaviors in response to them.

Ecosystems: Interactions, Energy, and Dynamics
How and why do organisms interact with their environment and what are the effects of these interactions?

Interdependent Relationships in Ecosystems
How do organisms interact with the living and nonliving environments to obtain matter and energy?

By end of grade 2: Animals and plants depend on their surroundings to get what they need for survival. Animals can move around but plants cannot.

By end of grade 5: A healthy ecosystem is one in which multiple species of different types are each able to meet their needs in a relatively stable web of life. Newly introduced species can damage the balance of an ecosystem.

By end of grade 8: Although species involved in competitive, predatory, and mutually beneficial interactions vary across ecosystems, the patterns of interactions of organisms with their environments, both living and nonliving, are shared.
By end of grade 12: Ecosystems have carrying capacities, which are limits to the numbers of organisms and populations they can support.

Cycles of Matter and Energy Transfer in Ecosystems
How do matter and energy move through an ecosystem?

By end of grade 2: Organisms obtain many materials they need for survival from other organisms which are then used again by still other organisms.
By end of grade 5: Organisms obtain gases, water, and minerals from the environment and release waste matter (gas, liquid, or solid) back into the environment.
By end of grade 8: Food webs are models that demonstrate how matter and energy is transferred between producers, consumers, and decomposers as the three groups interact—primarily for food—within an ecosystem.
By end of grade 12: Photosynthesis and cellular respiration provide most of the energy for life processes. Photosynthesis and cellular respiration are important components of the carbon cycle, in which carbon is exchanged between the biosphere, atmosphere, oceans, and geosphere through chemical, physical, geological, and biological processes.

Ecosystem Dynamics, Functioning, and Resilience
What happens to ecosystems when the environment changes?

By end of grade 2: The places where plants and animals live often change, sometimes slowly and sometimes rapidly. When animals and plants get too hot or too cold, they may die.
By end of grade 5: When the environment changes in ways that affect a place’s physical characteristics, temperature, or availability of resources, some organisms survive and reproduce, others move to new locations, yet others move into the transformed environment, and some die.
By end of grade 8: Disruptions to any physical or biological component of an ecosystem can lead to shifts in all of its populations. The completeness or integrity of an ecosystem’s biodiversity is often used as a measure of its health.
By end of grade 12: Anthropogenic changes (induced by human activity) in the environment— including habitat destruction, pollution, introduction of invasive species, overexploitation, and climate change—can disrupt an ecosystem and threaten the survival of some species.

Social Interactions and Group Behavior
How do organisms interact in groups so as to benefit individuals?

By end of grade 2: Groups may serve different functions and vary in size.
By end of grade 5: Groups can be collections of equal individuals, hierarchies with dominant members, small families, groups of single or mixed gender, or composed of individuals similar in age. They can be stable or fluid and have various specialized tasks or a range of functions.
By end of grade 8: Groups engage in signaling behaviors to maintain the groups integrity. They may dissolve if they no longer function.
By end of grade 12: Group behavior has evolved because membership can increase the chances of survival for individuals and their genetic relatives. Animals have strong drives for social affiliation.

**Heredity: Inheritance and Variation of Traits**

- How are characteristics of one generation passed to the next?
- How can individuals of the same species and even sibling have different characteristics?

**Inheritance of Traits**

- How are the characteristics of one generation related to the previous generation?

By end of grade 2: Organisms have characteristics that can be similar or different. Young animals and plants are very much, though not exactly, like their parents.

By end of grade 5: Many characteristics result from both inheritance and environment.

By end of grade 8: Genes are located in the chromosomes of cells. Sexual reproduction provides for transmission of genetic information to offspring.

By end of grade 12: An understanding of how DNA codes for proteins which carry genetic information.

**Variation of Traits**

- Why do individuals of the same species vary in how they look, function, and behave?

By end of grade 2: Individuals of the same kind of plant or animal are recognizable as similar but can also vary in many ways.

