Chapter 1

Introducing Planet Earth

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One of humanity's major discoveries is that we live on a round planet. We laugh about the idea that Earth is flat. Yet, we ourselves are in the midst of an even greater change in how to understand our planet. And most of us don't know about it.

When we realized that Earth is round, we learned how the places on our planet are physically connected to each other. We discovered that if we kept traveling in one direction, we would not fall off the edge. Instead we could go in a circle and return to our starting place. That was an important discovery for our ancestors.

Now we are learning something much more important than how the places on our planet are physically connected. We are discovering how Earth works as a whole system. Earth is not flat. Earth is much more than round. Earth is whole.

"Earth is Whole" means that all the planet's physical features and living organisms are interconnected. They work together in important and meaningful ways. The clouds, oceans, mountains, volcanoes, plants, bacteria and animals all play important roles in determining how our planet works.

Scientists have established a new field of science called Earth systems science to study and discover how all these parts work together. Earth systems scientists combine the tools and ideas from many scientific disciplines
including geology, biology, chemistry, physics and computer science. In addition, they use modern technologies to measure key features of our planet, such as the concentration of gases in the atmosphere and the temperature of the ocean in many locations. Satellites orbiting our planet provide enormous amounts of data that Earth systems scientists use to try to understand how our planet works and what kinds of changes are happening.

Of course, human beings do more than study and measure planet Earth. Just like any other organism, we are a part of this whole Earth system. More importantly, we now have a very challenging new role to play. For the first time in our history, we can dramatically change the way the planet works as a whole. There are so many of us and we have such powerful technologies that we can change Earth's climate, destroy its ozone shield and dramatically alter the number and kinds of other organisms that share the planet with us.

Over the past five years, I have developed a method of explaining Earth systems science to my family, friends, co-workers, teachers and students. I also perform a show where I use scientific demonstrations and audience participation to introduce the three Earth systems principles that are featured in this book. My experience is that people enjoy learning about Earth systems science, and they feel they get a better perspective on how our planet works and what they can do as local and global citizens.

*Dr. Art's Guide to Planet Earth* helps answer one of the most important questions of the twenty-first century: Can all of us live well on our planet without damaging the whole Earth system? To answer this question, we need to understand how our planet works. That sounds much more complicated than discovering that Earth is round. Fortunately, Earth systems science can explain many of the most important features of how our planet works.
The first step toward understanding how Earth works is to think about our planet as a system. We use the word “system” when we want to describe something that is made up of different kinds of parts that join together to form an interconnected whole. Learning to think in terms of systems is very useful because we are surrounded by all sorts of systems. In fact, each of us is our own little system.
Each of us is made up of more than 200 kinds of cells. These nerve, skin, muscle, bone, red blood and gland cells all join together to form an incredible system – an individual human person. All the structures that these cells form – our skin, muscles, bones, blood vessels, internal organs – function as an interconnected whole.

Looking at ourselves as a system reveals two important features of systems:

- each part of a system can itself be described as a system;
- a system can be very different from its parts.

Each part of a system can itself be described as a system. You are a system. One of the parts of the “you system” is the way blood moves throughout your body – in other words, your circulatory system. This circulatory system is part of the bigger “you system” but it itself is a system with many parts.

The parts of the circulatory system include heart, veins, arteries and blood cells. The heart, a part of the circulatory system, is also a system made of parts. Its parts include muscle cells, nerve cells and valves. A heart muscle cell is part of the heart system but it is also a system that is made up of a cell membrane, cell nucleus and many different proteins.
You could get dizzy visualizing all these systems within systems within systems that are inside each one of us. And the story does not end with us. We are not the biggest system around. Each of us systems is, in turn, part of many larger systems. Each of us is part of a family system. Each of us is part of an ecosystem. Each of us is part of an entire human system that is part of the system of life on this planet.

Why should we care about all these systems within systems within systems? The second system feature that we mentioned earlier provides an important clue.

