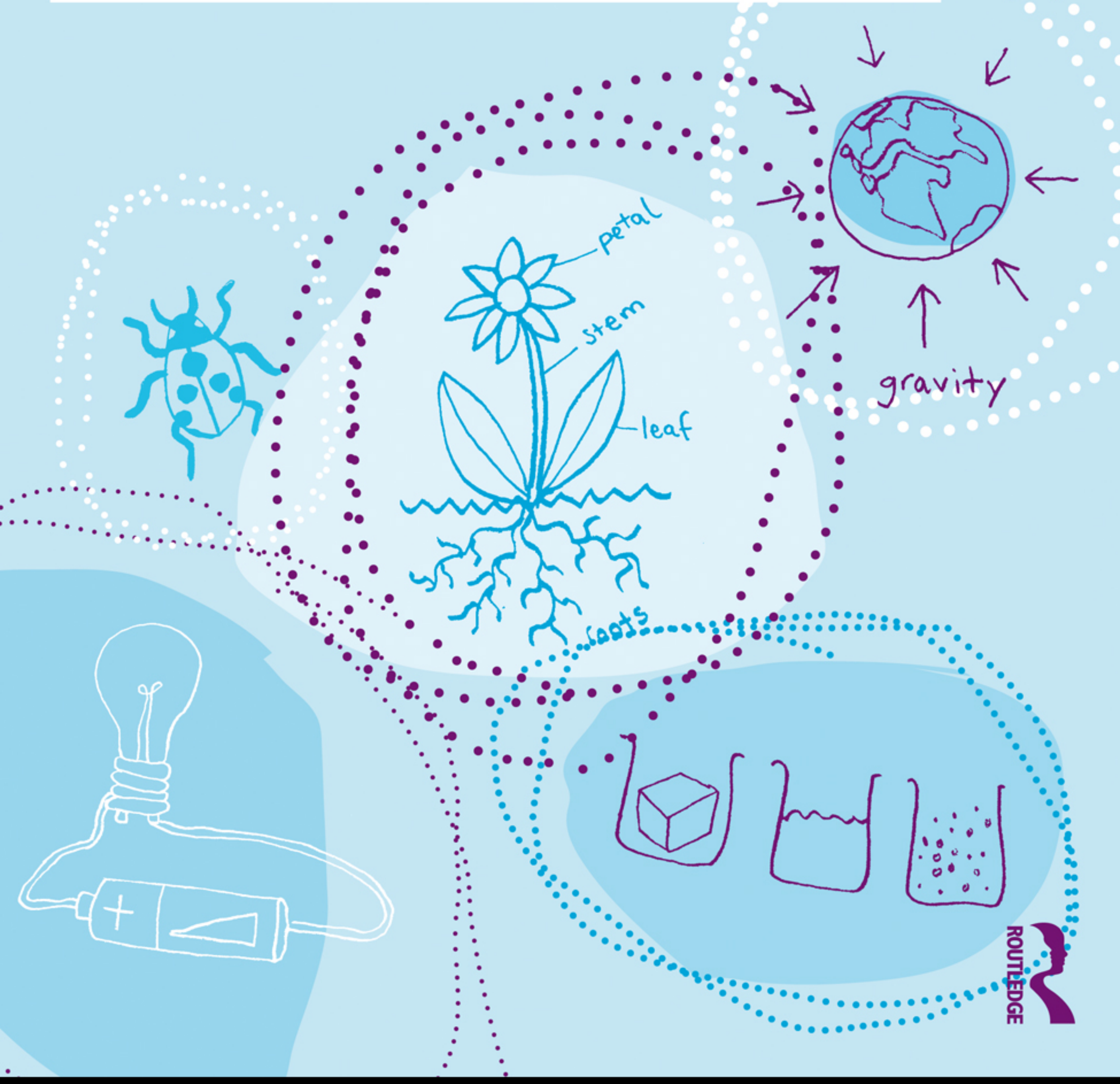
THE REALLY USEFUL ELEMENTARY SCIENCE BOOK