By end of grade 5: Offspring acquire a mix of traits from their biological parents, however the environment can also affect how the traits of an organism develops.

By end of grade 8: In sexually reproducing organisms, each parent contributes half of the genes acquired by the offspring. Some genetic information can be altered because of mutations, which can be beneficial, harmful, or neutral to the organism.

By end of grade 12: The information passed from parents to offspring is coded in DNA molecules that form chromosomes. The variation and distribution of traits depends on both genetic and environmental factors.

**Biological Evolution: Unity and Diversity**

- How can there be so many similarities among organisms yet so many different kinds of plants, animals, and microorganisms?
- How does biodiversity affect humans?

**Evidence of Common Ancestry and Diversity**

- What evidence shows that different species are related?

By end of grade 2: Some kinds of plants and animals that once lived on Earth are no longer
found anywhere, although others now living resemble them in some ways.

By end of grade 5: Fossils provide evidence about the types of organisms that lived long ago and also about the nature of their environments.

By end of grade 8: Fossils are mineral replacements, preserved remains, or traces of organisms that lived in the past. Anatomical similarities and differences between various organisms living today and between them and organisms in the fossil record enable the reconstruction of evolutionary history and the inference of lines of evolutionary descent.

By end of grade 12: Genetic information also provides evidence of evolution.

Natural Selection

How does genetic variation among organisms affect survival and reproduction?

By end of grade 5: Sometimes the differences in characteristics between individuals of the same species provide advantages in surviving, finding mates, and reproducing.

By end of grade 8: Natural selection leads to the predominance of some traits in a population and the suppression of others.

By end of grade 12: The traits that positively affect survival are more likely to be reproduced and thus are more common in the population.

Adaptation

How does the environment influence populations of organisms over multiple generations?

By end of grade 2: Living things can only survive where their needs are met.

By end of grade 5: Changes in an organism’s habitat are sometimes beneficial to it and sometimes harmful.

By end of grade 8: Adaptation by natural selection acting over generations is one important process by which species change over time in response to changes in environmental conditions.

By end of grade 12: Natural selection leads to adaptation.

Biodiversity and Humans

What is biodiversity, how do humans affect it, and how does it affect humans?

By end of grade 2: Different kinds of living things exist in different places on land and in water.

By end of grade 5: Populations of organisms live in a variety of habitats, and changes in those habitats affect the organisms living there.

By end of grade 8: Biodiversity is the wide range of existing life forms that have adapted to the variety of conditions on Earth. Changes in biodiversity can influence humans’ resources.

By end of grade 12: Biodiversity is increased by the formation of new species and decreased by the loss of species. Sustaining biodiversity so that ecosystem functioning and productivity are maintained is essential to supporting and enhancing life on Earth.
Dimension 3
Disciplinary Core Ideas- Earth and Space Sciences

1. Earth’s Place in the Universe
2. Earth’s Systems
3. Earth and Human Activity

Earth’s Place in the Universe
What is the universe, and what is Earth’s place in it?

The Universe and Its Stars
What is the universe and what goes on in stars?

By end of grade 2: Patterns of the motion of the sun, moon, and stars in the sky can be observed, described, and predicted.
By end of grade 5: The sun is a star that appears larger and brighter than other stars because it is closer.
By end of grade 8: The universe began with a period of extreme and rapid expansion known as the Big Bang. Earth and its solar system are part of the Milky Way galaxy, which is one of many galaxies in the universe.
By end of grade 12: The star called the sun is changing and will burn out over a life span of approximately 10 billion years. The sun is one of more than 200 billion stars in the Milky Way galaxy and the Milky Way is just one of hundreds of billions of galaxies in the universe.

Earth and the Solar System
What are the predictable patterns caused by Earth’s movement in the solar system?

