Climate Literacy: Essential Principles and Fundamental Concepts

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This guide was developed with input from recent workshops and discussions; this guide reflects the current efforts in defining climate literacy. It is inspired in part by the work conducted by AAAS Project 2061, federal science agencies, educators and other organizations to identify essential principles and fundamental concepts for Ocean Literacy and related work in other areas of Earth systems science education. References associated with particular key understandings are from AAAS Project 2061 benchmarks and other citations.

What is Climate Literacy?
You are climate literate if you understand the influence of the climate on you and society—and your and society's influence on climate. A climatically literate person:

- understands the Essential Principles and Fundamental Concepts about the functioning of weather and climate and how they relate to variations in the air, water, land, life and human activities in both time and space;
- can communicate about the climate in a meaningful way; and
- is able to make scientifically informed and responsible decisions regarding the climate.

Climate changes
Throughout Earth's history, climate has changed. Sometimes the change has been slow, over centuries and millennia, influenced by subtle differences in the Earth's orbit or movement of tectonic plates. Sometimes the change is abrupt, as sudden events, such as volcanic eruptions, collisions with meteors or shifts in ocean currents trigger rapid change in the state of the climate. Organisms and ecosystems adapt to the changes or perish. In human history, climate has influenced civilization in profound ways, playing an integral role in how societies thrive or survive. And in recent years, we have come to learn that human activities, especially over the past Century, such as destroying forest, agriculture and burning fossil fuels, can also alter the climate. To build sustainable communities and societies that are resilient to natural and human-caused climate changes and protect fragile ecosystems, a climate literate citizenry is necessary if not imperative. This framework for climate literacy seeks to identify and clearly communicate the overarching principles and key concepts that individuals will need in order to make responsible decisions about humans impact on climate and adaptation to changes in climate for future generations.

The 21st century may become known as The Climate Century, yet the basic dynamics of the atmosphere and climate processes are not easily understood. Many educated adults struggle to understand that Earth's seasonal changes are caused by the tilt of the planet on its axis, or that air has weight, that trees get most of their mass from carbon dioxide in the atmosphere, and that release invisible, odorless carbon dioxide when burned. However, even with recent films and television programs about human impacts on the climate system, there are still many who think incorrectly that the problem of global warming has to do with the hole in the ozone layer.

Climate is in many respects an ideal interdisciplinary, integrating theme for education. Beginning with simple concepts and observations of weather and water, and building increasingly complex inquiries and investigation into the physical, chemical, biological, geographical, social, historical and even technological dimensions of climate, students and citizens have the opportunity to better comprehend this important topic and make use of this knowledge in their lives and in their communities.

Teaching weather and climate is a substantial yet rewarding challenge that crosses numerous academic disciplines. Many teachers lack a background in the subject matter, and for many years climate has been largely missing from most science curricula. For younger students, the forecasts of melting ice caps and the extinction of species can be emotionally overwhelming, producing "eco-phobia" and a sense of paralysis. Research indicates some concepts, such as the understanding of how Earth's axial tilt causes the seasons and how longer-term orbital fluctuations affect the distribution of solar energy reaching Earth's surface, require a level of cognitive development for which younger students are unprepared. Thus it is essential that all citizens become climate literate in order to become aware of the magnitude of the problems and issues, understand the implications of various solutions, and make responsible decisions concerning the climate. We all want to know how to ensure that the future is sustainable.

Essential Principle 1: The climate system is observed and understood through scientific inquiry

Fundamental Concepts

a. Data based on observations of Earth from weather stations, buoys, satellites, ice cores, tree rings and other sources provide an understanding of the basic dynamics of the climate.
b. Constructing and revising scientific explanations (theories) and models using evidence, logic, and experiments lead to explanations for the climate system's behavior. (AAAS, 1B/H6 modified)
c. Climate scientists use measurements and models to test those theories and identify sources of error or uncertainty within each investigation.
d. Scientific knowledge is subject to modification as new information challenges prevailing theories and as a new theory leads to looking at old observations in a new way. (AAAS, 1A/M2)
e. Through a peer review process, the scientific thinking relating to climate dynamics is evaluated, refined and communicated. (AAAS, 1C/H7 modified)
f. Climate science has gained widespread acceptance by showing that it is borne out by the evidence, is logically consistent with other principles that are not in question, and explains more than its rival theories. (AAAS, 12A/H3 modified)