JEFFREY W. BLOOM



ROUTLEDGE

The Really Useful Elementary Science Book

Amongst the challenges that elementary teachers may often face as they introduce their students to science is the need to maintain a solid understanding of the many scientific concepts and details themselves. This essential resource, intended for pre- and in-service elementary school teachers, provides concise and comprehensible explanations of key concepts across science disciplines. Organized around the *National Science Education Standards*, the book tackles the full range of the elementary curriculum including life sciences, ecological sciences, physical sciences, and earth sciences. Although not a methods textbook, the clear and accessible definitions offered by veteran teacher educator Jeffrey W. Bloom will nonetheless help teachers understand science concepts to the degree that they will be able to develop rich and exciting inquiry approaches to exploring these concepts with children.

Perfect as a companion to any elementary science methods textbook or as a stand alone reference for practitioners, *The Really Useful Elementary Science Book* is a resource teachers will want to reach for again and again.

Jeffrey W. Bloom is Professor of Science Education at Northern Arizona University.

Adapted from *The Really Useful Science Book: A Framework of Knowledge for Primary Teachers* by Steve Farrow
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Section 1
Introduction

This book has been written as a resource for K–8 teachers and future teachers. Although this book is intended for elementary and middle school teachers, I have tried to “up the ante” a little bit. In my experiences with children, more often than not, I found that *my expectations* for what they can and want to understand about science fell far short of what they were actually capable. The *National Science Education Standards* and most state standards and curricular documents provide a minimum baseline for what we may expect children to learn. If children are interested and engaged, they are capable of learning fairly complex concepts.

As a result, the science content addressed in this book is at a somewhat higher level. The five basic reasons for raising the level of conceptual content include:

1. Many science concepts and theories need a higher degree of complexity in order for the explanations to make any sense at all.
2. Many children are quite capable of learning more complex concepts in science for which teachers need to be more prepared.
3. In order to design meaningful instructional activities around concepts, teachers need to have more extensive understandings of the subject matter.
4. If teachers are to teach through inquiry, they need to have better understandings of the subject matter in order to generate questions that guide student inquiry.
5. If teachers provide a community for conducting inquiry, such inquiry can move in directions that are completely unexpected. In such cases, teachers may not have prepared for the conceptual territory. This book aims to provide a resource for just such situations.

What this Book Does Not Do

This book maintains a focus on science content. It does **not** provide:

- activities for use in teaching science;
- approaches for planning and implementing science instruction;
- any pedagogical knowledge or recommendations.

A great deal of effort was taken in writing this book to keep the focus on essential content knowledge and to keep the length of the book reasonably short. However, it is hoped that readers of this book will not take the knowledge in this book and just present it to children. Rather, the intent is to help teachers understand science concepts to the degree to which they can develop rich and exciting inquiry approaches to exploring these concepts with children.

For those interested in matters of implementing science through inquiry, read *Creating a Classroom Community of Young Scientists (2nd edition)* from Routledge.

The Structure of this Book

The book is structured around the traditional subject matter headings in science:

- Life sciences
- Ecological sciences
- Physical sciences
- Earth sciences.

Although it was tempting to use a different and more integrated approach, this structure more closely fits with the structure of the National Science Education Standards, with the exception of ecology, which the Standards put into the other three subject matter areas. Throughout this book references are made to other sections where appropriate knowledge is explored in further depth. However, as you will see, concepts from other sciences come into play throughout each of these sections.

Science Language

It has been suggested that science introduces more new vocabulary per instructional day, than do foreign languages. Although it may be nice to have a book on science that avoids much of this language, this book does present the terminology where appropriate. I believe this is necessary for these reasons:

- The terms help if you want to look up further information on the topic.
- Once children understand concepts, they like to use the real vocabulary of scientists.

However, I do have two recommendations:

1. Try not to present the terminology first, but rather bring in the terms after children have developed understandings of the concepts in their own words.
2. Look up the words' roots, which are most often in Greek and Latin. What you find is that many of these words actually have rather simple meanings.

The Tentative Nature of Science Knowledge

Science knowledge changes all of the time. I was quite surprised in doing the research for this book just how much of the knowledge I had learned previously was no longer "true."