By end of grade 2: Seasonal patterns of sunrise and sunset can be observed, described and predicted.
By end of grade 5: Stars appear in patterns called constellations, which appear to move across the sky because of Earth’s rotation.
By end of grade 8: The seasons are a result of the Earth’s spin axis tilt. The solar system consists of the sun and a collection of objects, including planets, their moons, and asteroids that are held in orbit around the sun by its gravitational pull on them, which also contribute to the tides, eclipses and motion of the planets in the sky relative to the stars.
By end of grade 12: Kepler’s laws describe common features of the motions of orbiting objects, including their elliptical paths around the sun.

The History of Planet Earth
How do people reconstruct and date events in Earth’s planetary history?

By end of grade 2: Some events on Earth occur in cycles, and others have a beginning and an end. Some happen quickly and others occur very slowly.
By end of grade 5: Patterns of tree rings and ice cores from glaciers can help reconstruct Earth’s recent climate history.

By end of grade 8: The geological time scale interpreted from rock strata provides a way to organize Earth’s history. Analyses of rock strata and the fossil record provide only relative dates, not an absolute scale.

By end of grade 12: Radioactive decay lifetimes and isotopic content in rocks provide a way of dating rock formations and thereby fixing the scale of geological time.

**Earth’s Systems**

*How and why is Earth constantly changing?*

**Earth Materials and Systems**

*How do Earth’s major systems interact?*

By end of grade 2: Wind and water can change the shape of the land.

By end of grade 5: Earth’s major systems are the geosphere (solid and molten rock, soil and sediments), the hydrosphere (water and ice), the atmosphere (air), and the biosphere.

By end of grade 8: All Earth processes are the result of energy flowing and matter cycling within and among the planet’s systems. This energy is derived from the sun and the Earth’s hot interior. These interactions have shaped Earth’s history and will determine its future.

By end of grade 12: Earth’s systems cause feedback effects that can increase or decrease the original changes.

**Plate Tectonics and Large-Scale System Interactions**

*Why do the continents move, and what causes earthquakes and volcanoes?*

By end of grade 2: Maps show where bodies of water are located and land forms.

By end of grade 5: Most earthquakes and volcanoes occur in bands that are often along the boundaries between continents and oceans. Maps can help locate the different land and water features of the Earth and its populations.

By end of grade 8: Plate tectonics is the unifying theory that explains the past and current movements of the rocks at Earth’s surface and provides a framework for understanding its geological history.

By end of grade 12: The radioactive decay of unstable isotopes continually generates new energy within Earth’s crust and mantle providing the primary source of the heat that drives mantle convection.

**The Roles of Water in Earth’s Surface Processes**

*How do the properties and movements of water shape Earth’s surface and affect its systems?*

By end of grade 2: Water exists as solid ice or in liquid form and carry soil and rocks from one place to another, thereby determining the variety of life which can live in certain areas.
By end of grade 5: Water is found almost everywhere on Earth in different forms. The downhill movement of water as it flows to the ocean shapes the appearance of the land.

By end of grade 8: Water’s movements—both on land and underground—cause weathering and erosion, which change the land’s surface features and create underground formations.

By end of grade 12: The abundance of liquid water on Earth’s surface and its unique combination of physical and chemical properties are central to the planet’s dynamics.

Weather and Climate

What regulates weather and climate?

By end of grade 2: Weather is the combination of sunlight, wind, snow or rain and temperature in a particular region at a particular time.

By end of grade 5: Climate describes the ranges of an area’s typical weather conditions and the extent to which these conditions vary over years to centuries.

By end of grade 8: Weather and climate are influenced by interactions involving sunlight, the ocean, the atmosphere, ice, landforms, and living things. The ocean exerts a major influence on weather and climate by absorbing energy from the sun, releasing it over time, and globally redistributing it through ocean currents.

By end of grade 12: Changes in the atmosphere due to human activity have increased carbon dioxide concentrations and thus affect climate.

Biogeology

How do living organisms alter Earth’s processes and structures?

By end of grade 2: Plants and animals depend on the land to survive and can change their environment.

By end of grade 5: Many types of rocks and minerals are formed from the remains of organisms or are altered by their activities.

