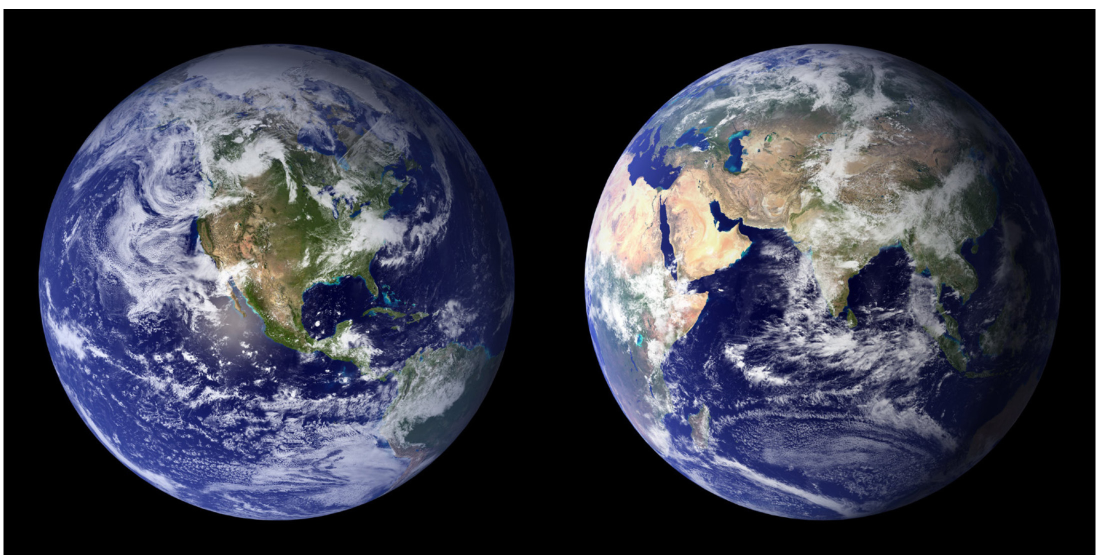
The Teacher-Friendly Guide™

to Climate Change



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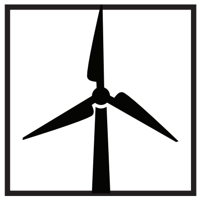
On the front cover: the "Blue Marble." Composite images produced by NASA in 2001-2002.

On the back cover: Atmospheric CO_2 concentration at Mauna Loa Observatory from 1958 to 2014 (NOAA).



Chapter 2: What Should Everyone Understand About Climate Change and Energy?

1. What Do You Think?

In this chapter, we approach the question in the chapter's title in three different ways:

- We provide responses from experts we surveyed—scientists both from the natural and social sciences, journalists, and educators—on what they think is most important for everyone to understand, and to boil it down to about 100 words or less.
- We review consensus documents written through collaborations of scientists and educators. These ideas were developed with input from many individuals.
- We share a framework of key ideas developed for this book, but drawn from a series of Earth Science Overarching Questions and Bigger Ideas we have used in our programming for many years.

Before sharing the specifics of any of these ideas, we ask that readers consider the question themselves. If you are going through the trouble of reading the book, it's a question you've at least wondered about.

The ideas that we are asking you to consider here and those that are discussed throughout this chapter are metaphorically at the 30,000-foot level. It is the core ideas that should persist throughout one's life. Don Weinshank[1] summarized a great deal of educational research rather succinctly: Ninety percent of your students will forget 90% of the content of your course within 90 days of finishing the course. This statement carries with it at least two important implications. We need to rework the nature of education so it no longer holds true, and we need to think very carefully about what that 10% of the content that is retained is composed of. This chapter is about that 10%. It is also about crafting a coherent conceptual framework for instruction that will hopefully lead to more than 10% ultimately being retained.

Now please pause and consider the question in the chapter's title. Then we'll share the answers we received from a set of selected experts. You should write your ideas down, since going by memory alone can be misleading: by writing it down, you decrease the odds of fooling yourself and have a much more reliable record of changes in thinking.

CHAPTER AUTHOR

Don Duggan-Haas

[1] Donald Weinshank was a Michigan State University professor. The 90% isn't based on research, but educators and learners alike widely agree on the spirit of the idea.

climate change *• the current increase in the average surface temperature worldwide, caused by the buildup of greenhouse gases in the atmosphere, and the related changes to other aspects of climate such as precipitation patterns and storm strength. See also GLOBAL WARMING.*

fossil fuel *• a non-renewable, carbon-based fuel source like OIL, NATURAL GAS, or COAL, developed from the preserved organic remains of fossil organisms.*

system *• a combination of interacting parts whose interaction creates behaviors that might not occur if each part were isolated.*

What Should Everyone Understand?

The idea for this exercise came from Richard Feynman's similar question:

"If, in some cataclysm, all of scientific knowledge were to be destroyed, and only one sentence passed on to the next generations of creatures, what statement would contain the most information in the fewest words?"[2]

2. Collecting Expert Opinions

We reached out to selected experts who work as climate scientists, as social scientists, as science educators, or as journalists with interests related to **climate change** communication. Feynman's answer about the most important scientific knowledge, and the invitation to contribute to our survey, are in an appendix at the end of this chapter.

2.1 What the Responses Say

Responses are arranged by author in alphabetical order.