**A system can be very different from its parts.** Think about your arteries, red blood cells, stomach and toenails. Your stomach is a part of who you are, but you are much more than your stomach. You are much more than the sum of your parts. As a functioning, interconnected whole, you have characteristics that do not exist in any of your parts. You have properties that transcend, that go far beyond, the qualities of your parts.

A car provides another example of a system. A car has brakes, wheels, cylinders, battery, windshield wipers, carburetor, gas tank, metal frame, steering wheel, and hundreds of other parts. Individually none of those parts will move you from your home to school, work, a restaurant or a lake. Joined together as an interconnected whole, the car system can take you away. It has properties that are qualitatively different than the properties of its parts. No part of a car gets 35 miles per gallon on the highway. No part of a car has the ability to transport you up a mountain road. Only the car as a functioning whole system has these properties.
The popular saying “the whole is more than the sum of its parts” describes this second system feature. This popular saying is much deeper than it might first appear. When we say that the whole is more than the sum of its parts, we mean that the whole system has qualities that are different than those of the parts. The whole is qualitatively different, which is a much more important difference than a mere increase in quantity.

Take water as another example of a system. Water is made of hydrogen and oxygen. At normal temperatures and pressures, they are both gases. Hydrogen is highly explosive, and fires require oxygen. Put them together and you have a liquid that extinguishes fires. The system of hydrogen joined with oxygen (H₂O) has properties that are qualitatively very different from the parts hydrogen alone or oxygen alone.
Many of us feel overwhelmed by the environmental issues that we encounter in newspapers and magazines, or on television, radio or the Internet. We see weird combinations of letters like PCB and CFC. We read statements from opposing Ph.D. experts, one of whom says that global warming is a serious problem while the other tells us we have nothing to worry about. How can we understand these complicated environmental issues?

The reason to care about “systems within systems within systems” is that systems thinking provides us with a way to understand any particular system, especially complicated ones like planet Earth. The system could be a person or your circulatory system or a car or planet Earth. No matter what the system is, we can always understand it better by asking three systems questions.

- What are the parts of the system?
- How does the system function as a whole?
- How is the system itself part of larger systems?
Dr. Art's Guide to Planet Earth uses systems thinking to help us understand how our planet works and how we can support the way our planet currently operates. We will learn three guiding principles that can provide a framework for our thinking. These principles help us focus on major concepts rather than becoming lost in confusing details. They provide a framework to guide our actions as individuals, local communities, nations and a global species. We begin with the first systems question: What are the parts of the Earth system? To understand how our planet works, I believe it is best to describe the Earth system in terms of the following three parts:

- Earth’s matter
- Earth’s energy
- Earth’s life

In examining Earth as a whole, we are going to focus on Earth’s matter, Earth’s energy and Earth’s life. In other words, we are going to examine from a systems point of view the stuff (matter) that exists on planet Earth, the energy that makes things happen on planet Earth, and the organisms that make our planet unique in the solar system.
Our planet has been circling the sun for more than four billion years. During those billions of years, the matter on our planet keeps changing its form. Water evaporates from the ocean, forms clouds and falls as snow and rain. Rocks get broken down into dirt that is washed as sediment into rivers. Plants take carbon dioxide gas from the atmosphere and convert it into solid sugars and starches. Why doesn't all the ocean water turn into mountain snow, or all the rocks turn into sediment or all the atmospheric carbon dioxide turn into sugar?

Earth still has oceans, mountains and atmospheric carbon dioxide because they are part of cycles – the water cycle, the rock cycle and the carbon cycle. Water flows in rivers back to the oceans; buried sediments reach the surface again through volcanoes; and animals chemically change sugars into carbon dioxide that goes back into the atmosphere.