By end of grade 8: Evolution is shaped by Earth’s varying geological conditions.

By end of grade 12: The many dynamic and delicate feedbacks between the biosphere and other Earth systems cause a continual co-evolution of Earth’s surface and the life that exists on it.

Earth and Human Activity

How do Earth’s surface processes and human activities affect each other?

Natural Resources

How do humans depend on Earth’s resources?

By end of grade 2: Living things need water, air and resources from the land for everything they do.

By end of grade 5: All materials, energy, and fuels that humans use are derived from natural resources, and their use affects the environment in multiple ways.
By end of grade 8: Minerals, fresh water, and biosphere resources are limited, and many are not renewable or replaceable over human lifetimes.

By end of grade 12: Resource availability has guided the development of human society.

**Natural Hazards**

How do natural hazards affect individuals and societies?

By end of grade 2: Weather scientists forecast severe weather so that communities can prepare for and respond to these events.

By end of grade 5: Humans cannot eliminate natural hazards but can take steps to reduce their impacts.

By end of grade 8: Mapping the history of natural hazards in a region, combined with an understanding of related geological forces can help forecast the locations and likelihoods of future events.

By end of grade 12: Natural hazards and other geological events have shaped the course of human history in various ways.

**Human Impacts on Earth Systems**

How do humans change the planet?

By end of grade 2: Things that people do to live comfortable can affect the world around them.

By end of grade 5: Human activities in agriculture, industry, and everyday life have had major effects on the land, vegetation, streams, ocean, air and even outer space.

By end of grade 8: Human activities have significantly altered the biosphere, including the extinction of some species.

By end of grade 12: The sustainability of human societies and the biodiversity that supports them requires responsible management of natural resources.

**Global Climate Change**

How do people model and predict the effects of human activities on Earth’s climate?

By end of grade 5: Understanding of how global temperature rising will effect humans and other organisms in different ways.

By end of grade 8: Climate science, engineering capabilities, and understanding human behavior and activities such as the release of greenhouse gases from burning fossil fuels as major factors in global warming.

By end of grade 12: Global climate models; Use of computer simulations and other studies to visualize human interactions with global climate change.
Dimension 3
Disciplinary Core Ideas- Engineering, Technology, and Application of Science

1. Engineering Design
2. Links Among Engineering, Technology, Science, and Society

Defining the terms-
- “technology” is any modification of the natural world made to fulfill human needs or desires.
- “engineering” is a systematic and often iterative approach to designing objects, processes, and systems to meet human needs and wants.
- “an application of science” is any use of scientific knowledge for a specific purpose, whether to do more science, to design a product, process, or medical treatment; to develop a new technology; or to predict the impacts of human actions.

Engineering Design

How do engineers solve problems?

Defining and Delimiting an Engineering Problem
What is a design for?
What are the criteria and constraints of a successful solution?

By end of grade 2: Developing a clear understanding of the problem at hand.
By end of grade 5: Solutions may be limited to resources (constraints). The criteria of a solution may also be defined. Both of these need to be taken into account.
By end of grade 12: Design criteria and constraints and address such things as the product’s or system’s function, durability, and limits on size and cost- should also take into account requirements set by society and explain them well.

Developing Possible Solutions
What is the process for developing potential design solutions?

By end of grade 2: Representational designs through sketches, drawings or physical models.
By end of grade 5: Research should be carried out (through internet searches, market research or field observations) before starting the design. Also students should be working together to brainstorm ideas and conduct tests of models.
By end of grade 8: Design solutions must be tested in order to improve the model. Also communication explaining the design is also important.
By end of grade 12: Evaluating solutions involve taking into account: cost, safety, reliability, aesthetics, and social, cultural and environmental impacts. Testing should lead to improvements in the design.

**Optimizing the Design Solution**

How can the various proposed design solutions be compared and improved?