Richard B. Alley, PhD, Evan Pugh University Professor, Department of Geosciences, and Earth and Environmental Systems Institute, The Pennsylvania State University:

"Wise policies that respect the solid scholarship on climate and energy will be helpful economically as well as environmentally and ethically."

Or, Alley suggested, if we want an answer with more motivation, though a longer sentence, here's another option.

*"We have a history of facing scarcity and unintended consequences after burning through energy sources such as trees, whales, and now **fossil fuels** far faster than nature makes more, but we are the first generation that knows how to build an energy **system** that can power everyone almost forever and that is economically beneficial, environmentally sound, and ethical."*

Don Duggan-Haas, PhD, Director of Teacher Programs, The Paleontological Research Institution:

"Fossil fuels both made modern society possible and endanger modern society. We know substantially reducing energy use is among the most straightforward ways to reduce the threats of climate change, yet we struggle to do so. Why? Largely because abandoning the status quo and forfeiting investments of time, money, and other resources is challenging psychologically even if the scientific evidence supporting such changes clearly shows wide ranging substantial benefits. These challenges are compounded by challenges related to: understanding perspectives of those who see the world differently than we do; thinking with a systems perspective; and, quite simply, being scared."

[2] Feynman, R.P. 1963.The Feynman Lectures on Physics. Reading, MA., Addison-Wesley Publishing Company.

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Alan Gould, PhD, specialist in Global Systems Science, University of California, Berkeley and The Lawrence Hall of Science:

"At first we might think that understanding climate change and making societies' energy systems sustainable are scientific and engineering endeavors respectively. But all too soon we realize they entail studies of economics, politics, sociology, psychology, religion, ethics, short-sightedness vs. long-term planning, greed vs. community spirit, and wholistic ecology vs. human-centeredness. They are wonderfully interdisciplinary and intricately interwoven."

Gabriele Hegerl, PhD, Fellow of the Research Society of Edinburgh, Chair of Climate System Science, GeoScience, University of Edinburgh:

*"The mean surface temperature of the planet is governed by **energy balance** between **solar** and **thermal fluxes**. If the balance changes, powerful feedbacks kick in to strengthen and change the climate response. They affect the global water cycle, the **cryosphere**, the **carbon cycle,** even the dynamics of the **atmosphere** and **oceans**. While some changes occur quickly, it takes centuries for climate to arrive at a new **equilibrium**, because the entire ocean needs to warm or cool, and **ice sheets** to change. Increasing **greenhouse gases** in the atmosphere changes the energy balance, and therefore starts these major changes."*

Joseph A. Henderson, PhD, is a research scientist at the University of Delaware where he specializes in climate change education.

"Climate change is a human construction. Millions of individuals have created a wicked collective action problem, and some bear more responsibility than others. Individual actions, while important, are insufficient to effect at scale. Educators must begin to teach collective solutions. Such a project is inherently political and cultural, and we should not shy away from this dimension of the challenge."

George Lakoff, PhD, Emeritus Professor of Linguistics, University of California at Berkeley:

"Systemic causation takes more than 100 words."

Lakoff advocates for use of the term "systemic causation" (in contrast to direct causation) for explaining such impacts of climate change as increased frequency in extreme weather events, noting that it is complex and hard to explain briefly.[3]

[3] See, e.g., Global Warming Systemically Caused Hurricane Sandy by G. Lakoff, 2012, The Huffington Post (http://www.huffingtonpost.com/george-lakoff/sandy-climate-change_b_2042871.html).

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Expert Opinions

energy balance *• a state in which the energy coming in to a system equals the energy going out.*

solar flux *• the rate of flow of solar energy across an area such as the surface of the Earth.*

thermal flux *• the rate of flow of thermal energy across an area such as the surface of the Earth.*

cryosphere *• the part of Earth's surface where water exists in solid form. This includes all major forms of ice, such as SEA ICE, GLACIERS, ICE SHEETS and permafrost.*

carbon cycle *• the exchange and recycling of carbon between the geosphere, hydrosphere, atmosphere, and biosphere.*

atmosphere *• the layer of gases that surrounds a planet.*

ocean *• the large, saline body of water that covers most of the Earth's surface.*

equilibrium *• a state of balance in opposing forces, amounts, or rates.*

2

Expert Opinions

ice sheet • *a mass of glacial ice that covers part of a continent and has an area greater than 50,000 square kilometers (19,000 square miles).*

greenhouse gas • *a gas that absorbs and re-radiates energy in the form of heat; carbon dioxide, water vapor, and methane are examples.*

potential energy • *the energy stored within an object or system, due to its position (gravitational potential energy), charge (electric potential), or other characteristics.*

Sankey Diagram • *a diagram that depicts flows of any kind, where the width of each flow pictured is based on its quantity.*

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R. G. (Bob) Landolt, Emeritus Professor of Chemistry, Texas Wesleyan University & currently, director of a Climate Science Toolkit Challenge Grant Project for the DFW Local Section of the American Chemical Society:

*"Twin major consequences impact the climate arising from using the high quality, **potential energy** stored in fossil fuels. Significant heat energy is wasted or "rejected" at every step in the energy flow, especially in the production and transmission of electricity, and carbon dioxide resulting from combustion and related processes has been generated in such quantities since the industrial revolution as to pose a threat to sustainable coexistence of many species, including humanity. The qualitative and quantitative aspects of these energy/mass flows are very complex and comprehension may be graphically demonstrated for past, present, and projected future through **Sankey Diagrams**.[4]"*

Tamara Shapiro Ledley, PhD, Senior Scientist, TERC:

"The Earth is a system of interacting components (air, water, land, life), each impacting the others and together shaping the Earth's climate. These components interact through the movement of energy (light and heat) and matter (water, gases, and minerals), determining the distribution of hot and cold temperatures and wet and dry conditions throughout the Earth system and influencing where and if life flourishes or declines."

