Exploring the Nature of Science in the Next Generation Science Standards: Understanding the Science of Nature through the Nature of Science

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What is Science?

• Science is...
• Science involves...
• Etc.
### Nature of Science Survey
**Answer “T” (True) or “F” (False)**
(Modified from the work of Steven M. Dickhaus)

<table>
<thead>
<tr>
<th>#</th>
<th>Statement</th>
<th>Your Answer</th>
<th>Correct Answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Science can prove anything, solve any problem, or answer any question.</td>
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<tr>
<td>2</td>
<td>Different scientists may get different solutions to the same problem.</td>
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<tr>
<td>3</td>
<td>Science is primarily concerned with understanding how the natural world works.</td>
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<td>4</td>
<td>Science can be done poorly.</td>
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<td>5</td>
<td>Science is primarily a method for inventing new devices.</td>
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<tr>
<td>6</td>
<td>Scientists have solved most of the major mysteries of nature.</td>
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<tr>
<td>7</td>
<td>Science can study things and events that happened in the past, even if there was no one there to observe the event.</td>
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<tr>
<td>8</td>
<td>Most engineers and medical doctors are practicing scientists.</td>
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<tr>
<td>9</td>
<td>Scientists often try to disprove their own ideas.</td>
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<tr>
<td>10</td>
<td>Scientists can believe in God or a supernatural being and still do good science.</td>
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<tr>
<td>11</td>
<td>Any research based on logic and reasoning is scientific.</td>
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<tr>
<td>12</td>
<td>Science can be influenced by race, gender, nationality, or religion of the scientist.</td>
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</tr>
<tr>
<td>13</td>
<td>Science involves dealing with many uncertainties.</td>
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<td></td>
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<tr>
<td>14</td>
<td>Scientific concepts and discoveries can cause new problems for people.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>Something that is &quot;proven scientifically&quot; is considered by scientists as being a fact, and therefore no longer subject to change.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>Science requires a great deal of creative activity.</td>
<td></td>
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</tr>
<tr>
<td>17</td>
<td>Disagreement between scientists is one of the weaknesses of science.</td>
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</tr>
</tbody>
</table>
What is NOS about?

- What is science?
- How do scientists do their work?
- What is the nature of scientific knowledge?
- How does scientific knowledge develop?
- Is science objective? (What is objectivity?)
- How does science differ from other ways of knowing?
Study of NOS

- The study of NOS is informed by:
  - Philosophy of Science
  - History of Science
  - Sociology of Science
  - Science Education
What Should a Scientific Explanation Include? (Examples)
What is a Scientific Explanation?
What is a Scientific Explanation?

• In common usage, an explanation is a statement made to clarify something and make it understandable.

• In science, “explanation” means something more concrete.

• Scientific explanations consist of three specific parts:
  1. claims,
  2. evidence,
  3. and reasoning.
What is a Scientific Explanation?

• Define **claim** & **evidence**.

• **Claim** is an assertion or conclusion that answers the original question.

• **Evidence** is scientific data that supports the student’s/scientist’s claim. It must be appropriate and sufficient. It can come from an investigation or other source, such as observations, reading material, or archived data.
What is a Scientific Explanation?

• Define reasoning.

• **Reasoning** is the justification that links the claim and evidence. It shows why the data counts as evidence to support the claim, using appropriate scientific principles.
Scientific Hypothesis, Law, Theory, and Fact

• What is a Fact?

• What is a Hypothesis?

• What is a Law?

• What is a Scientific Theory?
FACTS

• Fact: Facts are the objects and events that exist around us, which we might observe and experience.

• Facts or *shared empirical observations* are the foundation upon which all scientific knowledge is constructed, but what scientists do with those facts is key to a complete understanding and appreciation of the scientific enterprise (Fitzhugh 2009).
Scientific Fact

• **Fact**: In science, an observation that has been repeatedly confirmed (NRC, 1998).
How Can FACTS be Used in Science?