By end of grade 2: Compare designs, test them and discuss strengths and weaknesses. 
By end of grade 5: Test different solutions to see which one works best given the criteria and constraints. 
By end of grade 8: Systematic processes for testing models such as running them through tests, recording results and observing which one performs best. A complete understanding will refine the design based on multiple tests of different designs for optimal performance. The student will have the ability to discuss and explain what makes a particular design the most suitable solution.

**Links among Engineering, Technology, Science, and Society**

How are engineering, technology, science, and society interconnected?

**Interdependence of Science, Engineering, and Technology**

What are the relationships among science, engineering, and technology?

By end of grade 2: Questions about the natural world can often be answered through observation and measurement. 
By end of grade 5: Tools and instruments (rulers, balances, thermometers, graduated cylinders, telescopes, and microscopes) are used in scientific investigations to answer questions about the natural world. New tools can be designed with improved technologies. 
By end of grade 8: Engineering advances have led to important discoveries in every field of science. In order to design better technologies, new science may need to be explored. In turn, technologies extend the measurement capacity of scientific investigations. 
By end of grade 12: Research and development (R&D) is where science and engineering meet. Many different fields are involved in scientific inquiry such as physics, geology, economics, psychology and sociology.

**Influence of Engineering, Technology, and Science on Society and the Natural World**

How do science, engineering, and the technologies that result from them affect the ways in which people live? How do they affect the natural world?

By end of grade 2: Every human-made product is derived from knowledge about the natural world and is built using materials from the natural world. 
By end of grade 5: Engineers improve existing technologies or develop new ones to increase their benefits, to decrease known risks, and to meet social demands. Sometimes these technological advances change the way people interact with one another. 
By end of grade 8: The use of technologies and any limitations on their use are driven by individual or societal needs and can have short- and long- term consequences both positive or negative for humans and the natural world.
By end of grade 12: Modern civilization depends on major technological systems including those related to agriculture, health, water, energy, transportation, manufacturing, construction, and communications. Technological advances can have major impacts on human life and the natural world. Analysis of costs, environmental impacts, and risks, as well as expected benefits, is a critical aspect of decisions about technology use.

"The actual doing of science or engineering can pique students' curiosity, capture their interest, and motivate their continued study."
Implementation
Curriculum, Instruction, Teacher Development, and Assessment

Key Components of K-12 Science Education
1. Curriculum
2. Instruction
3. Teacher Development
4. Assessment

Curriculum
Curricula based on the framework and resulting standards should integrate the three dimensions- scientific and engineering practices, crosscutting concepts, and disciplinary ideas. Materials need to be developed as a multiyear sequence that helps students to develop increasingly sophisticated ideas across grades.

Learning and Instruction
What it means to learn science:
- Knowing, using, and interpreting scientific explanations of the natural world
- Generating and evaluating scientific evidence and explanations.
- Understanding the nature and development of scientific knowledge.
- Participating productively in scientific practices and discourse.

Teacher Development
Engagement in pre-service experiences
In-service professional development

Assessment
Purposes of Assessment:
1. Formative assessment for use in the classroom to assist learning.
2. Summative assessment for use at the classroom, school, or district level.
3. Assessment for program evaluation

Assessment Context: Classroom and Large-Scale Uses
Designing Assessments
Equity and Diversity in Science and Engineering Education

Science and Engineering Learning for All
All children should have adequate opportunities to learn, as well as the ability to explore their own interests and aspirations.

Considering Sources of Inequality
Profound demographic differences in homes, communities, schools, and districts can inhibit learning outcomes and increase stereotypes concerning students’ learning abilities.

Students’ Capacity to Learn Science
All students, with a few notable exceptions, from all demographics are capable of learning and achieving standards in the framework as long as supports are in place and the information taught is relevant to the students’ life.

Equalizing Opportunities to Learn
At-risk students in low socioeconomic populations are particularly vulnerable to fewer opportunities to learn science with supports.

Inclusive Science Instruction
Inclusive instruction builds upon the students’ interests and backgrounds to engage them more meaningfully in the curriculum. Students will learn science in part through active engagement in science practices.