Throughout this book, I have tried to bring the most current understandings. However, I am sure that some of this knowledge will change by the time this book is in print.

Units of Measurement

Scientists everywhere use metric units. All countries except the United States also use the metric system of measurement. I do think it is important for teachers to introduce and use metric as much possible. However, in this book I have used the American Standards units with metric equivalents in most situations. I have done this in part to provide more meaning to the measurements, as well as to bring in a certain sense of familiarity to the discussions.

Where to Go from Here

This book is only the start. There are so many interesting areas of science to explore that this book simply cannot cover. My suggestions are to add to your understandings in several ways:

- Read popular books on science. There are many excellent and easy to read books on a variety of subjects.
- There are many good sources of information on the Web. At the same time, there are many awful sites. Look at *where* you are going. *Is the site reliable and easily identifiable?* Sites connected to museums, to certain federal and state agencies, certain universities, and professional organizations are usually good bets. Others may look good, but may not be very reliable.
- Take more classes and volunteer to help scientists during the summer. Build it in as a vacation activity.
- Use some of the computer and internet resources for exploring science, such as Google Earth, Google Maps, Stellarium, and Celestia.

I have tried to provide a few good sources of information at the end of each section. However, there are many more. The sources I have provided are just the beginning.

Let your curiosity take you and your students to new and exciting places!

Section 2
Life Processes and Systems

The National Science Education Standards addressed in this section are:

Content Standard C: Life Science

K–4: 1 The characteristics of organisms
K–4: 2 Life cycles of organisms
K–4: 3 Organisms and environment
K5–8: 1 Structure and function in living systems
K5–8: 2 Reproduction and heredity
K5–8: 3 Regulation and behavior
K5–8: 4 Populations and ecosystems (in part in this section)
K5–8: 5 Diversity and adaptation of organisms

Content Standard G: History and Nature of Science

K–8: 1 Science as a human endeavor
K5–8: 2 Nature of science
K5–8: 3 History of science

How do we know that something is or was alive, or is the product of a living thing? The answers to this question may seem obvious, but it probably doesn't surprise you that children struggle with the concept. Young children often consider non-living things, such as bicycles and computers, to be alive. However, the question is a point of contention even beyond the world of children. Biologists are still arguing about whether viruses are alive. In many traditional Native American cultures, rocks, earth, and other natural objects may be considered alive. In some scientific circles, many scientists accept the Gaia Hypothesis, which considers the whole Earth system, including its atmosphere, geology, and life, as a living system.

While the question of what is living is fairly straightforward for most of what we investigate with children, there are many opportunities for children to engage in their own "theoretical" arguments about life and to explore the diversity of understandings across cultures. In the rest of this section, we will explore some of the basic concepts and theories involved in our current understandings of living things. The major theories and concepts that will be addressed in this section include: the characteristics and basic needs of living things; levels of organization of living things; development of complexity in animals; characteristics of plants; development of complexity in plants; issues of survival of living things; human survival and health; growth and development; the theory of evolution; replication and genetics; and the variety of life.

Key Idea 2.1 Characteristics and Basic Needs of Living Things

When we engage children in exploring what is alive, what was once living, and what is a product of living things, we can begin by exploring some of the basic attributes of living things on Earth. These attributes include ways to:

- acquire, utilize, and/or make *"food"* or *nutrients*;
- acquire and utilize *air*, which usually involves oxygen and/or carbon dioxide;
- convert and store *energy*;
- get rid of waste products (*excretion*) and unused food products (*elimination*);
- *reproduce* sexually and/or asexually;
- *respond* to various environmental, internal, and external factors, including interactions with other living things;
- acquire and keep a balance of *water*.

In addition, other characteristics that are common to many, but not all, living things include the ability to:

- *move*, at least during some stage of the life the cycle;
- *develop and grow* in size;
- *protect* itself and others of its species, including offspring.