- In brief, facts or shared data and observations are the raw materials of science that may be used in a variety of ways.
- **Facts** may be formed into a law or “a descriptive generalization about how some aspect of the natural world behaves under stated circumstances” (National Academy of Sciences (NAS), 1998, p. 5). Another distinct kind of scientific knowledge is a theory which is “a well substantiated explanation of some aspect of the natural world that can incorporate facts, laws, inferences, and tested hypotheses” (p. 5).
For instance, we have the facts that mammals have hair—a set of observations we wish to explain (Fitzhugh 2009).

American black bear *Ursus americanus* (Pallas, 1780)

http://www.nhm.org/site/explore-exhibits/permanent-exhibits/north-american-mammals/black-bear
HYPOTHESIS

• How would you incorporate the aforementioned fact(s) into a hypothesis?

• An evolutionary biologist might then present the following hypothesis:

• As the result of random mutation, hair originated in the earliest mammals, which were diminutive and likely nocturnal creatures, living among the dinosaurs, and there was a selective advantage to the presence of hair because it ensured a constant body temperature.
Scientific Hypothesis

• **Hypothesis**: A testable statement about the natural world that can be used to build more complex inferences and explanations (NRC, 1998).

• A hypothesis in the *classroom* or *museum* setting usually involves a prediction followed by an explanation.
Hypotheses suggest to us what might have happened in the past to account for what we observe in the present.
Scientific Law vs. Theory

• In the language of science, laws and theories are related but distinct kinds of scientific knowledge.
Scientific Law vs. Theory

• Laws and theories are both products and tools of science, but each has a distinct heritage and role. One does NOT become the other when more evidence is amassed (Horner & Rubba, 1978, 1979; McComas, 1997).

• Theories and laws are equally mature, important, useful and unique kinds of scientific knowledge. Understanding the fundamental distinctions and relationships between laws and theories is essential in fully appreciating and evaluating the work of scientists while gaining fluency in the language of science.
The Natural History Museum of Los Angeles can provide the opportunity for students to understand the roles and discrete contributions of laws and theories while providing opportunities for them to question their beliefs about these and other related issues in the nature of science.
• Theories, on the other hand, are used to not only guide us in understanding the present by way of the past, but to also anticipate what we might experience in the future.

• As with any human endeavor, however, hypotheses and theories might be incorrect. So a fundamental part of any field of science is the process of critically evaluating our hypotheses and theories, known as testing.
Scientific Law

- **Law**: A descriptive generalization about how some aspect of the natural world behaves under stated circumstances (NRC, 1998). Laws include predictions made about *natural* phenomena.
Scientific Theory

• **Theory**: A well-substantiated explanation/mechanism of some aspect of the natural world that can incorporate facts, laws, inferences, and tested hypotheses (NRC, 1998). Theories explain how the law works (McComas, 2003).

• **Scientific theories** are *explanations* that are based on lines of evidence, enable valid predictions, and have been scientifically tested in many ways.
Scientific Law vs. Theory

• Sonleitner, (1989) makes the point that theory and law, are qualitatively different in what they are and what they do.
• He states that laws are *generalizations* about phenomena while theories are *explanations* of phenomena.
• Theory and law are *not* distinguished by their degree of verification.
What do we know about NOS?

• Science cannot be singularly (and definitively) defined because it is interpreted in different ways by different people.

• Methods such as the NOS card sort and surveys encourage students to think specifically about their views on science.

• Scientists, science educators & philosophers of science have proposed some consensus views on NOS.
Core NOS Ideas to Inform K-12 Science Teaching

• The following NOS ideas are emerging as the consensus elements that should define the content core when NOS is taught as content in K-12 educational programs.

1) Science demands and relies on empirical evidence.

2) Knowledge production in science shares many common factors such as shared habits of mind, norms, logical thinking and methods (including careful data recording, truthfulness, observation, etc.)
   • However, there is no one scientific methods by which all science is done
   • Experiments are not the only route to knowledge
   • Science uses both inductive reasoning and hypothetico-deductive testing
   • Scientific conclusions are peer reviewed but observations and experiments are not generally repeated

3) Scientific knowledge is tentative but durable. (This means that science cannot prove anything but scientific conclusions are still valuable and long lasting)
   • The problem of induction makes ultimate “proof” impossible
Consensus Views on NOS (cont’d)

4) Laws and theories are related but distinct kinds of scientific knowledge. Hypotheses are special, but general, kinds of scientific knowledge (and the term probably causes more problems then it is worth).