Catherine Middlecamp, PhD, Professor, Nelson Institute for Environmental Studies, Madison, WI:

"Carbon is found in many places on our planet. It moves around. Where it ends up matters."

Joshua Sneideman, Einstein Fellow, Department of Energy, and middle school teacher, Irvine, CA:

"You can talk about energy without talking about climate change but you can't—shouldn't—talk about climate change without talking about energy."

Robert Ross, PhD, Associate Director for Outreach, Paleontological Research Institution:

"The climate system is complex, but the basic principles of human-induced climate change are not: the chemical properties of carbon dioxide have been long known, and we see the warming influence of CO_2 plainly from studies of other planets and Earth's history. Specific atmospheric CO_2 concentrations are not inherently good or bad. But current rapid rates of change in CO_2 and therefore climate are both faster and different than most natural changes in the geologic past. Such rapid changes will have impacts on humans and other life that, in many places, will lead to suffering and loss that cannot be undone."

[4] The 2016 Sankey Diagram for U.S. energy use can be viewed here: http://www.vox.com/energy-and-environment/2017/4/13/15268604/american-energy-one-diagram.

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***anthropogenic** • made by humans, or resulting from human activity.*

***sea level** • global sea level is the average height of Earth's oceans. Local sea level is the height of the ocean as measured along the coast relative to a specific point on land.*

William S. Spitzer, PhD, Vice President - Programs, Exhibits, and Planning, New England Aquarium:

"We need to shift the climate change conversation from 'doom and gloom' to 'hope, innovation, and change.' We need to go beyond describing the impacts, to help people understand how our systems for energy and transportation need to shift away from burning fossil fuels. Environmental education used to focus on the small things we can do to make a difference. Given the scope of the problems we face, we need to do big things and make a big difference. We need to act as a community, realizing our potential as citizens, not just as consumers."

Laura Faye Tenenbaum, Senior Science Editor, NASA Jet Propulsion Laboratory:

*"We can move from powerlessness to powerful. Our choices are important and we can make a difference. Yes, **anthropogenic** climate change is the greatest challenge of our time, but it's also our greatest opportunity. Remember, without struggle and challenge, nothing ever improves. So decide to welcome climate change as an exciting impetus. It's an opportunity to come together; to connect with each other and the world around us, and to re-evaluate what's important so we can build a cleaner way of living using new technologies. Go on, take responsibility for whatever you can and work together to make a difference."*

Kevin E. Trenberth, PhD, Distinguished Senior Scientist, National Center for Atmospheric Research:

"Carbon dioxide is a product of burning fossil fuels and thus human activity. It has a remarkably long lifetime in the atmosphere: centuries. That is why concentrations continue to sky-rocket and values are over 40% above pre-industrial: more than half the increase is since 1980. Many politicians and the public seem to think that global warming can easily be stopped if and when they decide it is time. It is not true. There is huge inertia that requires long-term planning."

Jim White, PhD, Director, Institute of Arctic and Alpine Research, Professor, Geological Sciences and Environmental Studies, University of Colorado, Boulder:

*"One of the most faithful relationships in nature is that between global temperature and **sea level**; when air and water warm, land ice melts and sea level rises, and when the earth cools, land ice forms taking water out of the ocean. The physics are simple. What is profoundly surprising and not well known is that small changes in temperature lead to large changes in sea level; on average 1 degree C change corresponds to 15 to 20 meters of sea level change. Think about that as world leaders work to limit warming to a 2 degree C change."*

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Ingrid Zabel, PhD, Climate Change Education Manager, The Paleontological Research Institution:

Two responses, one with an education perspective.

"1. Carbon emissions from the fossils fuels we burn to heat our buildings, generate electricity, and power our transportation are leading directly to a warming planet. We won't go back to a time before electricity, but we can be smarter about how we make and use energy. People are already taking action to limit climate change, and we need to join in to support their work, build on it, and innovate."

"2. How do we learn to read, to cook food, to use math to solve problems, to understand our past? Through education, with many different teachers to guide us. How are we going to reduce our carbon emissions so we can limit climate warming and secure our future? We start with education and then follow with action, so people understand that the goal is to find better ways to make and use energy, and that we can innovate and work toward this goal."

The collection of what we could call "big ideas" is impressively varied. We have purposefully not grouped them: you may wish to do this with your students. Do these ideas resonate with your own? Can you find common themes?

This section drew on individual responses. The next section discusses consensus documents of experts.

3. Consensus Documents

Several other documents already exist arising from initiatives to create a consensus among scientists and science educators of what everyone should know about climate change and energy. A fundamentally important document for those working to build understandings of climate is *Climate Literacy: The Essential Principles of Climate Science.*[5] This carefully crafted set of ideas was the result of a collaboration of many climate scientists and educators (including the author of this chapter). Its guiding principle might be considered a consensus statement of the most important thing everyone should understand about climate: "Humans can take actions to reduce climate change and its impacts." Seven more Climate Literacy Principles follow the guiding principle, each with several supporting concepts (see *Table 2.1*).