All of these characteristics relate to specific structures and functions. However, the most basic characteristic of living things that includes all of the above is that living things are self-generating, self-organizing, self-maintaining, and self-regulating. These processes are broadly known as *autopoiesis*, which is a set of processes or systems that act to perpetuate the whole. As individual human beings, all of our biological systems, such as our circulatory, respiratory, digestive, nervous, hormonal, and immune systems, act together to repair damage, coordinate functions, and, fortunately, keep us alive.

Basic Needs of Living Things

The basic needs of living organisms, which are based on the characteristics just discussed, include:

1. ***Food***: each species needs the ability to acquire, ingest or make (as in plants), and utilize food as a source of energy.

2. ***Air***: almost all living things need the ability to take in air: oxygen for use in cellular respiration and carbon dioxide for photosynthesis—the exceptions are Archaea, which are bacteria-like organisms that live in extreme conditions in volcanoes and deep oceans and use sulfur for energy production in a process called *chemosynthesis.*
3. ***Water***: each species needs the ability to ingest water and/or maintain a proper water balance within cells.

   - *The chemistry of water*—Water is of central importance because of its unique chemical characteristics that affect cellular biochemistry. Water has the ability to:

     – act as a solvent for a large number of substances;
     – transport chemicals;
     – function as part of biochemical reactions;
     – function in the regulation of various physiological processes;
     – facilitate neurotransmission and nerve function;
     – make various cell membrane functions possible;
     – provide a medium for deoxyribonucleic acid (DNA) functions;
     – provide hydrogen and oxygen for photosynthesis;
     – provide hydrogen and oxygen for cellular respiration;
     – provide a transport and functional medium for enzyme function.

   - *Water for organisms on land, in freshwater, and in the sea*—Terrestrial organisms need to acquire water; aquatic or fresh water organisms need to maintain a water balance without too much water coming into cells; and marine or salt water organisms need to maintain a water balance that doesn't allow the cells to lose water.

4. ***Reproduction***: each species needs to be able to produce enough viable and healthy young in order to maintain its population.
5. ***Protection***: each species needs one or more ways of protecting itself from environmental factors and predation so that enough of the population survives.

These needs can serve as a focus for classroom investigations of organisms and their structures and functions, adaptations, behavior, and other aspects of their natural history and evolution. Whenever studying organisms, it is always beneficial to compare across different types of organisms. For instance, in children's investigations of earthworms, you or they may ask, *which environments do earthworms move towards?* Along with the children you can generate a list of possible soil variables, such as: very wet, moist, dry, sandy, rocky, clay-like, filled with dead vegetation, warm, and cool. The children can use their results and everyday observations of earthworms to infer how these animals get oxygen and water. Since they breathe through their skin, they need a moist environment, but if it is too wet, they drown. Let's take into consideration that earthworms do not like to come to the surface and be exposed to predators, except for at night when they come part way out of their burrows to mate. So, when we find earthworms on sidewalks during and after heavy rain, we are seeing their desperate attempts not to drown. From these findings and observations, children can compare how other organisms deal with the same issues of air and water.

Structure and Function

The concept of "structure and function" is helpful in comprehending how organisms are adapted for meeting their survival needs, and is essential to understanding biological organisms and systems. The basic questions involved in exploring this concept are:

- For what function is this structure adapted?
- For this particular structure, what is the advantage to the organism and its survival?

When we consider these questions, we need to think about how particular functions can be achieved most effectively by specific structures. Some examples include tubular structures that function to transport materials or information, such as those of arteries, veins, digestive tract, plant xylem and phloem, elephant trunks, nasal passages, and nerve cells. Flat teeth or beaks function to crush food, while pointy teeth and beaks are used to capture, hold, and tear food. Flat, sheet-like structures are useful for expanding surface area, such as for broad-leaf trees to capture sunlight, or for elephants' ears to capture sound and radiate heat. Spherical shapes are useful for minimizing surface area to prevent loss of what is inside, such as for many fruits. Eyes are another spherical structure. The functions of an eye are involved in sensing (seeing) so that the animal can communicate, find food, see and escape danger, and move around the environment.