5) Science has a creative component.

6) Science has a subjective element. (Ideas and observations in science are “theory”-laden; this bias plays both potentially positive and negative roles in scientific investigation).
Consensus Views on NOS (cont’d)

7) There are historical, cultural and social influences on science.
8) Science and technology impact each other, but they are not the same.
9) Science and its methods cannot answer all questions. (In other words, there are limits on the kinds of questions that can be asked of science. There is no conflict between science and religion).

Goal of NGSS

Develop standards that will be rich in content and practice, arranged in a coherent manner across disciplines and grades to provide all students an internationally benchmarked science education.
## Moving from Current CA standards to NGSS-CA*

<table>
<thead>
<tr>
<th>Less emphasis on:</th>
<th>More emphasis on:</th>
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<tbody>
<tr>
<td>Discrete Facts</td>
<td>Conceptual understanding with a focus on depth over breadth</td>
</tr>
<tr>
<td>Isolated investigation and experimentation process skills</td>
<td>Integration of science and engineering practices with content</td>
</tr>
<tr>
<td>Student acquisition of information</td>
<td>Student understanding and use of scientific knowledge within and across science disciplines, and science and engineering practices</td>
</tr>
<tr>
<td>Numerous Standards</td>
<td>Limited number of disciplinary Core Ideas and Cross Cutting Concepts that unify the study of science and engineering</td>
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<tr>
<td>Uneven articulation throughout grade levels</td>
<td>Learning progressions that develop K-12</td>
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</table>

*Presentation to the State Board of Education, July 10, 2013*
<table>
<thead>
<tr>
<th>1998 CA Kindergarten Life Science &amp; Earth Science</th>
<th>NGSS Kindergarten Earth &amp; Space Science</th>
</tr>
</thead>
<tbody>
<tr>
<td>Students know how to observe and describe similarities and differences in the appearance and behavior of plants and animals.</td>
<td>Use a model to represent the relationship between the needs of different plants or animals (including humans) and the places they live. (K-ESS3-1.)</td>
</tr>
<tr>
<td>Students know characteristics of mountains, rivers, oceans, valleys, deserts, and local landforms.</td>
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</tbody>
</table>
### 1998 CA Standards vs. NGSS

<table>
<thead>
<tr>
<th>1998 CA 7th Grade Life Science</th>
<th>NGSS Middle School Life Science</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Students know the function of the Umbilicus and placenta during pregnancy</strong></td>
<td><strong>Use argument supported by evidence for how the body is a system of interacting subsystems composed of groups of cells. (MS-LS1-3.)</strong></td>
</tr>
<tr>
<td><strong>Students know how bones and muscles work together to provide a structural framework for movement.</strong></td>
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**1998 CA Standards:**
- Students know the function of the Umbilicus and placenta during pregnancy.
- Students know how bones and muscles work together to provide a structural framework for movement.

**NGSS Standards:**
- Use argument supported by evidence for how the body is a system of interacting subsystems composed of groups of cells. (MS-LS1-3.)
### 1998 CA Standards vs. NGSS

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<tr>
<th>1998 CA High School Chemistry</th>
<th>NGSS High School Physical Science</th>
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<tbody>
<tr>
<td>Students know how reaction rates depend on such factors as concentration, temperature, and pressure.</td>
<td>Apply scientific principles and evidence to provide an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs. (HS-PS1-5.)</td>
</tr>
</tbody>
</table>
Appendices

A Conceptual Shifts
B Responses to May Public Feedback
C College and Career Readiness
D All Standards, All Students
E Disciplinary Core Idea Progressions in the NGSS
F Science and Engineering Practices in the NGSS
G Crosscutting Concepts in the NGSS
H Nature of Science in the NGSS
I Engineering Design in the NGSS
J Science, Technology, Society, and the Environment
K Model Course Mapping in Middle and High School
L Connections to Common Core State Standards in Mathematics
M Connections to Common Core State Standards in English Language Arts
The Nature of Science and NGSS