Another of those literacy documents that is important for anyone teaching about climate is *Energy Literacy: Essential Principles and Fundamental Concepts for Energy Education*[6] (see *Table 2.1*). Pundit Chris Hayes notes, "Teaching about climate change without teaching about energy is like teaching about lung cancer without teaching about smoking." Thus, those who teach about climate change should be at least somewhat familiar with both sets of principles.

[5] Climate Literacy: The Essential Principles of Climate Science, http://oceanservice.noaa.gov/education/literacy/climate_literacy.pdf.

[6] Energy Literacy: Essential Principles & Fundamental Concepts for Energy Education, https://energy.gov/eere/education/energy-literacy-essential-principles-and-fundamental-concepts-energy-education.

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Table 2.1: The climate and energy literacy principles.[5, 6] For both sets of principles, each individual principle is supported by between five and eight fundamental concepts.

Climate Literacy Principles	Energy Literacy Principles
Guiding Principle: Humans can take actions to reduce climate change and its impacts. 1. The sun is the primary source of energy for Earth's climate system. 2. Climate is regulated by complex interactions among components of the Earth system. 3. Life on Earth depends on, has been shaped by, and affects climate. 4. Climate varies over space and time through both natural and man-made processes. 5. Our understanding of the climate system is improved through observation, theoretical studies and modeling. 6. Human activities are impacting the climate system. 7. Climate change will have consequences for the Earth system and human lives.	1. Energy is a physical quantity that follows precise natural laws. 2. Physical processes on Earth are the result of energy flow through the Earth system. 3. Biological processes depend on energy flow through the Earth system. 4. Various sources of energy can be used to power human activities, and often this energy must be transferred from source to destination. 5. Energy decisions are influenced by economic, political, environmental, and social factors. 6. The amount of energy used by human society depends on many factors. 7. The quality of life of individuals and societies is affected by energy choices.

In addition to the climate and energy literacy consensus documents, there are several literacy documents for other areas of Earth science (ocean science, atmospheric science, and (approximately) solid Earth science), each of which contain content relevant to climate change and energy. All of these documents are briefly described in Box 2, "Essential Earth system science ideas for science literacy."

4. Striving for a Coherent Conceptual Framework

While there is value in consensus documents that summarize the most important ideas within each discipline, taken together they also pose a serious challenge to educators in how or if to effectively cover them all. Collectively, they include 38 "big ideas" (easily half of which can be related to climate

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Box 2: Essential Earth system science ideas for science literacy

Over the course of about eight years from 2004–2012, a series of consensus documents was written that compiled the most important ideas of several of the fundament spheres (subsystems) of Earth system science. Each document had a slightly different impetus for its creation, but each was influenced in general structure by the documents that came before it.[7] These documents collectively cover most of Earth system science, and all have parts relevant to climate change and energy.

- The Ocean Literacy Network created the publication Ocean Literacy, the Essential Principles for the Ocean Sciences K12 (http://oceanliteracy.wp2.coexploration.org/ocean-literacy-framework). The document summarizes principles in ocean literacy and maps them to the National Science Education Standards.[8]

- The construction of the Atmospheric Science Literacy Framework (https://scied.ucar.edu/atmospheric-science-literacy-framework) involved creation of a set of essential principles for literacy in atmospheric science and climate broadly.

- The Climate Literacy Network created the guide Climate Literacy: The Essential Principles of Climate Science (http://cleanet.org/cln), a framework for understanding and communicating about climate science specifically, with special attention to climate change. The Climate Literacy Network is hosted by the Climate Literacy & Energy Awareness Network (CLEAN) (http://cleanet.org), which features an extensive set of educational resources.

- The booklet Energy Literacy: Essential Principles and Fundamental Concepts Framework (https://energy.gov/eere/education/energy-literacy-essential-principles-and-fundamental-concepts-energy-education) presents energy concepts to help individuals and communities make informed energy decisions.

- The Earth Science Literacy Principles (http://www.earthscienceliteracy.org) covers the most fundament concepts of the solid Earth geosciences, including interactions with hydrosphere and biosphere.[9]

- The approach of the Next Generation Science Standards (https://www.nextgenscience.org/) is to reimagine science education, with less attention to specific content areas ("Disciplinary Content Ideas") than previous sets of standards, replaced by more focus on the "Crosscutting Ideas" and "Science and Engineering Practices." The NGSS are based on the Framework K–12 Science Education (https://www.nap.edu/catalog/13165/a-framework-for-k-12-science-education-practices-crosscutting-concepts) created by the National Research Council.[10]

[7] The Earth Science Literacy Initiative is described at http://www.earthscienceliteracy.org/index.html, and brief descriptions of four other relative Earth system science initiatives are described under the tab "Complementary Projects."

change in some way) and 247 supporting concepts. There is, of course, some redundancy in big ideas among documents, and an ambitious teacher might try to boil the big ideas into a smaller set, but this isn't simple. Add to this the Next Generation Science Standards: eight science and engineering practices, seven crosscutting concepts, and thirteen disciplinary core ideas.