How do the structural characteristics of eyes relate to these functions? In humans, two eyes are pointed in the same direction with some distance in between, which provides for seeing depth of field and for judging relative distances. On the other hand, eyes placed on either side of the head provide for a greater field of vision approaching 360 degrees, which could be advantageous for protection against predators. Owls have a method of dealing with both depth of field and wide field of vision. They have two large eyes, so that their pupils can open very widely to capture as much light as possible at night. Their two eyes are positioned like those of humans, but they cannot move in their sockets. Having their eyes "locked in position" helps them focus on prey as they attack. However, owls have contended with the limited field of vision of eyes that are immovable by being able to turn their heads so that they can see 360° while they sit on a perch.

Why is it that most animals with eyes only have two of them? Three or more eyes don't offer any significant benefit to most animals, and one eye is a disadvantage in terms of depth perception and field of vision.

Why do eyes have the shape they do? The spherical shape of eyes allows for the arrangement of sensory nerve endings, such as rods and, in some animals, cones, that maximize the field of vision and provide for focusing through a lens. Some organisms, such as those of some snails and flatworms, have eyes that can't process images, but are sensitive to light. The compound eyes of insects, where each spherical eye has a large number of lenses, aren't very good at focusing on a single image. However, these multi-lens eyes are exceptionally good at detecting movement—try catching a fly with your hand!

Whenever we think about structures and their functions, we also must consider the environment or habitat(s) in which a particular organism lives. It is important to see how structures and their functions are adaptations for survival in a particular habitat. An accident, conflict, or disease that damages a structure or function will adversely affect the survival of an individual. A loss of one eye may not be immediately life-threatening, but in the long run, the individual with one eye may have difficulty acquiring food or protecting itself from predators. If the environment in which a particular organism lives changes dramatically, the structures and their functions that were adapted for one environment may not be suited for the new environment. For instance, the plants and animals that live in a grassy plain have structures adapted for this type of environment. However, if this environment changes to a desert, the structures adapted for living in grasslands are not likely to be suitable for surviving in this dramatically different environment that has very little water and vegetation. Such dramatic changes in environments affect the types of food, the way in which water is obtained and regulated, and the temperature differential that needs to be addressed. These kinds of environmental changes have occurred in the past and are occurring now from natural processes and from the indirect and direct affects of humans. As a result we are and will continue to see stresses placed on organisms that result in extinction (see "extinction" later in this section).

Key Idea 2.2 Levels of Organization

This section briefly describes the levels of organization of living organisms. We start by examining cells and cell theory, then proceed to tissues, organs, and organ systems. Keep in mind that some organisms are comprised of only a single cell, while others contain hundreds of trillions of cells that make up multiple organs systems.

Cells and Cell Theory

Up until 1655, no one had observed a cell. Then, Robert Hooke, a 20-year old assistant in English chemist Robert Boyle's laboratory, made himself a simple microscope. He placed a thin sliver of cork from the bark of a tree under the microscope and saw the first building blocks of living things, which he dubbed "cells." He incorrectly believed these cells were found only in plants and were the containers for the "noble juices," which probably referred to the sap of the cork tree as some sort of life-giving material. The Dutch scientist Anton Van Leeuwenhoek (1632–1723) perfected the construction of the microscope to where its powers of up to 270x allowed for its practical use. Following these developments, Van Leeuwenhoek was the first person to describe protozoa (1674), bacteria (1676), yeast cells (1680), and blood cells (1702). Despite these advances, it was not until 1838 that cell theory was proposed by two German biologists, Theodor Schwann and Matthias Schleiden.

Cell theory is based on three premises:

- All living things are composed of one or more cells.
- Cells can come only from cells that have existed before (i.e., replication).
- Cells are the smallest forms of life.

These three premises provide a working definition of life. In addition to these premises, a single cell addresses the characteristics of living organisms by absorbing or capturing food, absorbing air and other substances needed for energy production and storage, maintaining a water balance, reproducing or replicating, excreting and eliminating waste, and responding to external conditions. It is from this basis that viruses have been excluded from the classification of living things. Viruses are kind of rogue DNA containers that use cells of living things to replicate, but they have none of the other components of cells.

