Arizona Science Standards Science and Engineering Practices for HS | For use with Arizona Science Standards

Developing and Using Models

A practice of both science and engineering is to use and construct models as helpful tools for representing ideas and explanations.

- Use multiple types of models to represent and support explanations of phenomena, and move flexibly between model types based on merits and limitations.
- Develop, revise, and use models to predict and support explanations of relationships between systems or between components of a system.
- Use models (including mathematical and computational) to generate data to support explanations and predict phenomena, analyze systems, and solve problems.
- Design a test of a model to ascertain its reliability.
- Develop a complex model that allows for manipulation and testing of a proposed process or system.
- Evaluate merits and limitations of two different models of the same proposed tool, process, or system in order to select or revise a model that best fits the evidence. or design criteria.

Analyzing and Interpreting Data

Scientific investigations produce data that must be analyzed in order to derive meaning. Engineering investigations include analysis of data collected in the tests of designs.

- Use tools, technologies, and/or models (e.g., computational, mathematical) to generate and analyze data in order to make valid and reliable scientific claims or determine an optimal design solution.
- Consider limitations (e.g., measurement error, sample selection) when analyzing and interpreting data.
- Apply concepts of statistics and probability (including determining function fits to data, slope, intercept, and correlation coefficient for linear fits) to scientific and engineering questions and problems, using digital tools when feasible.
- Compare and contrast various types of data sets (e.g., self-generated, archival) to examine consistency of measurements and observations.
- Analyze data to identify design features or characteristics of the components of a proposed process or system to optimize it relative to criteria for success.
- Evaluate the impact of new data on a working explanation of a proposed process or system.

Using Mathematics and Computational Thinking

Mathematics and computation are fundamental tools for representing physical variables and their relationships in both science and engineering.

- Use mathematical or algorithmic representations of phenomena or design solutions to describe and support claims and explanations,and create computational models or simulations.
- Apply techniques of algebra and functions to represent and solve scientific and engineering problems.
- Use simple limit cases to test mathematical expressions, computer programs, algorithms, or simulations of a process or system to see if a model "makes sense" by comparing the outcomes with what is known about the real world.
- Create a simple computational model or simulation of a designed device, process, or system.

Planning and Carrying Out Investigations

Scientists and engineers plan and carry out investigations in the field or laboratory, working collaboratively as well as individually.

- Design an investigation individually and collaboratively and test designs as part of building and revising models, supporting explanations for phenomena, or testing solutions to problems.
- Consider possible confounding variables or effects and evaluate the investigation's design to ensure variables are controlled.
- Design and conduct an investigation individually and collaboratively, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly.
- Select appropriate tools to collect,record, analyze, and evaluate data.
- Design and conduct investigations and test design solutions in a safe and ethical manner including considerations of environmental, social, and personal impacts.
- Manipulate variables and collect data about a complex model of a proposed process or system to identify failure points or improve performance relative to criteria for success or other variables.
- Use investigations to gather evidence to support explanations or concepts.

Obtaining, Evaluating, and Communicating Information

Scientists and engineers must be able to communicate clearly and persuasively the ideas and methods they generate.

- Critically read scientific literature adapted for classroom use to determine the central ideas or conclusions of a text; summarize complex concepts, processes, or information presented in a text by paraphrasing them in simpler but still accurate terms.
- Synthesize, communicate, and evaluate the validity and reliability of claims, methods, and designs that appear in scientific and technical texts or media reports, verifying the data when possible.
- Produce scientific and/or technical writing and/or oral presentations that communicate scientific ideas and/or the process of development and the design and performance of a proposed process or system.
- Compare, integrate and evaluate multiple sources of information presented in different media or formats (e.g., visually, quantitatively) in order to address a scientific question or solve a problem.

The elements are not to be used as a check-off list, but rather a useful tool to help educators identify the specific pieces of knowledge and skill that make up the practice, crosscutting concept, or core idea at that grade-band.

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Constructing Explanations and Designing Solutions

The goal of science is the construction of theories that provide explanatory accounts of the world. The goal of engineering design is to find a systematic solution to problems that is based on scientific knowledge and models of the material world.

- Make quantitative and qualitative claims regarding the relationship between dependent and independent variables.
- Apply scientific reasoning, theory, and models to link evidence to claims to assess the extent to which the reasoning and data support the explanation or conclusion.
- Construct and revise explanations based on evidence obtained from a variety of sources (e.g., scientific principles, models, theories, simulations) and peer review.
- Base causal explanations on valid and reliable empirical evidence from multiple sources and the assumption that natural laws operate today as they did in the past and will continue to do so in the future.
- Apply scientific knowledge and evidence to explain phenomena and solve design problems, taking into account possible unanticipated effects.
- Design, evaluate, and refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and trade off considerations.

Engaging in Argument from Evidence

Reasoning and argument based on evidence are essential to identifying the best explanation for a natural phenomenon or the best solution to a design problem in science and engineering.

- Critique and evaluate competing arguments, models, and/or design solutions in light of new evidence, limitations (e.g., trade-offs), constraints, and ethical issues.
- Evaluate the claims, evidence, and reasoning behind currently accepted explanations or solutions to determine the merits of arguments.
- Construct a counter-argument that is based on data and evidence that challenges another proposed argument.
- Make and defend a claim about the natural world or the effectiveness of a design solution that reflects scientific knowledge, and student-generated evidence.
- Evaluate a claim for a design solution to a real-world problem based on scientific knowledge, empirical evidence, and logical arguments regarding relevant factors (e.g.economic, societal, environmental, ethical considerations).