There are no examples of creating large sets of ideas everyone should understand about any topic that has led to broad understanding the target content, in spite of countless attempts to do just that throughout history. Without a coherent framework to connect them one to another, it isn't likely that learners will understand or remember them. We need a *smaller set* of *bigger* ideas – a small set that cut across all of the big ideas from the various Earth science disciplines.

Once again, pause and consider a slightly different version of our original question (What should everyone understand about climate and energy?). If there were just a *few key ideas* that everyone understood about climate and energy, what should those few ideas be? To share an example from another discipline, E.O. Wilson suggests that if we taught biology as stemming from two key ideas, we'd be more effective in our efforts. Wilson identifies two "laws" for biology:

1. All organic processes are ultimately obedient to the laws of physics and chemistry.
2. All living systems and processes evolved by natural selection.

If you were to identify a *small set of big ideas* for energy and climate change, what would those ideas be? Come up with a list of somewhere between two and seven ideas. Here are suggested guidelines for framing those ideas.

- Each idea cuts across the curriculum area (in this case, climate and energy.
- Understanding of each idea is attainable by students and the understanding holds promise for retention.
- Each idea is essential to understanding a variety of topics.
- Each idea requires uncoverage; it has a bottomless quality.

Furthermore, the entirety of climate change and energy's role in the curriculum should be represented by this (small) set of ideas. (Again, writing down your ideas is helpful.)

Our big questions and ideas about climate change might serve to frame a climate change course, but we expect that most readers of this book will instead be working within the context of other courses, with broader foci than climate change (or energy) alone. These climate change and energy ideas offer

[8] The National Science Education Standards (NSES: https://www.nap.edu/catalog/4962/national-science-education-standards), published by the National Research Council in 1996, are a set of guidelines for K-12 science education in the US. One way the NSES were notable was including Earth science as a major subject with biology, physics, and chemistry. The NSES were superseded with the release of the Next Generation Science Standards.

[9] A co-author of this Guide, Ross, was on the Earth Science Literacy Initiative organizing committee.

[10] The author of this chapter was on the Earth science team for development of the Framework K–12 Science Education.

a coherent conceptual framework that can be nested within larger frameworks that serve courses, or across different grades and disciplines.

In our programming[11] with teachers from around the country, we have long used a set of five fundamental Earth system science big ideas that are "one size up," that is, more generalized than our climate change big ideas. These Earth System Science Bigger Ideas and Overarching Questions can serve to frame a course or to provide guidance across a series of courses with Earth and environmental science content, and their design can be used as a model for assembling and creating lists of big ideas for courses in other disciplines. The following section describes these ideas and questions.

4.1 Our Five Bigger Ideas and Two Bigger Questions about Climate Change

Our questions and ideas draw from a range of sources. One of them is the guiding principle from "Climate Literacy: The Essential Principles of Climate Science" described above. That idea, "Humans can take actions to reduce climate change and its impacts," stands alone among all of the ideas because it potentially has the most significant outcome. Perhaps it ranks as the biggest idea. We worked to craft a set of ideas of roughly that scale, that collectively meet the criteria described in the preceding section.

The pedagogical idea of whittling the list of ideas down to a small number (such as five) is grounded in research on how people learn and the related implications for curriculum and instruction. It is widely known that the US has not fared well in international comparisons of achievement in science and mathematics. In secondary mathematics and science courses in the US, dozens of key concepts are addressed in a single year. In Japan, the typical course covers about seven major concepts, and they consistently outperform the US in international science tests. One explanation for the better performance is that students appear to learn more deeply with a smaller set of chosen concepts.

A number of researchers have suggested that quality instruction benefits from covering fewer topics in depth, emphasizing a small number of big ideas.[12] Identifying such big ideas can help teachers and students to build a conceptual framework that ties the ideas of the discipline together in a meaningful way, one that facilitates the retrieval and application of that organized knowledge (Donovan et al., 1999). These big ideas are obviously not the full set of understandings every high school graduate should have, but rather should serve as a foundation for all of those ideas. This was part of the thinking behind the development of the various sets of literacy principles, but because there are sets of ideas for each of the sub-disciplines that are typically taught within the same one-year middle or high school course, the problem of too many concepts re-emerges.

[11] By "our" we mean education programs of the Paleontological Research Institution (PRI).

[12] The book Understanding by Design by Grant Wiggins and Jay McTighe (2005) provides a good overview on why focusing instructional attention on a small set of big ideas is more likely to yield deeper and more durable understandings than traditional approaches. The National Academy of Science's Committee on How People Learn issued a series of reports on key findings on learning research, including the importance of coherent conceptual frameworks.

4.1.1 The First Three Bigger Ideas

The answers to the above question varies to some degree related to the context in which you teach, but there are common ideas and principles that apply across a wide range of settings. Some bottom-line ideas that summarize what people such as those we surveyed think can and should be understood by most anyone from grade school to grad school (and beyond) are the following.

1. *Climate change is a real and serious problem facing global society in the coming decades and centuries.*
2. *Climate change in recent decades is primarily caused by human activities, especially as related to energy use.*
3. *Humans can take actions to reduce climate change and its impacts.*

These ideas are simultaneously simple and complex. While each can be stated in a single, clear sentence, they also possess a bottomless quality that allows for continued productive investigation for learners in most any setting, and at most any level. Their bottomless nature means that there is always more to learn about each of them even though they can be understood in a meaningful way by most anyone. That bottomless nature also points to two more important ideas that are necessary for deep understandings of climate change.