The nature of science is included in the Next Generation Science Standards. Here we present the NOS Matrix. The basic understandings about the nature of science are:

1. Scientific Investigations Use a Variety of Methods
2. Scientific Knowledge is Based on Empirical Evidence
3. Scientific Knowledge is Open to Revision in Light of New Evidence
4. Scientific Models, Laws, Mechanisms, and Theories Explain Natural Phenomena
5. Science is a Way of Knowing
6. Scientific Knowledge Assumes an Order and Consistency in Natural Systems
7. Science is a Human Endeavor
8. Science Addresses Questions About the Natural and Material World
One goal of science education is to help students understand the nature of scientific knowledge. This matrix presents eight major themes and grade level understandings about the nature of science. Four themes extend the scientific and engineering practices and four themes extend the crosscutting concepts. These eight themes are presented in the left column. The matrix describes learning outcomes for the themes at grade bands for K-2, 3-5, middle school, and high school. Appropriate learning outcomes are expressed in selected performance expectations and presented in the foundation boxes throughout the standards.

<table>
<thead>
<tr>
<th>Categories</th>
<th>K-2</th>
<th>3-5</th>
<th>Middle School</th>
<th>High School</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scientific Investigations Use a Variety of Methods</td>
<td>Science investigations begin with a question.</td>
<td>Science methods are determined by questions.</td>
<td>Science investigations use a variety of methods and tools to make measurements and observations.</td>
<td>Science investigations use diverse methods and do not always use the same set of procedures to obtain data.</td>
</tr>
<tr>
<td></td>
<td>Scientist use different ways to study the world.</td>
<td>Science investigations use a variety of methods, tools, and techniques.</td>
<td>Science investigations are guided by a set of values to ensure accuracy of measurements, observations, and objectivity of findings.</td>
<td>New technologies advance scientific knowledge.</td>
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<td>Science depends on evaluating proposed explanations.</td>
<td>Scientific inquiry is characterized by a common set of values that include: logical thinking, precision, open-mindedness, objectivity, skepticism, replicability of results, and honest and ethical reporting of findings.</td>
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<td></td>
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<td>Scientific values function as criteria in distinguishing between science and non-science.</td>
<td>The discourse practices of science are organized around disciplinary domains that share exemplars for making decisions regarding the values, instruments, methods, models, and evidence to adopt and use.</td>
</tr>
<tr>
<td>Scientific Knowledge is Based on Empirical Evidence</td>
<td>Scientists look for patterns and order when making observations about the world.</td>
<td>Science findings are based on recognizing patterns.</td>
<td>Science knowledge is based upon logical and conceptual connections between evidence and explanations.</td>
<td>Scientific investigations use a variety of methods, tools, and techniques to revise and produce new knowledge.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Scientists use tools and technologies to make accurate measurements and observations.</td>
<td>Science disciplines share common rules of obtaining and evaluating empirical evidence.</td>
<td>Science knowledge is based on empirical evidence.</td>
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<td>Science disciplines share common rules of evidence used to evaluate explanations about natural systems.</td>
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<td>Science includes the process of coordinating patterns of evidence with current theory.</td>
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<td>Science arguments are strengthened by multiple lines of evidence supporting a single explanation.</td>
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<tr>
<td>Scientific Knowledge is Open to Revision in Light of New Evidence</td>
<td>Science knowledge can change when new information is found.</td>
<td>Science explanations can change based on new evidence.</td>
<td>Scientific explanations are subject to revision and improvement in light of new evidence.</td>
<td>Scientific explanations can be probabilistic.</td>
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<td></td>
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<td></td>
<td>The certainty and durability of science findings varies.</td>
<td>Most scientific knowledge is quite durable but is, in principle, subject to change based on new evidence and/or reinterpretation of existing evidence.</td>
</tr>
<tr>
<td></td>
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<td>Science findings are frequently revised and/or reinterpreted based on new evidence.</td>
<td>Scientific argumentation is a mode of logical discourse used to clarify the strength of relationships between ideas and evidence that may result in revision of an explanation.</td>
</tr>
<tr>
<td>Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena</td>
<td>Scientists use drawings, sketches, and models as a way to communicate ideas.</td>
<td>Science theories are based on a body of evidence and many tests.</td>
<td>Theories are explanations for observable phenomena.</td>
<td>Theories and laws provide explanations in science, but theories do not with time become laws or facts.</td>
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<tr>
<td></td>
<td>Scientists search for cause and effect relationships to explain natural events.</td>
<td>Science explanations describe the mechanisms for natural events.</td>
<td>Science theories are based on a body of evidence developed over time.</td>