All cells are characterized by:

- a surrounding *membrane*;
- *cytoplasm*, which is a watery fluid that contains various organelles and other substances;
- *DNA*, which may or may not be contained within a nucleus;
- *RNA*, which carries information within the cell for making and maintaining cell structures and functions.

Figure 2.1 shows simple bacteria, plant, and animal cells. Each of these cells is surrounded by a cell membrane across which nutrients, wastes, and other materials flow. Only bacteria, fungi, and plant cells have *cell walls*, which provide a rigid structure. All cells are filled with a fluid and somewhat viscous cytoplasm that contains the cell structures, or organelles, as well as nutrients and waste products. The various organelles that appear throughout the cytoplasm carry out functions for survival, much like our organs do. All cells have DNA, but only protist, plant, fungi, and animal cells have a nucleus. Various other structures, such as mitochondria, ribosomes, and Golgi apparatuses, are also contained within the cell, as described below:

- ***Cell Membrane***: a semi-permeable barrier that allows some substances to pass through, while keeping in others.
- ***Cell Wall***: a rigid barrier around the outside of the cell membrane in bacteria, fungi, plants, and some protists. Cell walls are made of different substances in each of these types of organisms. Pores allow substances to cross.
- ***Chloroplasts***: have their own DNA and may have been simple alga that ended up becoming a part of some cells. These organelles contain photosynthetic pigments.
- ***Cytoplasm***: the fluid between the cell membrane and the outer covering of the nucleus. Its functions include: (a) maintaining the cell shape, (b) securing the position of organelles, (c) moving the cell as with amoebas, and (d) controlling the movement of internal structures.
- ***Endoplasmic Reticulum***: a network of membrane-covered canals, some of which have ribosomes attached. Not all functions are known, but they appear to be involved in constructing proteins, transporting ribonucleic acid (RNA) to the ribosomes, and transporting other materials.
- ***Golgi Apparatuses***: are found in complexes of flattened sacs. They function as packaging plants where various products are placed within a tiny sac. These sacs can then be used to transport secretory products, such as digestive enzymes, to the cell membrane for secretion outside of the cell. The sacs prevent the enzymes from digesting the cell itself.
- ***Lysosomes***: are sacs created by Golgi apparatuses that contain extracellular digestive enzymes that could damage the internal parts of the cells. When we eat, our digestive enzymes come from these sacs.
- ***Mitochondria***: are thought to have been commensal bacteria that are now a part of protist, fungi, plant, and animal cells. They have their own DNA, which biologists use

to track lineages where the mitochondrial DNA is passed from mother to child. This is where cellular respiration occurs. As such, they are the "power plants" of cells, where adenosine triphosphate (ATP) is produced and changed back to adenosine diphosphate (ADP) during energy release.

- ***Nucleus***: appears in the cells of eukaryotes: protists, fungi, plants, and animals. Nuclei hold the DNA for cell division and for making RNA and ribosomes.
- ***Plastids***: are surrounded by a membrane and store starch and occasionally proteins and oil. They are found in plants and photosynthetic protists.
- ***Ribosomes***: are not surrounded by a membrane and are where proteins are made.
- ***Vacuoles***: are single-membrane storage containers for water, waste products, and food. They can serve to help regulate water balance within the cell. Water vacuoles are easy to see in many single-celled organisms as they slowly grow in size, then disappear quickly as they eliminate the water.
- ***Chloroplasts***: plants cells have chloroplasts that contain the chlorophyll that use light energy to produce oxygen and food in the form of sugars.

From Tissues to Systems

Although cells comprise multicellular organisms, it does not necessarily mean that each of these cells has a similar function. When cells do group together to perform similar functions, they become *tissues*. Some examples of tissues include our epidermis (outer layer of skin), groups of muscles, and the thin transparent tissue that appears between layers of an onion. Different tissues can group together to form *organs* that perform specialized functions. Our hearts are organs composed of a several different tissues. The outside of the heart is composed of a layer of connective tissue—the *epicardium*. The layer underneath the epicardium is composed of spirals of smooth muscle cells held together by connective tissue—the *myocardium*. The inner layer of the heart, the *endocardium*, is composed of simple epithelial cells and a layer of connective tissue. The heart also contains valves that prevent blood from flowing backwards. The next level of organization is known as an *organ system*. If we return to the example of the heart, this organ is one part of the circulatory system. The other organs in this system include the arteries, capillaries, veins, and blood.

