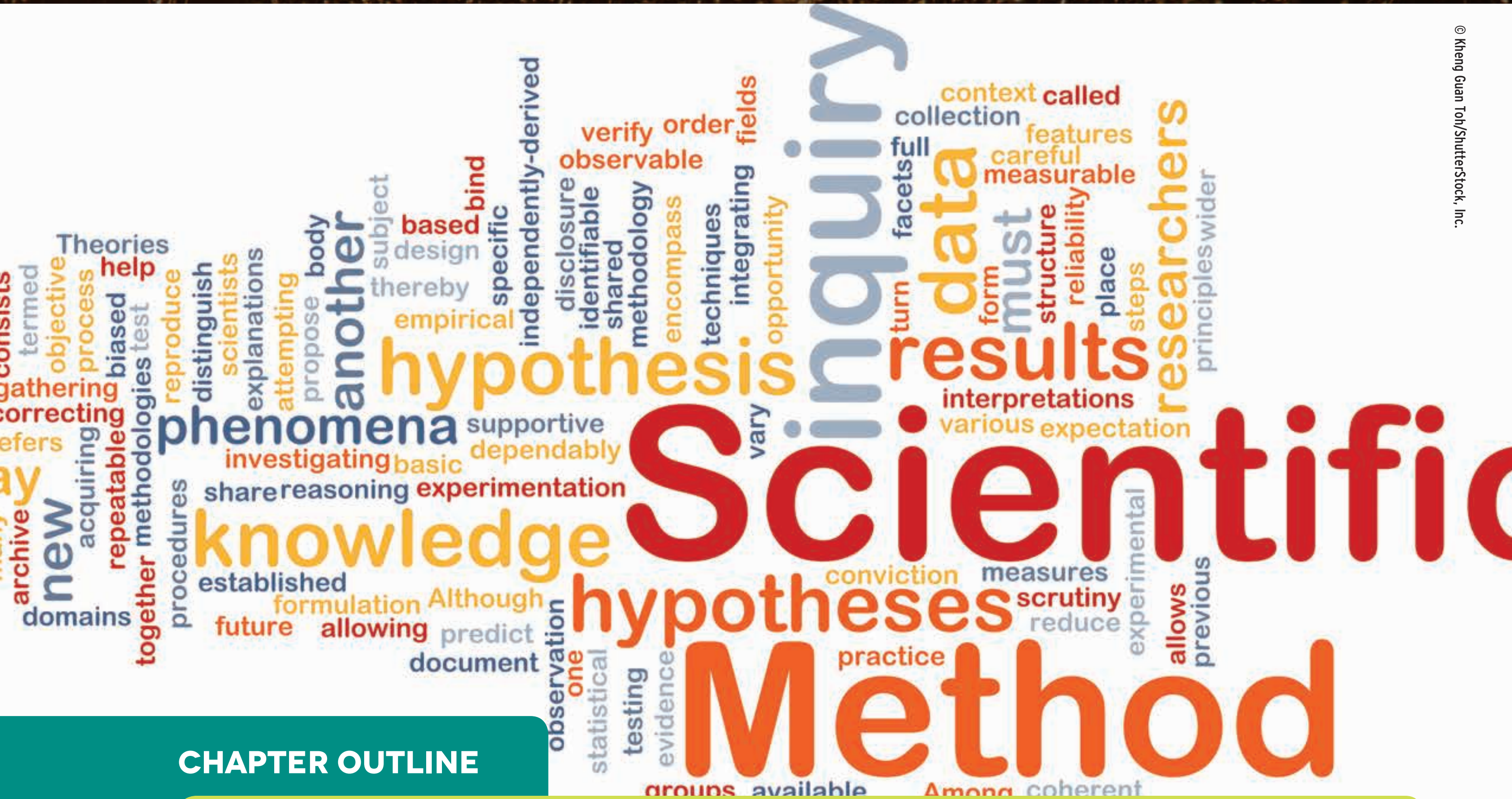
How to Approach the Issues in This Book

The Scientific Method, Critical Thinking, and Logical Fallacies

CHAPTER 1



CHAPTER OUTLINE

SCIENCE AS A WAY OF KNOWING

Science is one way of explaining our universe. Besides science, other ways of knowing include the humanities, belief systems, myths, and math. They are similar in that each has both a body of lore, knowledge, or information, as well as its own processes for discovering truths, answering questions, and solving problems. Scientific thought arose as an alternative to or—more accurately—a rejection of ideas that were accepted because a ruler or religious authority declared their truth without empirical (based on observation or experiment) **evidence**. This shift marked a revolution in our understanding of the natural world. It explained how the world works on the basis of observation and experimentation. Science thus differs from other ways of knowing in one essential way: It is the only form of discovery in which the process is the scientific method.

THE SCIENTIFIC METHOD

Students sometimes see the **scientific method** as an intimidating formal series of jargon-filled steps that scientists use to uncover truths or find answers. We have tried to abandon an arcane, philosophical approach and instead identify the scientific method's essence: the formation and rigorous, objective testing of hypotheses.

