



Climate Science Investigations (CSI), an online curriculum, includes modules developed through the NASA Innovations in Climate Education (NICE) program. The curriculum is designed to enable high school students to analyze NASA data to address the public's questions and commonly held alternative ideas about climate change. The table below shows the *Next Generation Science Standards* core ideas in *CSI* critical for developing the reasoning to address skeptics' questions about climate change. The topics in *CSI* also align to the *Climate and Energy Literacy Principles* (<http://cleanet.org>).

CSI's instructional approach is to use the public's questions—and the scientific evidence-based arguments that can address them—as a basis for teaching the disciplinary core ideas, crosscutting concepts, and practices of science and engineering as described in the NGSS. **The modules are sequenced in such a way that students are NOT simply told that the current warming trend is occurring rapidly and that 97-98% of climate scientists agree that it is due to human activity. Students instead examine data and are guided to this conclusion in the later modules.** In the *first module*, students are introduced to scientific inquiry and the nature of science. In the *second module*, students analyze extreme weather events and learn to differentiate weather from climate. Students balance Earth's energy budget (which is fundamental to understanding climate science) in the *third module*; and in the *fourth module*, students investigate the temporal and regional temperature data to answer the question of whether Earth is warming and if so, how rapid. In the *fifth module*, students compare natural and anthropogenic causes of climate change and learn that the observations can only be explained when both are included in the climate models. Students investigate the observed and projected impacts of climate change in the *sixth module*; and in the *final module*, students analyze a variety of ways to mitigate and adapt to climate change.

Description and Objectives of Modules

The Nature of Science - Students learn about the nature of science and how scientists do their work. They learn about what scientists assume, what makes science different from other ways of knowing, which methods scientists use to obtain information and construct reliable explanations of how our natural world works, and why skepticism is important to scientists' work. Students also learn about the important role scientific argumentation plays in the process and how scientists collaborate to reach consensus.

Objectives:

- Explain the nature of scientific inquiry.
- Differentiate between science and other ways of knowing.
- Explain the variety of methods that scientists use to revise and produce new knowledge.
- Describe the components of an evidence-based scientific argument.
- Explain the role of skepticism in scientific inquiry.
- Explain how the scientific community reaches consensus about certain findings and explanations.
- Provide an example of international collaboration among climate scientists.
- Explain how theories are developed.

Weather and Climate - This module examines the fundamentals of weather and climate and why scientists are cautious about confirming a link between the two. Students will learn the differences between weather and climate, how climate is classified, and how scientists define and identify weather extremes.

Objectives:

- Differentiate between weather and climate.
- Characterize the five general types of climate, as defined by Koppen's Climate classification system.
- Explain the relationship between global warming and climate change.
- Compare methods meteorologists use for forecasting weather to those used by climate scientists for predicting climate trends.
- Analyze temperature data to identify recent heat waves at various locations on Earth.
- Identify extreme weather events using the National Climatic Data Center (NCDC) website.

Energy: The Driver of Climate - In this module, students will learn about energy, the ultimate driver of climate. They will learn about Earth's unique atmosphere and the role it plays in moderating our climate, along with the balance of incoming energy from the sun and outgoing energy from Earth.

Objectives:

- Compare the composition of Earth's early atmosphere to the present composition.
- Compare and contrast the layers of Earth's atmosphere.
- Explain the relationship between wavelength and frequency of electromagnetic waves.
- Analyze the sun's electromagnetic spectrum to explain why different percentages of wavelengths reach Earth.
- Use two fundamental laws to explain the correlation between temperature and radiation for the sun and Earth.
- Describe the three ways that heat energy is transferred within Earth's atmosphere and between its surfaces and the atmosphere.
- Calculate Earth's global radiation balance by analyzing the amount of incoming solar radiation and outgoing terrestrial radiation.
- Explain why some greenhouse gases are more effective absorbers of infrared radiation.
- Explain the relationship between Earth's energy budget and the global average temperature of Earth.
- Explain how the greenhouse effect works.
- Differentiate between the natural greenhouse effect and an amplified greenhouse effect.

Temperature Over Time - In this module, students will investigate whether Earth is warming. First, they will review the causes of seasonal and daily temperature changes at different latitudes and locations. Students will then analyze a variety of temperature data to compare temperature trends over different time periods (from decades to centuries) and over different spatial scales (from local to global). These investigations will help answer whether the recent rise in Earth's global mean temperature (GMT) is unusual.