4.1.2 Models and Maps: The Fourth Bigger Idea

A fourth idea that highlights the need for mathematical thinking as related to understanding climate, energy, and the broader Earth system:

4. *To understand (deep) time and the scale of space, models and maps are necessary.*

The Earth's climate has been changing throughout its 4.5 billion year history, but for the last 10,000 years, the climate has been relatively stable. Agriculture originated about 10,000 years ago, and civilization, which depends upon agriculture, has grown to what it is today within the confines of that relatively stable climate. In the last two and a half centuries, the concentration of carbon dioxide in the atmosphere has grown substantially from about 280 parts per million in pre-industrial times to more than 400 parts per million (and still increasing) today. This is an increase of more than 40% and that increase in CO_2 is driving a rapid (on geologic time scales) increase in global temperature.

Maps and models aid in the understanding of things that are not possible to observe directly, and in the comprehension of time and space at both immense and sub-microscopic scales.[13] Models are also essential for making predictions. Given that climate change plays out over numerous spatial scales from local and global, maps of various kinds will be among the most commonly used models in this kind of work. Graphs are also an important type of model, and *Figure 2.1* shows an especially relevant example.

[13] A discussion of scale, and of big ideas in Earth system science generally, can be found in the first chapter of each of the regional Teacher-Friendly Guides to Earth Science: http://geology.teacher-friendlyguide.org.

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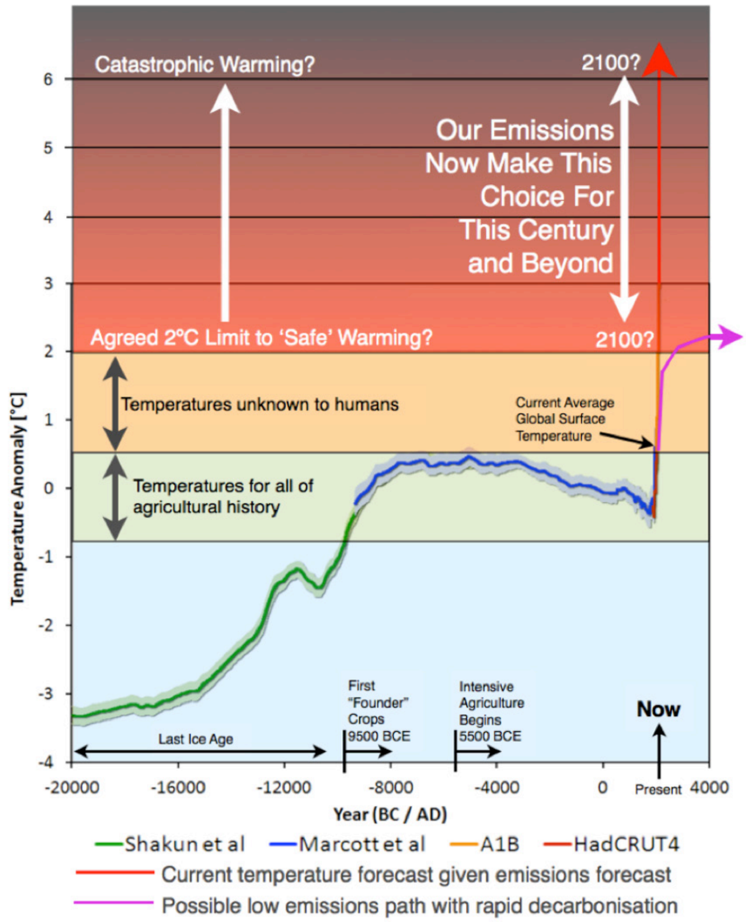

Figure 2.1: This graph is a model of climate change over the last 20,000 years and extending 4000 years into the future. Note that models are always limited in some ways. This shows only global average temperature over time. Climate is more than temperature. Since Homo sapiens *emerged as a species 200,000 years ago, the year 2016 experienced the warmest global temperature during that interval. (See Teacher-Friendly Guide website for a full color version.)*

Understanding geologic time entails understanding that humans as they are today have been around for only a remarkably small sliver of the history of the universe and occupy only the tiniest portion of the enormity of space. The graph in *Figure 2.1* shows only a tiny portion of geologic history: 24,000 years out of 4,540,000,000 years, or 0.0000053% of Earth history. Numbers and percentages are models as well.

4.1.3 Systems of Systems: The Fifth Bigger Idea

The fifth idea in this list of five is perhaps the most important, as all the others depend upon it. It highlights the importance of not only understanding the basics of climate and its component sciences, but also the many other topics with which it connects.

> *5. The Earth is a system of complex systems.*

Highlighting the importance of both simplicity and complexity is a recurring theme in climate change education, as it should be throughout all education. Issues surrounding climate and energy are profoundly complex. Neither complexity nor the nature of systems have been prominent in school curricula historically. However, these issues are central to some newer reform initiatives, including the Next Generation Science Standards. Like journalists and politicians, educators often strive to simplify the seemingly complex, and that clearly has its place. The world, however, is indeed a complex place, and the desire to simplify too much can become an obstacle to effective teaching. At such times, educators need to complexify the seemingly simple.