Steps of the Scientific Method

Typically, the first step of the scientific method is observation, either some phenomenon of nature or observation of an experiment. In this context, observation means more than merely seeing. It uses all of the human senses as well as the vast array of measurement techniques, some of which detect signals that human senses are incapable of receiving. Our knowledge of the Earth's core, mantle, and crust, for example, is based in part on the behavior of seismic waves, only some of which human senses can perceive, as discussed elsewhere in this text. Another example: Accurate measurements of global temperature date back to the mid to late 1800s, but scientists use proxies (substitutes) such as tree rings, corals, ice cores, and lake sediments to reconstruct high-resolution paleoclimate temperatures from at least 500,000 years ago.

Here's an important point: If an event or process cannot be observed, either directly or indirectly, it cannot be explained by science. In the hands of a scientist, or even a curious lay person, observations and experiments lead to hypotheses, which can be educated guesses, carefully crafted explanations, or even questions. Consider the observation made first in the 1970s that Caribbean coral reefs were (and still are) suffering increased frequencies of disease and overgrowth by algae (FIGURE 1-1).

It has long been known that the coral polyps, the minute living animals that form the calcareous foundation of the reef, are very sensitive to environmental factors such as temperature, salinity, light, nutrients, and sediment in the water. Researchers noticed that the onset of the coral decline coincided with increasing aridity and **desertification** in northern Africa (FIGURE 1-2). Now, of course, there could have been some other factor causing the coral decline, because corals are sensitive to a variety of environmental insults ranging from temperature extremes

FIGURE 1-1 Dead coral reef. Coral disease and overgrowth by algae may be due to a variety of human impacts, including:

- Sediment and nutrient pollution from airborne dust and terrestrial runoff
- Overexploitation and damaging fishing practices
- Engineering modification of shorelines
- Global climate change causing coral bleaching, rising sea levels, and potential acidification of shallow marine water threatening the ability of corals to form skeletons

Courtesy of David Burdick/NOAA.

to overfishing. This observation, however, led to a **hypothesis**. Scientists proposed that dust from Africa resulting from drought and a loss of vegetative cover (desertification) was blown across the Atlantic Ocean by prevailing winds (coming from the northeast at those latitudes) and caused the coral problem, either through smothering the coral or by transportation of pathogens that harmed the coral. To formulate their hypothesis, they had to be familiar with the nature of global wind belts.

This story shows a key feature of the scientific method: Explanations can (and frequently must) be changed as new evidence becomes available. A *hypothesis* is thus a proposed explanation of some phenomenon. The word phenomenon is from Greek *phainomenon*, meaning "to appear." It refers to any fact or experience that can be sensed and scientifically described.

After you have devised a hypothesis, the next step is to test it. Testing implies that your hypothesis can be falsified, that is, your hypothesis can be shown to be incorrect. Guesses, explanations, and questions that cannot be tested and falsified—like things that cannot be observed—are not science.

This *testability* requirement also means that science cannot make value judgments because qualities such as goodness or beauty cannot be subjected to scientific tests.

Similarly, a scientist, acting solely as a scientist, does not conclude that something is good or bad, beautiful or ugly, and so forth.

For the coral reef example, tests of the dust hypothesis were, in some cases, consistent with the hypothesis. Satellite photos showing dust clouds emanating from sub-Saharan Africa led to the calculation that several hundred million **tonnes**[1] of dust are transported over the Atlantic Ocean annually.

FIGURE 1-2 The scientific method in practice. Scientists make observations and then formulate hypotheses to explain what they observed. Next, these hypotheses are tested and retested and, if they withstand the rigor of scientific scrutiny, they are provisionally accepted. If data contradict the working hypothesis, then the hypothesis is either reformulated or rejected and replaced with one consistent with the new data.

Here are some important points about hypotheses. If the data[2] you collect support your hypothesis, then your hypothesis can be tentatively accepted. A hypothesis is never proven, as science does not deal in proofs, despite claims to the contrary in advertisements for consumer products. Moreover, acceptance of a hypothesis may be only temporary because scientists suspend judgment on making final determinations, except in very unusual situations. The original hypothesis may need to be revised or even abandoned completely as new information becomes available, new approaches to testing are undertaken, and/or as new technology becomes available. This means that scientists do not "jump to conclusions."

Science also demands that tests of hypotheses be repeatable. Other researchers must be able to duplicate your findings, for example. Thus, science advances very cautiously. If the data do not support a hypothesis, then the hypothesis is modified or rejected, no matter how good it may have seemed or how much a scientist wanted to accept it. In 1989, to much fanfare, Drs. Stanley Pons and Martin Fleischmann shook the scientific community with the major announcement that they had achieved so-called cold fusion, nuclear fusion at room temperature, in a beaker of water. If true, their discovery would have led to the large-scale production of a cheap and infinite energy source. Other scientists were unable to replicate their experiment, however, thus invalidating the original finding as unscientific.

SCIENTIFIC THEORIES AND UNIFYING PRINCIPLES

Some hypotheses considered central to the understanding of a discipline—that is, some branch of science—have been subjected to an enormous amount of testing and, having withstood this level of scrutiny, have come to be regarded as

scientific theories. In science, a theory is a broadly accepted explanation for an important phenomenon; in other words, a scientific theory denotes a truth. This definition is very different from the nonscientific dictionary connotation of the word *theory*, which is simply conjecture, and implies considerable doubt. *This is a very important distinction that you should carefully note and remember.* A scientific theory could never be referred to as "only" a theory because extensive testing and retesting leave virtually no room for doubt.