Approaching Science Learning as a Cultural Accomplishment
A culturally responsive approach to science instruction involves the recognition of community practices and knowledge as being central to the scientific endeavor.

Relating Youth Discourses to Science Discourses
Diverse linguistic practices for making sense of natural phenomena can generate learning and be leveraged in instruction.

Building on Prior Interest and Identity
Learning science depends not only on the accumulation of facts and concepts but also on the development of an identity as a competent learner of science with motivation and interest to learn more.

Leveraging Students’ Cultural Funds of Knowledge
Educators should accept and enlist diversity as a means of enhancing science learning.

Making Diversity Visible
Underlying theoretical perspectives related to diversity, equity, and social justice should be transparent in standards development. Multiple nationalities and genders should be included in the discussion of contributions in science, when relevant and possible.

Value Multiple Modes of Expression
Multiple modes of expression and competence must be used in assessment.
Guidance for Standards Developers

Recommendations
1. Standards should set rigorous learning goals that represent a common expectation for all students.
2. Standards should be scientifically accurate yet also clear, concise, and comprehensible to science and educators.
3. Standards should be limited in number.
4. Standards should emphasize all three dimensions articulated in the framework—not only crosscutting concepts and disciplinary core ideas but also scientific and engineering practices.
5. Standards should include performance expectations that integrate the scientific and engineering practices with the crosscutting concepts and disciplinary core ideas. These expectations should include criteria for identifying successful performance and require that students demonstrate an ability to use and apply knowledge.
6. Standards should incorporate boundary statements. That is, for a given core idea at a given grade level, standards developers should include guidance not only about what needs to be taught but also about what does not need to be taught in order for students to achieve the standard.
7. Standards should be organized as sequences that support students’ learning over multiple grades. They should take into account how students’ command of the practices, concepts, and core ideas becomes more sophisticated over time with appropriate instructional experiences.
8. Whenever possible, the progressions in standards should be informed by existing research on learning and teaching. In cases in which insufficient research is available to inform a progression or in which there is a lack of consensus on the research findings, the progression should be developed on the basis of a reasoned argument about learning and teaching. The sequences described in the framework can be used as guidance.
9. The committee recommends that the diverse needs of students and of states be met by developing grade band standards as an overarching common set for adoption by multiple states. For those states that prefer or require grade-by-grade standards, a suggested elaboration on grade band standards could be provided as an example.
10. If grade-by-grade standards are written based on the grade band descriptions provided in the framework, these standards should be designed to provide a coherent progression within each grade band.
11. Any assumptions about the resources, time, and teacher expertise needed for students to achieve particular standards should be made explicit.
12. The standards for the sciences and engineering should align coherently with those for other K-12 subjects. Alignment with the Common Core Standards in Mathematics and English/Language Arts is especially important.
13. In designing standards and performance expectations, issues related to diversity and equity need to be taken into account. In particular, performance expectations should provide students with multiple ways of demonstrating competence in science.
Looking toward the Future
Research and Development to Inform K-12 Science Education Standards

Research to inform implantation and future revisions of the Framework

Core questions behind an R&D agenda on learning and teaching

- What are the typical preconceptions that students hold about the practices, crosscutting concepts, and core ideas at the outset?
- What is the expected progression of understanding, and what are the predictable points of difficulty that must be overcome?
- What instructional interventions can move students along a path from their initial understanding to the desired outcome?
- What general and discipline-specific norms and instructional practices best engage and support student learning?
- How can students of both genders and of all cultural backgrounds, languages, and abilities become engaged in the instructional activities needed to move toward more sophisticated understanding?
- How can the individual student’s understanding and progress be monitored?

Key Areas of Research
- Learning Progressions
- Scientific and Engineering Practices
- Development of Curricular and Instructional Materials
- Assessment
- Supporting Teachers’ Learning


Compiled and annotated by Candy Boerwinkle (2014) Southern Oregon University, expressly for the Ronald E. McNair Post-Baccalaureate Program.