Essential Principle 2: The Sun is the primary source of Earth's energy

Fundamental Concepts

a. Solar energy heats the atmosphere and propels water through the global water cycle.
b. The intensity of electromagnetic waves from the sun allows water to be present in the liquid state. (AAAS, 4B/H1b)
c. Daily variations of solar energy caused by Earth's rotation drive many weather processes.
d. The number of hours of daylight and the intensity of the sunlight both vary in predictable pattern that depends on how far north or south of the equator the place is. (AAAS 4B/M13)
e. Because Earth turns daily on an axis that is tilted relative to the plane of Earth's yearly orbit around the sun, sunlight falls more intensely on different parts of Earth during the year. (AAAS, 4B/H3a)
f. The difference in intensity of sunlight and the resulting warming of Earth's surface produces the seasonal variations in temperature. (AAAS, 4B/H3b)
g. Without greenhouse gases, Earth's temperature would be too low to sustain life as we know it.
h. Natural variations of solar energy, such as solar cycles, influence Earth's atmosphere, but such variations do not account for the majority of the current increases in global temperatures.
i. Sunlight is the ultimate source of most of the energy we use. The energy in fossil fuels such as oil and coal comes from energy that organisms captured from the sun long ago. (AAAS 8C/H8 modified)

Essential Principle 3: Earth' surface is influenced by and influences climate

Fundamental Concepts

a. Earth is mostly rock. Three-fourths of Earth's surface is covered by a relatively thin layer of water (some of it frozen), and the entire planet is surrounded by a relatively thin layer of air. (AAAS 4B/M2ab)
b. Climate has changed slowly in the past due to the movement of land masses (plate tectonics) which have altered ocean and atmospheric circulations.
c. Thousands of layers of sedimentary rock confirm the long history of the changing surface of Earth and the changing climate and life forms whose remains are found in successive layers. (AAAS, 4C/M5a modified)
d. Waves, wind, water, and ice shape and reshape Earth's land surface by eroding rock and soil in some areas and depoisiting them in other areas, sometimes in seasonal layers. (AAAS 4C/1)

Essential Principle 4: Earth's weather and climate vary over time and place

Fundamental Concepts

a. The temperature of a place on Earth's surface tends to rise and fall in a ***somewhat predictable*** pattern every day and over the course of a year. (AAAS 4B/M12)
b. Weather occurs at local and regional scales over short time scales.
c. The weather is always changing and can be described by measurable quantities. Large masses of air with certain properties move across the surface of Earth. The movement and interaction of these air masses is used to forecast the weather. (AAAS 4B/E5 modified)
d. Climate varies on regional, continental and global scales, influencing ecosystems and the uses of energy.
e. Earth has a variety of climates, defined by the average temperature, precipitation, humidity, air pressure, and wind, over decades-long timescales in a particular place. (AAS 4B/M14 modified)
f. Climatic conditions result from latitude, altitude, and from the position of mountain ranges, oceans, and lakes. (AAAS, 4B/H5a)
g. Dynamic processes such as cloud formation, ocean currents, and atmospheric circulation patterns influence climates as well. (AAAS, 4B/H5b)
h. Earth's climates have changed in the past, are currently changing, and are expected to change in the future, primarily due to changes in the amount of light reaching places on Earth and the composition of the atmosphere. (AAAS, 4B/H6a)
i. Climates have sometimes changed abruptly in the past as a result of volcanic eruptions, impacts of huge rocks from space or shifts in ocean or atmospheric circulation. (AAAS 4B/M6 modified)

Essential Principle 5: Earth's atmosphere and ocean are dynamic and impact climate in complex ways