Plate tectonics and evolution are theories in geology and biology, respectively. Plate tectonics and evolution also represent **unifying principles** in their disciplines. A unifying principle is one that offers an overarching, or unifying, explanation for seemingly diverse phenomena and assembles them into a coherent whole.

CAUSE–EFFECT VERSUS CORRELATION

Let us revisit the African dust hypothesis that we used to explain the decline of some Caribbean corals. The evidence obtained through scientific research suggests three things: There were no coral health problems when dust concentration was low; the first appearance of African dust was associated with coral disease and death, and higher dust levels resulted in increased levels of disease and mortality.

This research shows a connection between dust levels and coral health. Such a comparison that demonstrates a relationship between two variables—in the previously mentioned case, dust concentration and coral health—is known as a **correlation**. Correlations are important to the advancement of science and in many cases may be the only data available from which we can draw conclusions. Unfortunately, erroneous conclusions are also made from spurious correlations, especially in the media.

A much stronger case for accepting a hypothesis can be made if there is a better link, preferably verified experimentally, between a cause and an effect. Currently, a **cause–effect** relationship between coral health and African dust has not been firmly established, although the hypothesis remains a possible explanation for the observations. The possibility also remains that dust is one contributing factor in the decline of reefs, along with pollution, higher ocean temperatures associated with climate change, or some other factor or factors.

To summarize: science offers a way to understand our natural world that incorporates numerous "firewalls"—that is, phenomena must be observable, and hypotheses must be testable and falsifiable. Scientists also suspend judgment, and try to refrain from assessments of value.

In the following section, we examine how policy makers use scientific information.

SCIENCE AND PUBLIC POLICY: THE PRECAUTIONARY PRINCIPLE AND SCIENTIFIC UNCERTAINTY

At the start of the third millennium, there is an overwhelming consensus among Earth scientists that our growing human population is changing the composition of the planet's atmosphere. Even though scientists cannot yet be certain what the effect of these changes will be, the preponderance of evidence suggests that the impact will be, on the whole, negative and could be catastrophic for hundreds of millions of people crowded into the planet's coastal cities as well as for entire ecosystems like coral reefs, mangroves, and tropical rainforests. Although the present level of agreement among scientists has grown over the past decades to a consensus, there is still vigorous debate on the magnitude, timing, and nature of specific impacts.

Science, as you have learned, advances cautiously, in accordance with the principles of the scientific method. In the case of global warming and climate change, the scale of the phenomenon is so large and the subject so complex that achieving scientific certainty of the impacts is likely not possible. In this section, we introduce you to two approaches to applying science to policies such as climate change. They are the **precautionary principle** and the **principle of scientific uncertainty**.

Scientific certainty, as the preceding pages should have impressed on you, is very difficult to achieve. Even things we consider to be "laws" can be modified with new observations. Because the 100% level of certainty is thus not a practical threshold for accepting hypotheses, scientists typically use the 95% standard, which basically means that a hypothesis is accepted if 95% of the observations of a test are in line with the hypothesis, the other 5% varying because of random chance, experimental error, or some other factor.

When it comes to artificial chemicals like the category called **persistent organic pollutants (POPs)**, scientists can rarely be 95% certain as to their impacts on individuals or ecosystems, as there are so many variables. In those cases, according to the "Rio Declaration" from the 1992 United Nations Conference on Environment and Development,

> *"In order to protect the environment, the precautionary approach shall be widely applied.... Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation."*

This standard is known as the *precautionary principle*.

Embedded in this principle is the notion that "there should be a reversal of the burden of proof, whereby the onus should now be on the operator or polluter to prove that an action *will not* cause harm, rather than on science to prove that harm (is occurring or) will occur."[3]

Another way to express this principle is "better safe than sorry." The products of science and technology are often brought to the marketplace without adequate investigation into any possible long-term effects on human health and the global environment. Some examples are the uses of POPs, lead, and mercury detailed elsewhere in this text.

In most industrialized nations, the so-called burden of proof falls not on the producers of goods, but rather on those who allege that they have suffered harm. Known as the **risk paradigm**, this is the basis of our tort system of civil law. As a result of the proliferation of new products, government agencies like the Food and Drug Administration, the Environmental Protection Agency, and the Federal Trade Commission, to name but a few, are sometimes unable to keep pace. For example, in deciding whether to approve pharmaceuticals for the market, the Food and Drug Administration uses the precautionary principle and requires drug companies to submit evidence that their products are safe and effective *before* they are sold. Even this approach, however, does not prevent many potentially harmful products to be marketed (FIGURE 1-3).

Although adult individuals have recourse to law if they believe they have been injured, fetuses, children, wildlife, and ecosystems have no such means of redress. Strict adherence to the precautionary principle in the view of many could facilitate democratic oversight.

Similarly, under the precautionary principle, a potentially serious threat such as global warming or the proliferation and buildup of organochlorines (a form of POP) in the ocean would trigger action to address the threat even if the science is not yet conclusive but is supported by the preponderance of available evidence.