The next section will combine our earlier discussion of the basic needs and characteristics of living things with our understandings of cells, tissues, organs, and organ systems. We will examine how the life processes carried on by cells up through organs systems serve to provide for the survival of the vast diversity of life on this planet.

Life Processes and Levels of Organization

From living organisms with only a single cell to vertebrates with hundreds of bones, all of these creatures have developed ways of surviving in their environments. They have developed processes for obtaining and utilizing food, air, and water; for excreting and eliminating waste products and materials; for reproducing; for transporting and communicating within the organism; for protecting themselves. All of these processes occur across levels of complexity and scale—from within a cell to the systems of organs to the behaviors of more complex organisms. Processes involved in survival sometimes occur as cooperative actions among individuals within and between species, such as when female lions hunt together and cattle egrets pick off insects from the skin of cattle. Many processes are similar across species, especially at the cellular level. However, there are organisms that have developed unique approaches to specific survival needs.

Some of the basic approaches to meeting survival needs at both the cellular and system or organ levels are described in the list below.

- ***Gas Exchange***
  - *Cellular Level*: cell membrane.
  - *Organ Level*: lungs, gills, trachea (in insects), skin/tissues in amphibians and some invertebrates.
- ***Elimination of Waste***
  - *Cellular Level*: vacuoles, pores, etc.
  - *Organ Level*: end of intestinal tract; anus.
- ***Excretion of Waste Products***
  - *Cellular Level*: waste vacuoles.
  - *Organ Level*: skin (sweat), lungs (CO_2), liver (bile), gut (mucosa cells, etc.), kidneys (urine, urea, etc.).

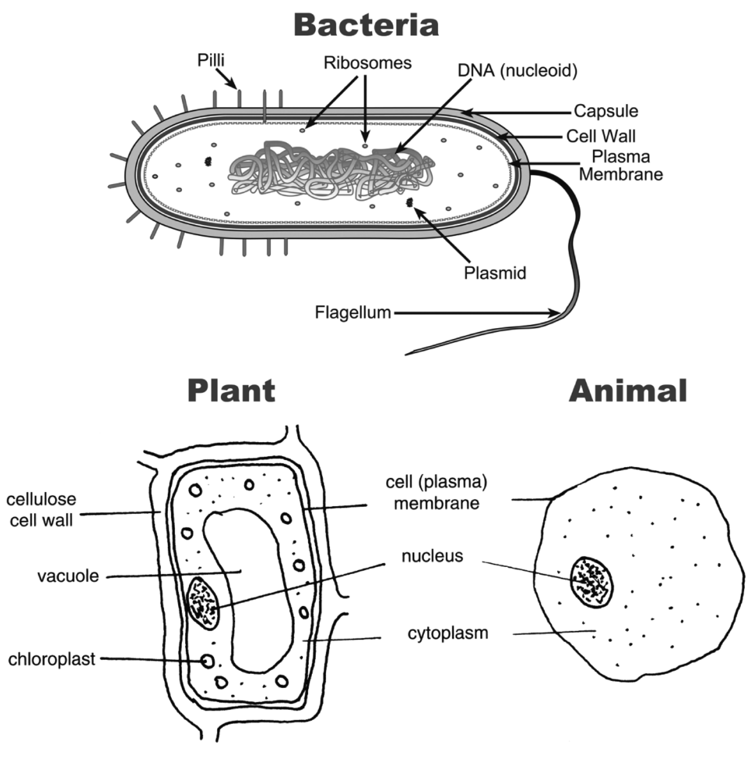

Figure 2.1 The structures of typical bacteria, plant, and animal cells.

Source: Adapted from Farrow.