<td>A scientific theory is a substantiated explanation of some aspect of the natural world, based on a body of facts that has been repeatedly confirmed through observation and experiment, and the science community validates each theory before it is accepted. If new evidence is discovered that the theory does not accommodate, the theory is generally modified in light of this new evidence.</td>
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<td></td>
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<td></td>
<td>Laws are regularities or mathematical descriptions of natural phenomena.</td>
<td>Models, mechanisms, and explanations collectively serve as tools in the development of a scientific theory.</td>
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<td></td>
<td></td>
<td></td>
<td>A hypothesis is used by scientists as an idea that may contribute important new knowledge for the evaluation of a scientific theory.</td>
<td>Laws are statements or descriptions of the relationships among observable phenomena.</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>The term “theory” as used in science is very different from the common use outside of science.</td>
<td>Scientists often use hypotheses to develop and test theories and explanations.</td>
</tr>
<tr>
<td>Categories</td>
<td>K-2</td>
<td>3-5</td>
<td>Middle School</td>
<td>High School</td>
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<td>------------------------------------------------</td>
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<td>------------------------------------------------------------------------------</td>
<td>------------------------------------------------------------------------------</td>
</tr>
<tr>
<td><strong>Science is a Way of Knowing</strong></td>
<td>• Science knowledge helps us know about the world.</td>
<td>• Science is both a body of knowledge and processes that add new knowledge. Science is a way of knowing that is used by many people.</td>
<td>• Science is both a body of knowledge and the processes and practices used to add to that body of knowledge. Science knowledge is cumulative and many people, from many generations and nations, have contributed to science knowledge. Science is a way of knowing used by many people, not just scientists.</td>
<td>• Science is both a body of knowledge that represents a current understanding of natural systems and the processes used to refine, elaborate, revise, and extend this knowledge. Science is a unique way of knowing and there are other ways of knowing. Science distinguishes itself from other ways of knowing through use of empirical standards, logical arguments, and skeptical review. Science knowledge has a history that includes the refinement of, and changes to, theories, ideas, and beliefs over time.</td>
</tr>
<tr>
<td><strong>Scientific Knowledge Assumes an Order and Consistency in Natural Systems</strong></td>
<td>• Science assumes natural events happen today as they happened in the past. Many events are repeated.</td>
<td>• Science assumes consistent patterns in natural systems. Basic laws of nature are the same everywhere in the universe.</td>
<td>• Science assumes that objects and events in natural systems occur in consistent patterns that are understandable through measurement and observation. Science carefully considers and evaluates anomalies in data and evidence.</td>
<td>• Scientific knowledge is based on the assumption that natural laws operate today as they did in the past and they will continue to do so in the future. Science assumes the universe is a vast single system in which basic laws are consistent.</td>
</tr>
<tr>
<td><strong>Science is a Human Endeavor</strong></td>
<td>• People have practiced science for a long time. Men and women from all cultures and backgrounds choose careers as scientists and engineers.</td>
<td>• Men and women from different social, cultural, and ethnic backgrounds work as scientists and engineers.</td>
<td>• Men and women from different social, cultural, and ethnic backgrounds work as scientists and engineers. Scientists and engineers rely on human qualities such as persistence, precision, reasoning, logic, imagination and creativity. Scientists and engineers are guided by habits of mind such as intellectual honesty, tolerance of ambiguity, skepticism and openness to new ideas. Advances in technology influence the progress of science and science has influenced advances in technology.</td>
<td>• Scientific knowledge is a result of human endeavor, imagination, and creativity. Individuals and teams from many nations and cultures have contributed to science and to advances in engineering. Scientists’ backgrounds, theoretical commitments, and fields of endeavor influence the nature of their findings. Technological advances have influenced the progress of science and science has influenced advances in technology. Science and engineering are influenced by society and society is influenced by science and engineering.</td>
</tr>
<tr>
<td><strong>Science Addresses Questions About the Natural and Material World.</strong></td>
<td>• Scientists study the natural and material world.</td>
<td>• Science findings are limited to what can be answered with empirical evidence.</td>
<td>• Scientific knowledge is constrained by human capacity, technology, and materials. Science limits its explanations to systems that lend themselves to observation and empirical evidence. Science knowledge can describe consequences of actions but is not responsible for society’s decisions.</td>
<td>• Not all questions can be answered by science. Science and technology may raise ethical issues for which science, by itself, does not provide answers and solutions. Science knowledge indicates what can happen in natural systems—not what should happen. The latter involves ethics, values, and human decisions about the use of knowledge. Many decisions are not made using science alone, but rely on social and cultural contexts to resolve issues.</td>
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Nature of Science understandings most closely associated with Practices