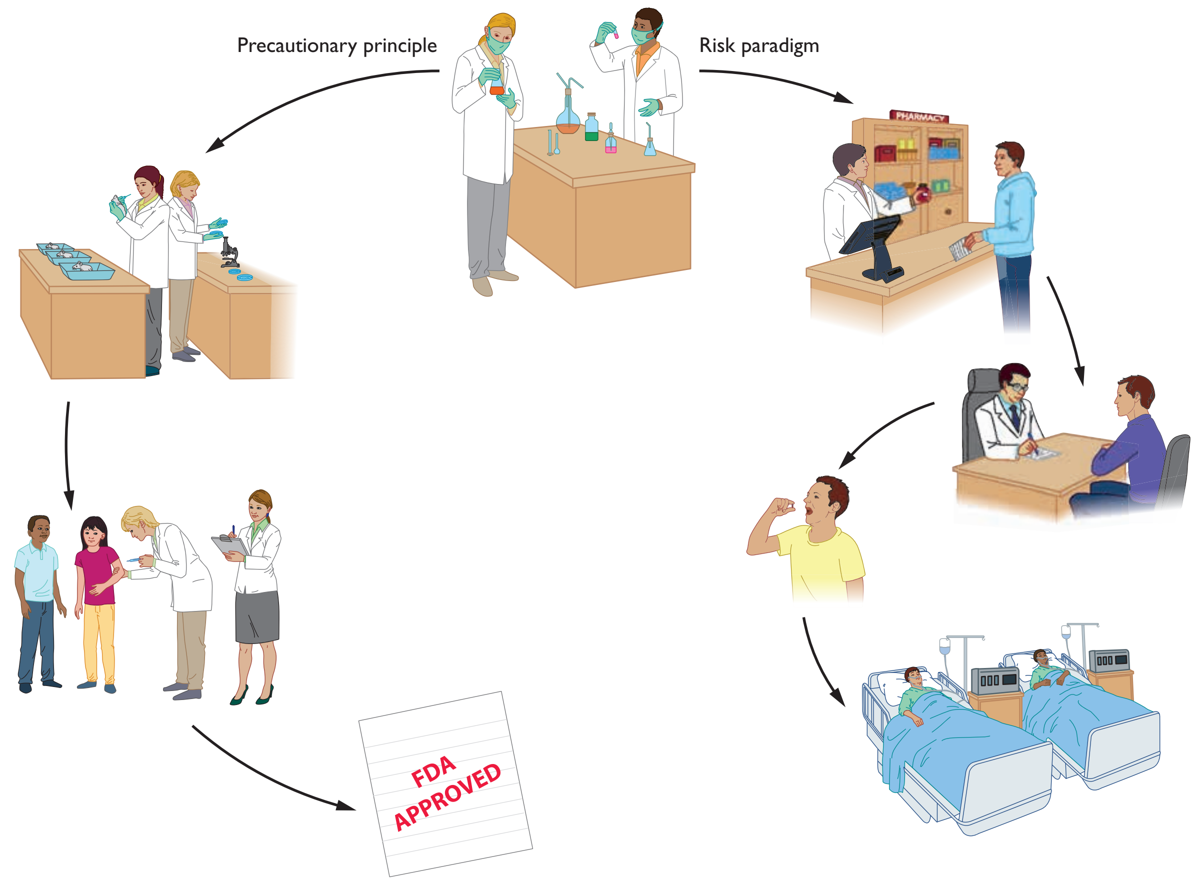


FIGURE 1-3 The precautionary principle versus risk paradigm in determining the safety and efficacy of pharmaceuticals. Consider these different approaches in the context of environmental geology, for example, would you build a subdivision on the site of a landfill or hazardous waste dump? What are the advantages and disadvantages of using each approach?

CRITICAL THINKING

It behooves us all to use the mind's power effectively, which involves **critical thinking**. Much of our thinking is spontaneous, is often emotional, and is rarely analytical and reflective. As such, it contains prejudice, bias, truth and error, inspiration, and distortions—in short, good and bad reasoning, all mixed together. Critical thinking essentially requires that we apply analysis, assessment, and the rules of logic to our thought processes.[4]

Some scientists equate critical thinking with the application of the scientific method, but we think critical thinking is a far broader and more complex process. Critical thinking involves developing skills that enable you to dissect an issue (analyze it) and put it together (synthesize it) so that interrelationships become apparent. It involves identifying *assumptions*, the basic ideas and concepts that guide our thoughts. Critical thinking also encourages an appreciation for our own and others' points of view, which is important when approaching complex environmental issues.

Too often, analyzing complex issues leads some to a belief that everyone is "entitled" to an **opinion** that should be respected (BOX 1-1). We do not necessarily concur;

In Other Words

John Milton said in *Paradise Lost*:

The mind is its own place
And in itself can make
A hell of heav'n
And a heav'n of hell.

BOX 1-1 The McDonald's Hot Coffee Incident

When you hear *McDonald's Hot Coffee Incident,* do you immediately know and react to it? Surprisingly, even though the incident occurred in 1992, and was not of any historical importance (and of no direct importance to environmental geology, but please bear with us), a surprisingly large number of students are aware of the event. More significantly, many people have an opinion on the matter. Are you one of them?

We have discovered that a majority of people aware of the case view it the quintessential frivolous lawsuit. They believe a woman driving a car spilled hot coffee on herself while driving and collected several million dollars from suing McDonald's.

