Planning and Carrying Out Investigations

Planning and carrying out investigations in 9–12 builds on K–8 experiences and progresses to include investigations that provide evidence for and test conceptual, mathematical, physical, and empirical models.

- Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, 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. (HS-ESS2-5)

Analyzing and Interpreting Data

Analyzing data in 9–12 builds on K–8 experiences and progresses to introducing more detailed statistical analysis, the comparison of data sets for consistency, and the use of models to generate and refine a model.

- Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution. (HS-ESS2-2)

Disciplinary Core Ideas

**ESS1.B: Earth and the Solar System**

- Cyclical changes in the shape of Earth’s orbit around the sun, together with changes in the tilt of the planet’s axis of rotation, both occurring over hundreds of thousands of years, have altered the distribution of sunlight falling on the Earth. These phenomena cause a cycle of ice ages and other gradual climate changes. (secondary to HS-ESS2-4)

**ESS2.A: Earth Materials and Systems**

- Earth’s systems, being dynamic and interacting, cause feedback effects that can increase or decrease the original changes. (HS-ESS2-1), (HS-ESS2-2)
- Evidence from deep probes and seismic waves, reconstructions of historical changes in Earth’s surface and its magnetic field, and an understanding of physical and chemical processes lead to a model of Earth with a hot but solid inner core, a liquid outer core, a solid mantle and crust. Motions of the mantle and its plates occur primarily through thermal convection, which involves the cycling of matter due to the outward flow of energy from Earth’s interior and gravitational movement of denser materials toward the interior. (HS-ESS2-3)
- The geological record shows that changes to global and regional climate can be caused by interactions among changes in the sun’s energy output or Earth’s orbit, tectonic events, ocean circulation, volcanic activity, glaciers, vegetation, and human activities. These changes can occur on a variety of time scales from sudden (e.g., volcanic ash clouds) to intermediate (ice ages) to very long-term tectonic cycles. (HS-ESS2-4)

**ESS2.B: Plate Tectonics and Large-Scale System Interactions**

- 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. Plate tectonics can be viewed as the surface expression of mantle convection. (HS-ESS2-3)

Crosscutting Concepts

**Cause and Effect**

- Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. (HS-ESS2-4)

**Energy and Matter**

- The total amount of energy and matter in closed systems is conserved. (HS-ESS2-6)
- Energy drives the cycling of matter within and between systems. (HS-ESS2-3)

**Structure and Function**

- 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. (HS-ESS2-5)

**Stability and Change**

- Much of science deals with constructing explanations of how things change and how they remain stable. (HS-ESS2-7)
- Change and rates of change can be quantified and modeled over very short or very long periods of time. Some system changes are irreversible. (HS-ESS2-1)
- Feedback (negative or positive) can stabilize or destabilize a system. (HS-ESS2-2)

Connections to Engineering, Technology, and Applications of Science

The performance expectations marked with an asterisk integrate traditional science content with engineering through a Practice or Disciplinary Core Idea. The section entitled “Disciplinary Core Ideas” is reproduced verbatim from A Framework for K-12 Science Education: Practices, Cross-Cutting Concepts, and Core Ideas. Integrated and reprinted with permission from the National Academy of Sciences.
### Engaging in Argument from Evidence

Engaging in argument from evidence in 9–12 builds on K–8 experiences and progresses to using appropriate and sufficient evidence and scientific reasoning to defend and critique claims and explanations about the natural and designed world(s). Arguments may also come from current scientific or historical episodes in science.

- Construct an oral and written argument or counter-arguments based on data and evidence. (HS-ESS2-7)

### Connections to Nature of Science

#### Scientific Knowledge is Based on Empirical Evidence

- Scientific knowledge is based on empirical evidence. (ESS2-4)
- Science disciplines share common rules of evidence used to evaluate explanations about natural systems. (HS-ESS2-3)
- Science includes the process of coordinating patterns of evidence with current theory. (HS-ESS2-3)
- Science arguments are strengthened by multiple lines of evidence supporting a single explanation. (HS-ESS2-4)

### Scientific Knowledge is Based on Empirical Evidence

- The foundation for Earth's global climate systems is the electromagnetic radiation from the sun, as well as its reflection, absorption, storage, and redistribution among the atmosphere, ocean, and land systems, and this energy's re-radiation into space. (HS-ESS2-2)
- Gradual atmospheric changes were due to plants and other organisms that captured carbon dioxide and released oxygen. (HS-ESS2-6)
- Changes in the atmosphere due to human activity have increased carbon dioxide concentrations and thus affect climate. (HS-ESS2-6)

### ESS2: Biogeology

- 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. (HS-ESS2-7)

### PS4.A: Wave Properties

- Geologists use seismic waves and their reflection at interfaces between layers to probe structures deep in the planet. (Secondary to HS-ESS2-3)

### Articulation of DCIs across grade-bands:

| MS | HS
| --- | ---
| MS.PS1.A | (HS-ESS2-3), (HS-ESS2-5)
| MS.PS1.B | (HS-ESS2-3), (HS-ESS2-5)
| MS.PS2.B | (HS-ESS2-3), (HS-ESS2-5)
| MS.PS3.B | (HS-ESS2-3), (HS-ESS2-5)
| MS.PS3.C | (HS-ESS2-3), (HS-ESS2-5)
| MS.PS3.D | (HS-ESS2-3), (HS-ESS2-5)
| MS.PS4.A | (HS-ESS2-5)
| MS.PS4.B | (HS-ESS2-5)
| MS.PS5.A | (HS-ESS2-5)
| MS.LS2.A | (HS-ESS2-5)
| MS.LS2.B | (HS-ESS2-5)
| MS.LS2.C | (HS-ESS2-5)
| MS.LS2.D | (HS-ESS2-5)
| MS.LS3.A | (HS-ESS2-5)
| MS.LS3.B | (HS-ESS2-5)
| MS.LS3.C | (HS-ESS2-5)
| MS.LS3.D | (HS-ESS2-5)
| MS.LS3.E | (HS-ESS2-5)
| MS.LS3.F | (HS-ESS2-5)
| MS.LS3.G | (HS-ESS2-5)
| MS.LS3.H | (HS-ESS2-5)
| MS.LS4.A | (HS-ESS2-5)
| MS.LS4.B | (HS-ESS2-5)
| MS.LS4.C | (HS-ESS2-5)
| MS.LS4.D | (HS-ESS2-5)
| MS.LS4.E | (HS-ESS2-5)
| MS.LS4.F | (HS-ESS2-5)
| MS.LS4.G | (HS-ESS2-5)
| MS.LS4.H | (HS-ESS2-5)
| MS.LS4.I | (HS-ESS2-5)
| MS.LS4.J | (HS-ESS2-5)
| MS.LS4.K | (HS-ESS2-5)
| MS.LS4.L | (HS-ESS2-5)
| MS.LS4.M | (HS-ESS2-5)
| MS.LS4.N | (HS-ESS2-5)
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| MS.LS4.V | (HS-ESS2-5)
| MS.LS4.W | (HS-ESS2-5)
| MS.LS4.X | (HS-ESS2-5)
| MS.LS4.Y | (HS-ESS2-5)
| MS.LS4.Z | (HS-ESS2-5)
| MS.LS5.A | (HS-ESS2-5)
| MS.LS5.B | (HS-ESS2-5)
| MS.LS5.C | (HS-ESS2-5)
| MS.LS5.D | (HS-ESS2-5)
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| MS.LS6.B | (HS-ESS2-5)
| MS.LS6.C | (HS-ESS2-5)
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