Earth is a recycling planet. Essentially all the matter on Earth has been here since the planet was formed. We don't get new matter; old matter does not go away into outer space. The same matter keeps getting used over and over again. From a systems point of view, we say that Earth is essentially a closed system with respect to matter.*

* Of course, Earth is not a totally closed system with respect to matter. For example, we are constantly bombarded by meteorites. Yet, the total amount of matter that has entered the Earth system during the past three billion years is less than 0.00001% of Earth's total mass.
MATTER CYCLES

Each of the elements that is vital for life exists on Earth in a closed loop of cyclical changes. From a systems point of view, Earth is essentially a closed system with respect to matter.
Imagine what would happen if the sun stopped shining! This disastrous scenario emphasizes the crucial role of solar energy. Our planet relies on a constant input of energy from the sun. Earth receives an inflow of solar energy that is more than 15,000 times the amount of energy consumed by all human societies. This constant flow of solar energy into the planet system provides virtually all the energy to keep our planet warm, drive the cycles of matter and sustain life.
If Earth retained all that energy, it would become so hot that it would just boil away. But energy does not stay in any one place. Energy flows away from Earth in the form of heat radiating to outer space. The amount of energy radiating to outer space balances the amount of energy flowing in from the sun.

Note the difference between Earth's matter and Earth's energy. With respect to matter, Earth is a closed system. Matter does not enter or leave. With respect to energy, Earth is an open system. Sunlight energy flows in and heat energy escapes.

**ENERGY FLOWS**

The functioning of our planet relies on a constant input of energy from the sun. This energy leaves Earth in the form of heat flowing to outer space. From a systems point of view, Earth is an open system with respect to energy.
Earth's organisms form an intricate web of interconnections, with every organism depending on and significantly affecting many others. As one very important example, virtually all communities of organisms ultimately depend on plants. Plants capture energy from the sun and store it as chemical energy. Plants are Earth's producers.

With respect to food energy, the rest of the organisms are consumers. Some eat plants, others eat animals that eat plants and some eat both plants and animals. The plants, in turn, rely on animals for pollination or for spreading seeds, and on decomposers for creating rich soil from dead waste.

With respect to life, Earth is a networked system. Not only do organisms form an interconnected web, they also participate actively in Earth's matter cycles and energy flows. Human beings depend on the web of life for the air that we breathe and the food that we eat. As our numbers have exponentially increased and our technologies have altered virtually every part of the globe, we have become a very important part of this web of life.
LIFE WEBS

A vast and intricate network of relationships connects all Earth's organisms with each other and with the cycles of matter and the flows of energy. From a systems point of view, Earth is a networked system with respect to life.
We began investigating the Earth system by asking the first system question: What are the parts of the Earth system? Our answer focused on three parts – Earth’s matter, Earth’s energy and Earth’s life. The second system question asks: How does the system function as a whole?

Guess what? We have already answered that question. When we looked at each part of the Earth system, we learned how that part works for the planet as a whole. As a result, we can say that there are three simple principles that work together:

**MATTER CYCLES**
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**LIFE WEBS**
A vast and intricate network of relationships connects all Earth’s organisms with each other and with the cycles of matter and the flows of energy. From a systems point of view, Earth is a networked system with respect to life.
These three principles can help us understand essentially all environmental issues. When we confront an environmental issue, we should first explore the roles of matter, energy and living organisms. Where does the matter (carbon, water, pollutant) come from and where does it go? Does the issue involve changes to our planet's energy flows? How do plants, animals and microorganisms influence the issue and how are they affected by it? As a result of answering these kinds of questions, we will discover that the three guiding principles provide an organizing framework that makes common sense out of complicated issues.

**Book Overview**

In the twenty-first century, we find ourselves in a new world. Without meaning to, we can change the way that our planet works. At the same time, we are developing a much deeper understanding of the Earth system.

This chapter has introduced three principles that can help us focus on major concepts rather than become lost in confusing details. The next three chapters will help us understand each of these three principles much more deeply. We will be able to explain how Earth works in terms of cycles of matter, flows of energy and the web of life.

But merely knowing something, even something as important as how our planet works, is not enough. We need to apply that information in our lives. The last two chapters apply this understanding of the whole Earth system to environmental issues that we face globally and locally. The three Earth systems principles help us understand these issues, and they also provide guidance regarding what we need to do as a global species, nations, local communities and as individuals.