Fundamental Concepts

a. The atmosphere and ocean plays a crucial role in water, carbon, biological, geological and chemical cycles and systems.
b. The atmosphere and ocean are made up of layers, which have different thermal and chemical properties that influence weather, climate and life on Earth.
c. Variations in atmospheric composition and ocean currents can influence and are influenced by variations and changes in climate.
d. Energy can be transferred from one system to another (or from a system to its environment) in different ways: 1) thermally, 2) mechanically, 3) electrically, or 4) by electromagnetic waves. (AAAS 4E/M2 modified)
e. As frozen regions begin to thaw, methane and carbon dioxide may be released into the atmosphere, further increasing global average temperatures. (IPCC WG1 Ch4, 2007)
f. Areas near oceans tend to have more moderate temperatures than they would if they were farther inland but at the same latitude because water in the oceans can hold a large amount of thermal energy. (AAAS. 4B/M9b)

Essential Principle 6: Earth's atmosphere is the primary domain of weather and climate

Fundamental Concepts

a. The atmosphere is seemingly weightless, but it contains matter and has a density that varies depending on factors such as altitude, temperature and air pressure.
b. Transfer of thermal energy between the atmosphere and the land or oceans produces temperature gradients in the atmosphere and the oceans. (AAAS, 4B/H2)
c. Regions at different temperatures rise, sink or mix, resulting in winds and ocean currents. These winds and ocean currents, which are also affected by Earth's rotation and the shape of the land, carry thermal energy from warm to cool areas. (AAAS, 4B/H2)
d. Particles in the atmosphere from natural and human sources, such as dust and pollution, can impact the climate by altering the amount of solar energy reaching Earth's surface.
e. Gases in the atmosphere, such as carbon dioxide and water vapor, are transparent to much of the incoming sunlight but not to the infrared light/thermal energy from the warmed surface of Earth. (AAAS, 4B/H4a modified)
f. When greenhouse gases increase, more thermal energy is trapped in the atmosphere, and the temperature of Earth increases the light energy radiated into space until it again equals the light energy absorbed from the sun. (AAAS, 4B/H4b)
g. Water is the primary greenhouse gas in the atmosphere. Changes in other greenhouse gases can cause warming that can further increase the atmospheric concentration of water vapor.
h. Increases in greenhouse gases are very likely to increase global average temperatures and lead to other significant changes in Earth's climate.

Essential Principle 7: Water is fundamental to weather and climate

Fundamental Concepts

a. Water absorbs and releases much of the sun's energy.
b. Water evaporates from the surface of Earth, rises and cools, condenses into rain or snow, and falls again to the surface. The cycling of water in and out of the atmosphere is a significant aspect of the weather patterns on Earth. (AAAS 4B/M6)
c. The cycling of water in and out of the atmosphere is a significant aspect of the weather patterns on Earth. (AAAS, 4B/M7c)
d. Thermal energy carried by ocean currents has a strong influence on climates around the world. (AAAS, 4B/M9a)
e. Areas near oceans tend to have more moderate temperatures than they would if they were farther inland but at the same latitude because water in the oceans can hold a large amount of thermal energy. (AAAS, 4B/M9b)
f. Ocean circulation serves as a thermostat for Earth. Changes in the ocean's circulation have produced large, abrupt changes in climate in the past.
g. Water from warm seas provides the energy for hurricanes, cyclones and other tropical storms.
h. Climate processes, such as El Niño Southern Oscillation (ENSO), cause important changes in global weather patterns because of how they capture heat in the ocean and release it into the atmosphere. (Ocean Literacy 3C, 2005 modified)
i. The water cycle is closely connected to Earth's carbon cycle through biologic processes, including photosynthesis and decay, and chemical processes.
j. The ocean currently absorbs roughly half of all carbon dioxide added to the atmosphere, altering the chemical balance of the ocean, and much of the increased heat, contributing to sea level rise due to thermal expansion.

Essential Principle 8: Life on Earth has been shaped by, depends upon and affects climate

Fundamental Concepts

a. Life on Earth has been shaped by, depends upon and affects climate.
b. Life is permissible within a narrow range of climatic conditions, particularly temperature and precipitation.
c. Life is adapted to conditions on Earth, including the force of gravity that enables the planet to retain an adequate atmosphere. (AAAS, 4B/H1a)
d. All organisms are adapted to climatic conditions on Earth, including temperature, precipitation, time and nature of seasonal change, and weather and climate extremes.
e. Photosynthesizing organisms (plants and plankton) influence regional, continental and global climate processes, including atmospheric composition, absorbing carbon dioxide while alive, releasing it when in decay.
f. Plants on land and under water alter Earth's atmosphere by removing carbon dioxide from it, using the carbon to make sugars and releasing oxygen. This process is responsible for the oxygen content of the air. (AAAS, 4C/H1)
g. Human societies have developed food, energy, transportation and social systems that are dependent on climate and vulnerable to climate variations and changes.