Let's quickly examine the facts that emerged from the case. First, according to McDonald's operations and training manual, the brewing temperature for their coffee should be between 195° and 205°F and the coffee was supposed to be held between 180° and 190°F.

These details should stimulate a few questions, for example, at what temperature is coffee typically served? (The answer is between 135° and 160°F, although some establishments serve it hotter). Why would McDonald's serve their coffee at a higher temperature? (1. To satisfy customer demand, because many people do not drink their coffee for 20 minutes or longer after purchasing it and expect it to be hot when they do. 2. Perhaps doing so also extracts more flavor from inexpensive coffee beans.) At what temperature does coffee cause serious injury? (At about 180°F for a full skin-thickness burn). Was McDonald's aware that consumers had complained their coffee being too hot? (Yes, as approximately 1,000 complaints had been lodged.)

The case involved a 79-year-old woman passenger in a stopped car (a former department store clerk who had never before filed suit against anyone) who had placed the cup of hot coffee between her knees and, while attempting to remove the plastic lid, spilled the entire contents into her lap. She required hospitalization. A jury awarded her $2.7 million in punitive damages, which a judge later reduced to $480,000.

If you had one, was your opinion based on adequate facts and information? If not, does knowing the facts now change your opinion? If your answer to both questions was no, do you believe that your current opinion is more well-informed?

We use this example to illustrate the importance of knowing facts before forming an opinion, and to stress that it is acceptable to have no opinion on an issue until you are well-informed on the issue.

You will have many opportunities to have opinions on issues involving environmental geology (e.g., Should deepwater or, for that matter, any drilling be allowed in the Gulf of Mexico? Is building your home in a floodplain a good idea? Is radon gas a problem in your house?). You'll be a lot happier, and feel a great deal smarter, if you have the facts in hand before forming opinions and making decisions. Critical thinking requires an awareness and understanding of the facts surrounding an issue, especially when it results in an opinion.

however, problem-solving demands a willingness to listen for content to what others are saying. Talking is easy, but listening is not.

To develop critical thinking skills, all of us must learn to use a set of intellectual standards as an "inner voice" by which we constantly test and hone our reasoning, but the standards must be set in an appropriate framework in order for true critical assessment to take place.

The following describes the intellectual standards we should apply when assessing the quality of our reasoning. This is the basis for critical thinking, which in turn is the approach that we try to apply throughout this book.[5]

Intellectual Standards: The Criteria of Solid Reasoning

Clarity. Clarity is the most important standard of critical thinking. If a statement is not clear, its accuracy or relevance cannot be assessed. For example, consider the following two questions:

1. What can we do about marine pollution?
2. What can citizens, regulators, and policy makers do to ensure that toxic emissions from industry, transportation, and power generation do not cause irreversible ecological damage to the marine environment, or harm human health?

Accuracy. How can we find out if a statement is true? A statement can be clear but not accurate. For example, the assertion "Clean coal is not a major contributor to climate change" is inaccurate.

Precision. A statement can be clear and accurate, but not precise. For example, we could say that, "there are more floods in the United States than ever before." That statement is clear and accurate; however, how many more floods are there? 1? 1,000? 1,000,000? (There is a difference between the way many scientists use the word *precision* and the more general way it is used here.) A lack of precision is the basis of much advertising.

Relevance. How is the statement or evidence related to the issue we are discussing?

A statement can be clear, accurate, and precise, but not relevant. Assume that we are given the responsibility to eliminate the harmful marine environmental impact of mercury emitted from coal-burning power plants, and we invite public comment on our proposals. Someone might say, "Coal-burning power plants provide 100,000 jobs in this state alone." That statement may be clear, accurate, and precise, but it is not relevant to our specific responsibility of removing mercury.

Breadth. Are we considering all lines of evidence that could provide us with some insight in addressing an issue? Is there another way to look at this question? For example, in assessing the impact of African dust on coral reefs that we discussed previously, we also must consider other causes, such as global warming, increased sedimentation due to deforestation of slopes on Caribbean Islands, and so forth.

Depth. Is a proposed solution realistic? How does it address the real complexities of an issue? This question is one of the most difficult to tackle because here is where reasoning, "instinct," and moral values may interact. The points of view of all who take part in the debate must be carefully considered. For example, politicians have offered the statement "just don't do it" as a solution to the problem of teenage drug use, including smoking. Is that a realistic solution to the problem, or is it a superficial approach? How would you defend your answer? Is your defense grounded in critical thinking?

Logic. Does one's conclusion clearly follow from the evidence? Why or why not? When a series of statements or thoughts are mutually reinforcing and when they exhibit the intellectual standards described above, we say they are logical. When the conclusion does not make logical sense, is internally contradictory, or not mutually reinforcing, it is not "logical." We give examples of logical fallacies later in the chapter.

APPLYING INTELLECTUAL STANDARDS IN A CRITICAL THINKING FRAMEWORK

The intellectual standards described previously are essential to critical evaluation of issues, but there are more factors to be considered. The following criteria constitute the framework in which these standards should be applied.

Point of view. What viewpoint does each contributor bring to the debate? Is it likely that someone who has a job on an ocean fishing fleet would have the same view on marine sanctuaries as someone who does not? Why or why not?