Asking Questions and Defining Problems

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

- Ask questions that arise from careful observation of phenomena, models, theory, or unexpected results.
- Ask questions that require relevant empirical evidence to answer.
- Ask questions to determine relationships, including quantitative relationships, between independent and dependent variables.
- Ask and evaluate questions that challenge the premise of an argument, the interpretation of a data set, or the suitability of a design.
- Define a design problem that involves the development of a process or system with interacting components and criteria and constraints that may include social, technical, and/or environmental considerations.

Arizona Science Standards Crosscutting Concepts for HS | For use with Arizona Science Standards

Patterns

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

- Patterns in the natural and human designed world can be observed, used to describe phenomena, and used as evidence.
- Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena.
- Classifications or explanations used at one scale may fail or need revision when information from smaller or larger scales is introduced; thus requiring improved investigations and experiments.
- Patterns of performance of designed systems can be analyzed and interpreted to reengineer and improve the system.
- Mathematical representations are needed to identify some patterns.
- Empirical evidence is needed to identify patterns.
  - How do you describe the pattern?
  - How can you use this pattern in an explanation?
  - Is there a way to use mathematics to describe the pattern?
  - What predictions are possible based on the pattern?

Energy and Matter

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

- The total amount of energy and matter in closed systems is conserved.
- Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system.
- Energy cannot be created or destroyed—only moves between one place and another place, between objects and/or fields, or between systems.
- Energy drives the cycling of matter within and between systems.
- In nuclear processes, atoms are not conserved, but the total number of protons plus neutrons is conserved.
  - How do energy changes appear in this scenario or investigation?
  - Describe the cycles of matter represented in this scenario or investigation.
  - How do energy and matter interact in this scenario or investigation?
  - I think energy changed because _____.
  - Matter in this system went from _____ to _____.
  - The evidence I have for matter being conserved in this system is _____.
  - The interaction of energy and matter in this system is observed when _____.

Structure and Function

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

- Investigating or designing new systems or structures requires a detailed examination of the properties of different materials, the structures of different components, and connections of components to reveal its function and/or solve a problem.
- The functions and properties of natural and designed objects and systems can be inferred from their overall structure, the way their components are shaped and used, and the molecular substructures of its various materials.
  - What structures are important in this scenario or investigation?
  - How are the structures related to the functions in this scenario or investigation?
  - Describe a different structure that might be able to perform the same function.
  - The important structures are _____.
  - The _____ (structure) performs _____ (function).
  - I think that _____ (structure) could perform the same function because _____.

Cause and Effect

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

- Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects.
- Cause and effect relationships can be suggested and predicted for complex natural and human designed systems by examining what is known about smaller scale mechanisms within the system.
- Systems can be designed to cause a desired effect.
- Changes in systems may have various causes that may not have equal effects.
  - Does the effect have more than one cause?
  - What predictions are possible from the cause-effect relationship?
  - How have you used the cause-effect relationship in a scientific argument?
  - One cause of _____ (effect) might be _____.
  - From the cause-effect relationship, I would claim that _____.
  - I tested what I thought was the cause-effect relationship by _____.

Systems and System Models

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

- Systems can be designed to do specific tasks.
- When investigating or describing a system, the boundaries and initial conditions of the system need to be defined and their inputs and outputs analyzed and described using models.
- Models (e.g., physical, mathematical, computer models) can be used to simulate systems and interactions—including energy, matter, and information flows—within and between systems at different scales.
- Models can be used to predict the behavior of a system, but these predictions have limited precision and reliability due to the assumptions and approximations inherent in models.
  - What are the parts of the system?
  - Describe how the parts of the system interact.
  - What are the interactions of the system?
  - How does the model represent the system?
  - The parts of the system are _____ , _____ , _____...
  - In this system _____ interacts with _____ to cause _____.
  - The model I used to describe the system we studied was _____ because it _____.

Stability and Change

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

- Much of science deals with constructing explanations of how things change and how they remain stable.
- Change and rates of change can be quantified and modeled over very short or very long periods of time. Some system changes are irreversible.
- Feedback (negative or positive) can stabilize or destabilize a system.
- Systems can be designed for greater or lesser stability.
  - How does the system display stability?
  - What changes were occurring while the system was stable?
  - Describe how the system is able to remain stable.
  - Where else have you seen this type of stability (or change)?
  - The system displays stability by _____.
  - Even though the system appears stable, I know that _____ (changes) were happening.
  - The reason this system can remain stable is _____.

Scale, Proportion, and Quantity

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

- The significance of a phenomenon is dependent on the scale, proportion, and quantity at which it occurs.
- Some systems can only be studied indirectly as they are too small, too large, too fast, or too slow to observe directly.
- Patterns observable at one scale may not be observable or exist at other scales.
- Using the concept of orders of magnitude allows one to understand how a model at one scale relates to a model at another scale.
- Algebraic thinking is used to examine scientific data and predict the effect of a change in one variable on another (e.g., linear growth vs. exponential growth).
  - How does proportion fit into this scenario or investigation?
  - How does scale fit into this scenario or investigation?
  - How does quantity fit into this scenario or investigation?
  - Is this phenomenon visible at other scales? Explain your thinking.
  - In this science idea, scale is important because _____.
  - In this science idea, proportion is important because _____.
  - In this science idea, quantity is important because _____.

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