Objectives:

- Explain how Earth's tilt and orbit cause the seasons and the variation in temperature at different latitudes.
- Differentiate between the factors that cause changes in temperature.
- Explain the main factors, other than latitude, that cause variations in temperature at different locations.
- Compare and contrast temporal (time-based) temperatures trends.
- Compare and contrast spatial (geographic-based) temperatures trends.

Causes Of Climate Change - In this module, students will learn about climate forcings. Climate forcings are any factors that cause a change to Earth's energy balance, which will ultimately lead to a change in global mean temperature (GMT) and global climate.

Objectives:

- Explain natural causes of global climate change.
- Trace the flow of carbon through the carbon cycle.
- Explain the natural and human-related processes that cause increases and decreases in the concentration of greenhouse gases in the atmosphere.
- Explain how patterns (or fingerprints) can be used to identify the source of recent climate change.
- Explain the trends in carbon dioxide concentration over different time scales.
- Compare the changes in carbon dioxide and temperature over different time scales.
- Compare climate models of observed temperature changes due to natural causes to those that include both natural and anthropogenic (human) causes.
- Describe the types of feedbacks (or processes) that amplify and reduce the changes in climate.

Impacts of Climate Change- In this module, students will study the impacts that are already observable and those predicted over the next century. The investigations will help students analyze observed and projected impacts indicative of a warmer Earth and be able to assess the potential risk that these impacts present to humans and ecosystems.

Objectives:

- Compare temperature change projections for different emission scenarios.
- Analyze past and projected melting of polar sea ice, Greenland and Antarctica ice sheets, permafrost, and mountain glaciers.
- Analyze past and projected sea level.
- Analyze past and projected frequency and distribution of precipitation.
- Explain consequences of climate change for different ecosystems.
- Explain the impacts of climate change on human health.
- Analyze the impacts of climate change on south Florida.

What Can We Do - In this module students will learn about possible solutions, how to evaluate the cost effectiveness of those solutions and some of the legislative issues involved.

Objectives:

- Analyze the current and impending demand for energy on a national and global level.
- Explain the concepts of energy and how electricity is made.

- Describe and compare various climate change mitigation and adaptation strategies.
- Explain the economic factors that drive decisions on strategies for mitigating and adapting to climate change.
- Discuss the role of government in regulating and managing the nation’s energy consumption.
- Explain the role of sustainable development.

CSI’s Core Science Concepts and NGSS Disciplinary Core Ideas Underlying Scientific Arguments that Address Alternative Explanations