Identifying a point of view does not mean that the point of view should automatically be accepted or discounted. We should strive to identify our own point of view and the bases for this, we should seek other viewpoints and evaluate their relevance, and we should strive to be fair-minded in our assessment. Few people are won over by having their ideas ridiculed. Furthermore, our points of view are often informed by our assumptions, which we address later here.

Evidence. All problem-solving is, or should be, based on evidence and factual information. Our conclusions or claims must be based on sufficient relevant evidence.

The information must be laid out clearly. The evidence against our position must be evaluated, and we must be open to new evidence that challenges our conclusions.

Purpose. All thinking to solve problems has an obvious purpose. It is important to have a clear understanding of that purpose and to ensure that all participants understand what that purpose is. Because it is easy to wander off the subject, it is advisable to check periodically to make sure that the discussion is still on target. For example, students working on a project occasionally stray into subjects that are irrelevant and unrelated, although they may be interesting or even seductive. It is vitally important, therefore, that the issue being addressed must be defined and understood as precisely as possible.

Assumptions. The Intergovernmental Panel on Climate Change's (IPCC) Fourth Assessment Report (2007) projected a rise in sea level by 2100 of between 18 to 59 cm, ***assuming no contribution by melting ice sheets*** (emphasis ours). When melting ice sheets and other factors are taken into account, the estimated sea level rise by 2100 is conservatively projected to be a meter or more. Reports of the IPCC projected sea level rise frequently omitted this seminal assumption.

All reasoning and problem-solving depends on assumptions, which are *statements accepted as true without proof*. For example, students show up in class because they assume that their professor/teacher will be there. We should identify our assumptions, and always be ready to examine and evaluate them. They often need to be revised in the light of new evidence.

Now, before we analyze our own assumptions, let us summarize some characteristics of sound reasoning. Critical thinking requires that we do the following:

- Continually exercise our thinking skills
- Eliminate irrelevant topics and explain why they are irrelevant
- Come to well-reasoned conclusions and solutions

Moreover, we should strive to understand concepts, key terms, and phrases essential to our discussion (such as greenhouse gas, ocean circulation, etc.).

Additionally, the effective reasoner continually assesses and reassesses the quality of his or her thinking in light of new evidence. Finally, one must be able to communicate effectively with others.

Next, let's do an exercise to allow you to test your assumptions about an issue.

Assumptions About Government's Role in Protecting the Environment

To assess the importance and power of assumptions in guiding your reasoning, take the following self-directed quiz. In it, you will identify your assumptions in defining government's responsibility to protect the environment, determine your assumptions as to the proper level of government that may act, determine your position on the precautionary principle and, finally, identify your assumptions concerning the extent to which individuals, governments, or institutions may impose costs on others with or without their knowledge or consent.

Thomas Jefferson and Government. Most politicians and many Americans probably consider themselves to have "Jeffersonian" principles. Read the following quotation taken from Thomas Jefferson's First Inaugural Address delivered on March 4, 1801.

> *What more is necessary to make us a happy and prosperous people? Still one thing more, fellow citizens—a wise and frugal Government, which shall restrain men from injuring one another, shall leave them otherwise free to regulate their own pursuits of industry and improvements, and shall not take from the mouth of labor the bread it has earned.*

Concept Check 1-1. In a clear sentence or two, explain what you think Jefferson meant by the phrase "which shall restrain men from injuring one another". Now assess the breadth of your response by considering this and the next three questions.

Concept Check 1-2. Do you think he was referring solely to thugs who physically brutalize their fellow citizens? Explain.

Concept Check 1-3. Could he logically also have been referring to citizens who sought to poison others? In other words, is restraining "poisoners" a legitimate role of government? Explain your answer.

Concept Check 1-4. Now, what if a citizen or organization dumps a toxin into water or air that all citizens depend on or if a citizen or organization fills in a wetland that performed valuable ecological functions on which local residents depend? May government under Jefferson's principle restrain that person or organization?

Your answer to these questions will define your assumptions as to the proper role of government. On what did you base your assumptions?

The Proper Level of Government That May Act

Next, evaluate your assumptions about the level of government, if any, which may properly intervene in environmental issues.

One of the major discoveries of the past two decades has been the extent to which much marine pollution is **transboundary** in nature. For example, one third of the air pollution affecting the Oregon coast comes from marine vessels outside the 5-km (3-mi) territorial limit controlled by the state, and from power plants in Asia thousands of kilometers away. This situation is repeated over and over across the country and around the world.

Concept Check 1-5. In the light of the transboundary nature of pollution, is it appropriate that local government by itself (e.g., the coastal city of Newport, Oregon) bear the responsibility for protecting its own environment? May the states and federal government have a legitimate role? Should international agencies be involved? Explain and justify your answers.

Your answer will help evaluate your assumptions about the extent to which state, federal, or global agencies have responsibilities to intervene to protect local environments.

The Question of Externalities

Economists define *externalities* as any cost of production not included in the price of the good. An example would be environmental pollution or health costs resulting from burning diesel fuel, not included in the price of the fuel. Another example is the cleanup costs paid by governments resulting from animal waste pollution of water bodies from large-scale meat-processing operations. In this example, the price of chicken or pork at your local supermarket is lower than it would be if all environmental cleanup costs were included in the price of the meat.