Nature of Science understandings most closely associated with Crosscutting Concepts
Scientific and Engineering Practices

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 information
## Disciplinary Core Ideas

<table>
<thead>
<tr>
<th>Life Science</th>
<th>Physical Science</th>
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</thead>
<tbody>
<tr>
<td>LS1: From Molecules to Organisms: Structures and Processes</td>
<td>PS1: Matter and Its Interactions</td>
</tr>
<tr>
<td>LS2: Ecosystems: Interactions, Energy, and Dynamics</td>
<td>PS2: Motion and Stability: Forces and Interactions</td>
</tr>
<tr>
<td>LS3: Heredity: Inheritance and Variation of Traits</td>
<td>PS3: Energy</td>
</tr>
<tr>
<td>LS4: Biological Evolution: Unity and Diversity</td>
<td>PS4: Waves and Their Applications in Technologies for Information Transfer</td>
</tr>
</tbody>
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<thead>
<tr>
<th>Earth &amp; Space Science</th>
<th>Engineering &amp; Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>ESS1: Earth’s Place in the Universe</td>
<td>ETS1: Engineering Design</td>
</tr>
<tr>
<td>ESS2: Earth’s Systems</td>
<td>ETS2: Links Among Engineering, Technology, Science, and Society</td>
</tr>
<tr>
<td>ESS3: Earth and Human Activity</td>
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</tbody>
</table>


Crosscutting Concepts

1. Patterns, similarity, and diversity
2. Cause and effect
3. Scale, proportion, and quantity
4. Systems and system models
5. Energy and matter
6. Structure and function
7. Stability and change
Age of Mammals

• Age of Mammals tells an epic evolutionary story that spans 65 million years! But its theme can be distilled into just six words:

• Continents move.
• Climates change.
• Mammals evolve.

http://www.nhm.org/site/explore-exhibits/permanent-exhibits/age-of-mammals
Resources

• Next Generation Science Standards
  www.nextgenscience.org/

• CDE updates to the NGSS
  www.cde.ca.gov/pd/ca/sc/ngssintrod.asp

• http://www.cde.ca.gov/pd/ca/sc/ngssstandard
  s.asp

• NSTA Common Core Resources
  www.nsta.org/about/standardsupdate
References


University of California Museum of Paleontology at UC Berkeley and the National Center for Science Education: evolution.berkeley.edu,evosite/evohome.html

Key Concepts

• A **scientific theory** is an explanation inferred from multiple lines of evidence for some broad aspect of the natural world and is logical, testable, and predictive. As new evidence comes to light, or new interpretations of existing data are proposed, theories may be revised and even change; however, they are not tenuous or speculative.

• A **scientific hypothesis** is an inferred explanation of an observation or research finding; while more exploratory in nature than a theory, it is based on existing scientific knowledge.

• A **scientific law** is an expression of a mathematical or descriptive relationship observed in nature. It also has predictive power.