CSI Module Topics	Core Science Concepts Underlying Scientific Arguments/NGSS Disciplinary Core Ideas	Skeptics’ Questions
1. Nature of Science	Nature of Scientific Inquiry, Experimental Design, Evidence-Based Argumentation, Role of Skepticism in Science, Scientific Consensus and Certainty	How certain are climate scientists about their findings?
<i>(PS3.D: Energy in Chemical Processes)</i>		
2. Weather and Climate	Difference Between Weather and Climate, Types of Climate, Extreme Weather Events	Are extreme weather events happening more frequently and are they likely due to climate change?
<i>(ESS2.D: Weather and Climate; Global Climate Change)</i>		
3. Energy – The Driver of Climate	Composition and Structure of the Atmosphere, Electromagnetic Radiation, Temperature and Radiation, Heat Transfer, Energy Balance, Natural versus Amplified Greenhouse Effect	How can humans affect the atmospheric composition and change Earth’s energy balance?
<i>(PS1.A: Structure and Properties of Matter; PS.1.B. Chemical Reactions; PS.1.C. Nuclear Processes; PS3.A: Definitions of Energy; PS3.B: Conservation of Energy and Energy Transfer; PS3.D: Energy in Chemical Processes and Everyday Life; PS4.A: Wave Properties; PS4.B: Electromagnetic Radiation; ESS1.A: The Universe and Its Stars; ESS2.C: The Roles of Water in Earth’s Surface Processes)</i>		
4. Temperature Change Over Time	Factors that Affect Temperature (Latitude, Angle of Solar Radiation, Seasons, Properties of Water, Ocean Currents, Elevation), Methods for Studying Temperature, Temperature Over Geologic Time, Past 2,000 Years, and Since Industrial Revolution.	Is Earth’s temperature increasing and is the recent trend unusual compared to temperature trends in the past?
<i>(ESS.C: The History of the Planet Earth; ESS2.B: Earth and the Solar System; ESS2.A: Earth Materials and Systems; ESS2.C: The Roles of Water in Earth’s Surface Processes)</i>		
5. Causes of Climate Change	Radiative Forcing, Carbon Cycle, Natural Causes, (Milankovich Cycles, Volcanic Eruptions, Solar Activity, ENSO), Anthropogenic Causes (Fossil Fuel Combustion, Land-Use Changes), Climate Feedbacks, Global Climate Models	Are humans and/or natural factors mostly responsible for recent changes in climate?
<i>(LS1.C: Organization for Matter and Energy; LS2.B: Cycles of Matter and Energy Transfer in Ecosystems; PS3.D: Energy in Chemical Processes; ESS2.A: Earth Materials and Systems; ESS2.E: Biogeology)</i>		
6. Impacts of Climate Change	Observed/Projected Impacts for Different Emission Scenarios (Global Mean Temperature Increase, Land and Sea Ice Melt, Sea Level Rise), Changes to Hydrologic Cycle, Ocean Currents, Ocean Chemistry, Ecosystems and Species Diversity, Human Health	Is there evidence Earth has already warmed? What are the projected physical impacts to Earth? Are the impacts of a few degrees of warming harmful to societies and ecosystems on Earth?
<i>(LS2.A: Interdependent Relationships in Ecosystems; LS2.C: Ecosystem Dynamics, Functioning, and Resilience; LS2.D: Biodiversity and Humans; LS4.C: Adaptation; ESS2.C: The Roles of Water in Earth’s Surface Processes; SEE3.B: Natural Hazards)</i>		
7. What We Can Do	Mitigation, Adaptation, Energy Consumption, Renewable Energy, Sustainable Development	Can humans reduce the risks and costs of climate change?
<i>(PS3.A: Definitions of Energy; ETS1.C: Optimizing Design Solutions; ETS1.A: Defining and Delimiting Engineering Problems; ETS1.B: Developing Possible Solutions; ESS3.A: Natural Resources; ESS3.C: Human Impacts on Earth Systems)</i>		

The practices of science and engineering and crosscutting concepts (patterns; cause and effect; scale, proportion, and quantity; systems and system models; energy and matter, and stability and change), as identified by the *Next Generation Science Standards*, are embedded in the CSI modules. Throughout the modules students ask questions; develop and use models; plan and carry out investigations; analyze and interpret data; use mathematics and computational thinking; construct explanations; engage in argument from evidence; and obtain, evaluate, and communicate information. The modules provide several coherent illustrations of

crosscutting concepts. For example, the crosscutting concept, cause and effect, is integrated throughout the modules. To understand the causes of climate change, students learn the physical and chemical processes involved in the greenhouse effect, the biological processes involved in the carbon cycle, and the orbital changes of Earth and the cause of glacial periods.

Individual CSI modules are inquiry-based and designed for flexibility. Teachers can choose from a menu of learning resources to tailor the modules to meet their specific course objectives (<http://www.ces.fau.edu/nasa/content/teacher-materials/index.php>). Each module contains online and print background content, PowerPoint presentations, guided-reading questions, note-taking worksheets, inquiry-based hands-on lesson plans, online investigations of climate-related data, and quizzes. Each module has a scope and sequence that begins with topic background to prepare students to conduct a series of online investigations guided by questions. Engaging tools, such as interactive graphing, are utilized to increase student interest and engagement. For example, see the interactive graph in the investigation on temperature over the past 800,000 years. (<http://www.ces.fau.edu/nasa/module-3/temperature-changes/investigation-4.1.php>)

CSI has shown promise for improving education outcomes. In a pre-post design study with 1050 Ventura County, California ninth-grade earth science students who used *CSI* and other resources, there was a significant change in climate science knowledge (SEM = 0.09, $t = 5.14$, Sig (2-tailed) < 0.001). Teachers also demonstrated a significantly improved understanding of the climate science after participation in the 4-day Summer Institute ($t = 2.966$, sig (two-tailed) = 0.006, SEM = 0.112). We are currently seeing funding to update the CSI Program through the US Department of Education Institute for Educational Studies and the NFS Discovery Research K-12 Programs.

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