Assumptions About Corporations

Here is another choice quotation from Thomas Jefferson on the impact of those new organizations called corporations. Read Jefferson's words, and then respond to the following question:

> *I hope we shall take warning from, and example of, England, and crush in its birth the aristocracy of our moneyed corporations, which dare already to challenge our Government to trial, and bid defiance to the laws of our country.*

Concept Check 1-6. Do you share or reject Jefferson's opinions concerning corporations? Justify your conclusion.

Concept Check 1-7. Prepare a list of positive and negative contributions corporations make to our environment and economy. Do you conclude corporations have "too much power" in contemporary life? Why or why not?

If you are interested in corporate power, research the 1886 U.S. Supreme Court ruling: *Santa Clara County v. Southern Pacific.* The Court ruled that Southern Pacific was a "natural person" entitled to the protections of the U.S. Constitutions Bill of Rights and 14th Amendment.[6] In 2010, the U.S. Supreme Court affirmed the principle of corporate personhood. After researching these cases, answer Concept Check 1-8.

Concept Check 1-8. Do you believe the Court acted correctly in deciding that a corporation was a person? Is the 1886 ruling relevant to the 21st century? Why or why not? If you did not research the case, do you feel you are still entitled to an opinion? Should your opinion be given as much credence as someone's who did research the case? Why or why not?

After having thoughtfully responded to the previous scenarios, you should now have a better awareness of the assumptions that you bring to the analysis of issues in environmental geology that you are about to undertake in *Environmental Geology Today*.

Summary of Critical Thinking

Intellectual standards by which critical thinking is carried out are clarity, accuracy, precision, relevance, breadth, depth, and logic. These standards are applied in a framework delineated by points of view, assumptions, evidence or information, and purpose. We encourage you to return to this section whenever you need to refresh and polish your critical thinking skills.

Knowledge and Opinion

The philosopher Mortimer Adler pointed out[7] that there is no contradiction in the phrase "true opinion," nor is it redundant to speak of "false opinion." Thinking about the subject matter of this book requires that we separate truth and knowledge from opinion, and false opinion from true opinion.

There are few things that are both incorrigible and immutable: One example is the statement that the sum of a finite whole is greater than any of its parts. Sometimes definitions are self-evident truths: For example, a triangle has three sides.

Few scientific concepts meet these rigid standards. Does that mean that everything else is opinion? That depends on how we define opinions. Some opinions deserve the status of knowledge, even if they are not immutable and incorrigible. Examples are theories that have an overwhelming body of supporting evidence. We can say with confidence that such ideas are true at a particular time. Should new evidence come to light, we may have to evaluate our theory.

Contrast these kinds of opinions with personal prejudices, which we assert often without any evidence or force of reason to support them. We may, for example, believe that "the government has no business telling people what to do with their land." This is what philosophers would call a "mere" opinion, as opposed to a "true" opinion, which we illustrated earlier. There is nothing "wrong" with having mere opinions, but we all should recognize them for what they are.

Common Logical Fallacies

Much of your information concerning scientific issues will come from the media: television, magazines, radio talk shows, newspapers, and blogs and other websites. These sources often exhibit evidences of poor reasoning, such as logical fallacies (as well as mere opinions). Learn to identify them to ensure that you are getting the best information possible. Here, in no particular order, are some of the more common examples of **logical fallacies**:

- The fallacy of composition: assuming that what is good for an individual is good for a group. An example is standing at sports events—this is an advantage to one person but not when everybody does it.
- The fallacy of starting with the answer: including your conclusion in your premises or assumptions. For example, "America runs on high levels of energy consumption. We can't have the American lifestyle without energy. Thus, America can't afford to cut energy use." Here, the arguer is simply defining his way out of the problem. By this reasoning, we would have to continue to increase energy consumption forever, an obvious impossibility.
- The fallacy of hasty generalization: "Senegal and Mali have very low levels of energy consumption. They are very poor countries. Low levels of energy consumption lead to poverty." How is poverty measured? Are there any "wealthy" countries that have relatively low levels of energy consumption? Are there any relatively poor countries that have high levels of energy consumption?
- The fallacy of false choice: stating an issue as a simplistic "either–or" choice when there are other more logical possibilities. "Those who don't support fossil fuel use want to go back to living in caves."
- Fallacy of an appeal to deference: accepting an argument because someone famous supports it.

- Fallacy of *ad hominem* argument (literally, "at the person"): attacking a person (or his or her motives) who advocates a position without discussing the merits of the position.
- The fallacy of repetition: the basis of most advertising: repeating a statement without offering any evidence. "Population growth is good. People contribute to society. We need population growth to survive."
- The fallacy of appealing to tradition: "Coal built this country. Eliminating coal use would threaten our society."
- The fallacy of appealing to pity: "The commercial fishing industry supports millions of American families. We have to support them."
- The fallacy of an appeal to popularity: "Seventy five percent of Americans support this position." Perhaps the poll asked the wrong question. Perhaps the respondents did not have enough information to properly respond, or perhaps they were uninformed, and so forth.
- The fallacy of confusing coincidence with causality: "After passage of the Endangered Species Act, jobs in sawmills fell 70%; therefore, the Endangered Species Act was bad for the economy." Were there other possible explanations for the drop in jobs?
- The fallacy of the rigid rule: "Hard-working people are good for the economy. Immigrants are hard-working people; therefore, the more immigrants we have, the better for our economy." "Large numbers of immigrants commit crimes. Crimes are bad for the economy; therefore immigration should be curtailed."
- The fallacy of irrelevant conclusion: using unrelated evidence or premises to support a conclusion. "Development raises the value of land and provides jobs. Developed land pays more taxes than undeveloped land; therefore, any available land should be developed."