Complex systems, including the Earth itself and its climate system:

- are evolving;
- involve the interplay of different disciplines;
- are composed of multiple nested subsystems (indicating an importance for understandings of scale);
- are better understood from perspectives that include contextualization in space and time (perspectives that include the history of the system);
- are partially defined by feedback; and
- are not necessarily greater than, but qualitatively different from, the sum of their parts.

The list, of course, is not exhaustive (see *Figure 2.2*).

One fundamental aspect of complexifying as related to climate change is recognizing that deciding not to do something often brings with it a decision to do something else that has not been carefully considered. For example, unless we use less energy, choosing not to use one energy source is indirectly a choice to use other available (possibly *status quo*) sources.

Another fundamental aspect of complexifying is that it is confusing. There is no way around that—if science wasn't confusing, we wouldn't need careful methods to study it.

4.1.4 Two Big (Overarching) Questions

Introduction of these big ideas also invites discussion of the nature of science. As curricula are designed and implemented, the traditional topics of science should be complemented with ideas on how we have come to know what we know about the natural world. Within our big ideas framework, we draw attention to the nature of science with two overarching questions:

1. How do we know what we know?
2. How does what we know inform our decision-making?

These questions, when addressed in concert with the big ideas, provide a gateway into the nature and utility of the range of scientific ideas.

A very important complicating factor in understanding both questions is recognizing that we all "know" things that just aren't true and for which there exists contradictory evidence. Our minds can play tricks on us in ways that make it very challenging to see or accept evidence that runs counter to our expectations. **Cognitive biases** and **logical fallacies** are types of

For more information about cognitive biases, see Chapter 10: Obstacles to Addressing Climate Change.

cognitive bias • *a holding on to incorrect thinking even in the presence of contrary information, because of beliefs or points of view one has.*

logical fallacy • *incorrect reasoning due to faulty logic.*

errors in reasoning that stand in the way of what others might call rational decisions. Of course, our decisions seem rational to us—and they are rational within the context of how we interpret the world.

Taken individually, these big ideas and overarching questions represent important aspects of Earth system science, but together they are more significant. Keeping these ideas in mind—and considering how they arose through scientific methods and investigation—is invaluable as one proceeds throughout his or her curriculum, and it can provide a conceptual framework upon which to build an enduring understanding of the discipline.

4.2 Even Bigger Ideas

The five *even bigger* Earth system science big ideas and overarching questions in the "Rainbow Chart" (named for color-coding the chart and other content according to the five big ideas) shown in *Figure 2.2* have been refined with extensive input from scientists and educators. You can see their close relation to the climate change big ideas—in fact the first and last of the Bigger Ideas also appear in our list of climate change ideas.

Here the Bigger Ideas are stated at different depths—a "nickname" of a single word, at the sentence level, and in a short paragraph.[14] Stating them as a single word in the form of an idea's nickname is intended to make them easier to remember. A simple exercise is to have learners describe how a specific activity demonstrates (or is otherwise connected to) one or more of the Bigger Ideas, and to draw connections between ideas and the topic or field site under study.[15]

Any course in the natural sciences can be viewed through the lens of these five biggest ideas, as can any part of a curriculum that includes climate change and energy.

[14] Each big idea is described in more detail in the first chapter of each of the regional Teacher Friendly Guides to Earth Science: http://geology.teacherfriendlyguide.org.

[15] To explore more about Bigger Ideas and the "rainbow" chart of Figure 2.2, see the Prezi by Don Duggan-Haas "Bigger Ideas in Earth System Science" at http://virtualfieldwork.org/Big_Ideas.html.

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Overarching Questions:
How do we know what we know? How does what we know inform our decision-making?

	Systems	*Energy*	*Life*	*Change*	*Models*
Earth System Science Bigger Ideas	**The Earth is a System of Systems.**	**The Flow of Energy Drives the Cycling of Matter.**	**Life, including human life, influences and is influenced by the environment.**	**Physical and chemical principles are unchanging and drive both gradual and rapid changes in the Earth system.**	**To Understand (Deep) Time and the Scale of Space, Models and Maps are Necessary.**
	The Earth System is composed of and part of a multitude of systems, which cycle and interact resulting in dynamic equilibrium (though the system evolves). The Earth is also nested in larger systems including the solar system and the universe. However there is an inherent unpredictability in systems, which are composed of an (effectively) infinite number of interacting parts that follow simple rules. Each system is qualitatively different from, but not necessarily greater than the sum of its parts.	The Earth is an open system – it is the constant flow of solar radiation that powers most surface Earth processes and drives the cycling of most matter at or near the Earth's surface. Earth's internal heat is a driving force below the surface. Energy flows and cycles through the Earth system. Matter cycles within it. Convection drives weather and climate, ocean currents, the rock cycle and plate tectonics.	Photosynthetic bacteria reformulated the atmosphere making Earth habitable. Humans have changed the lay of the land, altered the distribution of flora and fauna and are changing atmospheric chemistry in ways that alter the climate. Earth system processes affect where and how humans live. For example, many people live in the shadow of volcanoes because of the fertile farmland found there, however they must keep a constant vigil to maintain their safety. The human impact on the environment is growing as population increases and the use of technology expands.	Earth processes (erosion, evolution or plate tectonics, for example) operating today are the same as those operating since they arose in Earth history and they are obedient to the laws of chemistry and physics. While the processes constantly changing the Earth are essentially fixed, their rates are not. Tipping points are reached that can result in rapid changes cascading through Earth systems.	The use of models is fundamental to all of the Earth Sciences. Maps and models aid in the understanding of aspects of the Earth system for which direct observation is not possible. Models assist in the comprehension of time and space at both immense and sub-microscopic scales. When compared to the size and age of the universe, humanity is a speck in space and a blip in time.