h. Human beings are part of Earth's climate system. Human activities can, deliberately or inadvertently, alter the equilibrium of the climate system. (AAAS, 5D/H3 modified)

Essential Principle 9: Recent climate change is primarily caused by human activities

Fundamental Concepts

a. Human activities, such as reducing the amount of forest cover, increasing the amount and variety of chemicals released into the atmosphere, and intensive farming, have changed Earth's land, oceans, and atmosphere. (AAAS, 4C/M7a)
b. Some changes resulting from human activities have decreased the capacity of the environment to support some life forms. (AAAS, 4C/M7b)
c. At the global scale the human component of warming over the last three decades has had a discernible influence on many physical and biological systems.
d. The burning of fossil fuels in the last century has increased the amount of greenhouse gases in the atmosphere, which has contributed to Earth's warming. (AAAS, 4B/H6b)
e. Industrialization brings an increased demand for and use of energy.
f. By burning fossil fuels, changing land cover and intensive farming, people are releasing large amounts of carbon dioxide and other greenhouse gases into the atmosphere which spread throughout the environment and contributed to Earth's warming. (AAAS, 8C/M11 modified)
g. The processes of how Earth's climate has changed in the past due to natural processes ***do not explain*** the present changes that have been observed and are predicted.
h. The observed increase in global average temperatures since the mid-20th century is unequivocal and very likely due to the observed increase in human-induced greenhouse gas concentrations. (IPCC, 2007)

Essential Principle 10: Humans decision-making influences Earth's climate system

Fundamental Concepts

a. Decisions about energy resource use and adapting to climate variability and change are made at all societal levels, from the individual to the global. (AAAS 8CH5 modified)
b. Societal change is triggered from both the individual and community level as well as from leadership in industry and government.
c. Individual and societal decisions influence the direction of progress in technology.
d. Because energy sources are not evenly distributed on the planet, industry, transportation, urban development, agriculture and most other human activities are closely tied to the amount and kind of energy that is available in different regions of the country and the world.
e. Energy from the sun (and the wind and water energy derived from it) is available virtually indefinitely. Because the transfer of energy from these resources is weak and variable, systems are needed to collect and concentrate the energy. (AAAS, 8C/M5)
f. Slowing or reversal of climate change can be accomplished by combining short term (such as conservation, efficient use of resources, the use of renewable energy and buying choices) and long term (including investments in technological research, infrastructure and building resilient, sustainable communities) strategies.

Climate & Weather Literacy: Using the AAAS Project 2061 Science Literacy Research to Develop Weather and Climate Literacy Framework

NOAA Climate Program Office, education and outreach program worked to define climate literacy in the United States during a recent Framework for Climate & Weather Education Workshop held in Washington, DC, at the Department of Commerce, April 11-13, 2007. Supported through a NOAA Education Grant, the workshop brought together over twenty individuals representing various numerous NOAA line offices, other federal science agencies, formal and informal educators, non-governmental organizations, and other vested institutions involved with climate research, education and outreach to work together towards the goal of building of a framework for climate and weather literacy, building on the research and science and technology education benchmarks developed by the American Association for the Advancement of Science (AAAS) Project 2061.

The workshop developed the initial framework through an iterative process rooted in scientific research, including education and social research, on weather and climate related topics. Conducted as an initial step with broad community involvement toward the development of a robust conceptual framework that will help address misconceptions about weather processes, the workshop focused on natural as well as human-induced climate processes, the workshop sought to identify the key and essential concepts that a climate literate citizen or student should know.

A core group agreed to continue to pursue developing the envisioned climate literacy product after the end of the workshop. Broader participation by other agencies, non-governmental organizations, and individuals will be sought. A NSF/NOAA funded follow-up workshop is planned in the November of 2007 in Boulder Colorado.

All draft and final reports will be posted at NOAA's Climate Program Office's Education site, http://www.climate.noaa.gov/education/.

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