Figure 2.2: The "Rainbow Chart" of big ideas. (See Teacher-Friendly Guide website for a full color version.)

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Resources

Books

This book is a good introduction to the series of reports from the National Academy of Science on how people learn. It's available as a free pdf or for sale in hardcopy. Donovan, M. Suzanne, and John D Bransford, eds. How Students Learn: History, Mathematics, and Science in the Classroom. National Academy Press, Committee on How People Learn, A Targeted Report for Teachers, Center for Studies on Behavior and Development, National Research Council, 2005. https://www.nap.edu/catalog/10126/how-students-learn-history-mathematics-and-science-in-the-classroom.

Wiggins and McTighe describe the "backward design" process for instructional design. Their book clearly steps through an approach where big ideas and essential questions are the starting point for developing curriculum. Its two key ideas are contained in the book's title: 1) focus on teaching and assessing for understanding and learning transfer, and 2) design curriculum "backward" from those ends. Wiggins, Grant P, and Jay McTighe. Understanding by Design. Expanded 2nd edition. Alexandria, VA: Association for Supervision and Curriculum Development, 2005.

Online Resources

See Box 2 for links to the different Earth science literacy initiative documents. Big Ideas that synthesize these different efforts are discussed in both the chapters of that name in each of the Teacher Friendly Guides to the Earth Science of the United States (http://geology.teacherfriendlyguide.org/) and in Ross, R. M, and D. Duggan-Haas. "Big Ideas in Earth System Science." American Paleontologist 18, no. 1 (2010): 24. http://virtualfieldwork.org/downloadabledocs/AP_18_1%20Ross_Duggan-Haas.pdf.

Famed biologists E.O. Wilson and James Watson discussed the "laws of biology" as part of a longer discussion about Charles Darwin on Charlie Rose's PBS program. See the full program here: https://charlierose.com/videos/18174. E.O. Wilson describes his ideas about biological laws just before the six minute mark.

Appendix

We asked a set of experts in the science and communication of climate change for statements on the most important thing to know about climate and energy. The request included a deadline and an email address to submit responses. It was sent to 44 individuals. Following is the letter:

"***If you could help everyone understand one key concept about climate and energy, what would that concept be?"***

What we're asking: We're asking selected distinguished natural and social scientists, educators, and journalists who work on issues related to climate change and energy to contribute 50 to 100 word responses to the question above. All of the statements will be included, with authors' permissions, on the website for book, The Teacher-Friendly Guide to Climate Change. The best answers will be included in the book, authored by myself and my colleagues, Ingrid Zabel, and Rob Ross. This is part of the broader impacts outreach for Natalie Mahowald's NSF grant Improved Regional and Decadal Predictions of the Carbon Cycle (NSF 1049033). The book is also part of our series of Teacher-Friendly Guides.

We hope that contributors will find this to be an interesting exercise that may be helpful in their own work.

The inspiration comes from Richard Feynman's similar question:

> *"If, in some cataclysm, all of scientific knowledge were to be destroyed, and only one sentence passed on to the next generations of creatures, what statement would contain the most information in the fewest words?"*
>
> \- Feynman, 1963

While it would be wonderful if we could identify some sort of gateway or keystone ideas that trigger a cascade of understanding, our goal is honestly less ambitious. We want to learn and share what important thinkers think is most fundamental to understand about climate, energy, or the nature of learning related to climate and energy.

Feynman's answer to his own question was 51 words:

"*I believe it is the atomic hypothesis (or the atomic fact, or whatever you wish to call it) that all things are made of atoms—little particles that move around in perpetual motion, attracting each other when they are a little distance apart, but repelling upon being squeezed into one another*."

He continued, "*In that one sentence, you will see, there is an enormous amount of information about the world, if just a little imagination and thinking are applied*" (Feynman, 1963). We're allowing twice the length of Feynman, though you might wish to match his concision.

We've also worked on similar projects about big ideas in different areas in the past. You may wish to look to this work for examples, but you may wish to first consider the question without being influenced by this work. We have

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contributed to the literacy principles efforts in Climate, Energy, and Earth Science, and have created a synthesis set of big ideas that encompasses these different efforts. We are glad to talk about the nature of your contribution if you would like.

The book will address important aspects of the physical science that underlie climate change, but it is intended to be about much more than just that physical science. Climate change and energy are scientific issues, but they are also much more than that. While we expect the lion's share of the readership to be middle and high school science teachers, we are hoping to engage educators from across the disciplines and from informal settings as well as K-12 schools and colleges. We are also explicitly addressing social and psychological issues that make teaching and learning controversial issues challenging. That's why this request is going to social and cognitive scientists, and selected journalists as well scientists and science educators.

Sincerely,

Don Duggan-Haas, PhD, Director of Teacher Programs, the Paleontological Research Institution