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CHAPTER SUMMARY

1. Science is the discovery of truths about the universe using the scientific method.
2. Science differs from other ways of knowing in that it relies on empirical evidence.
3. The scientific method begins with observation; if an event or process cannot be observed, either directly or indirectly, it cannot be explained by science.
4. Observations lead to hypotheses, or educated explanations of some phenomenon.
5. Hypotheses are tested, with one possibility being that the hypothesis can be falsified, or shown to be incorrect.
6. Science makes no value judgments.
7. Hypotheses are never proven; they are simply either accepted or rejected.
8. Tests of hypotheses must be repeatable, or the hypothesis is not valid.
9. Broad hypotheses that have withstood enormous scrutiny may become scientific theories, which are not conjectures, but denote truths.

10. Unifying scientific principles, like evolution or plate tectonics, offer an overarching, or unifying explanation for seemingly diverse phenomena and assembling them into a coherent whole.
11. A comparison that shows a simple relationship between two variables is known as a correlation.
12. Correlations based on cause and effect make a more powerful case for accepting hypotheses.
13. Scientific certainty is very difficult to achieve; scientists thus typically use the 95% standard (a hypothesis is accepted if 95% of the observations of a test are in line with the hypothesis).
14. The precautionary principle and risk paradigm are alternate approaches to regulate the introduction of chemicals into the environment.
15. Critical thinking is higher order thinking that essentially requires that we apply analysis, assessment, and the rules of logic to our thought processes.
16. Intellectual standards of critical thinking include clarity, accuracy, precision, relevance, breadth, depth, and logic.
17. The framework of critical thinking includes point of view, evidence, purpose, and assumptions.
18. Having an opinion on an issue comes with the responsibility to know the underlying facts of the issue.
19. You should be aware of common logical fallacies, which are evidence of poor reasoning.

KEY TERMS

accuracy
assumptions
breadth
cause–effect
clarity
correlation
critical thinking
depth
desertification
evidence
hypothesis
logic
logical fallacy
opinion
persistent organic pollutant (POP)
point of view
precautionary principle
precision
principle of scientific uncertainty
purpose
relevance
risk paradigm
science
scientific method
scientific theory
tonne
transboundary
unifying principle

REVIEW QUESTIONS

1. Science differs from other ways of knowing in that
   a. science has both a body of knowledge and a process.
   b. science answers questions about the natural world.
   c. science relies upon empirical observation.
   d. only science and the humanities use the scientific method.

2. Which of the following is a part of the scientific method?
   a. Making an observation.
   b. Formulating a hypothesis.
   c. Testing the hypothesis.
   d. All of the above.

3. Because science relies on observation, the Earth's temperature 500,000 years ago is unknown because humans had not yet appeared on Earth and thus could not measure it.
   a. True
   b. False

4. The hypothesis that dust from Africa was killing some coral in the Caribbean was
   a. tested and not rejected.
   b. conclusively demonstrated.
   c. proven.
   d. rejected.

5. The Pons and Fleischman experiment was
   a. scientific because it tested a valid hypothesis.
   b. scientific because it could solve the energy crisis.
   c. unscientific because nuclear fusion could never occur in a beaker.
   d. unscientific because it could not be repeated.

6. A scientific theory
   a. is an explanation for a phenomenon.
   b. is not conjecture.
   c. has withstood the scrutiny of repeated testing.
   d. all of the above.

7. The idea that dust from the Sahara has killed Caribbean corals is
   a. a unifying principle.
   b. a scientific theory.
   c. both a and b.
   d. none of the above.

8. The precautionary principle
   a. is used to regulate the introduction of pharmaceuticals.
   b. is a unifying principle in science.
   c. puts the burden of proof on the polluter.
   d. is none of the above.

9. In assessing the cause of coral die-offs, if we consider only dust and not other causes such as global warming or increased sedimentation, we violate the critical thinking criterion of
   a. clarity.
   b. accuracy.
   c. depth.
   d. relevance.

10. The statement, "Those who don't support fossil fuel use want to go back to living in caves" is an example of which logical fallacy?
   a. False choice.
   b. Starting with the answer.
   c. Straw man.
   d. None of the above.

FOOTNOTES

[1] A *tonne*, as you will see throughout this book, is also known as a *metric tonne* and equals 1,000 kg, or 2,200 pounds. A *ton*, or *short ton*, equals 2,000 pounds.

[2] The word *data* is plural and thus takes the plural form of a verb. The singular form of *data*, that is, one piece of information, is known as a *datum*. In practice, the word *data* is sometimes used to denote the singular, but technically this is incorrect.

[3] Glegg, G., and P. Johnston. 1994. The policy implications of effluent complexity. In *Proceedings of the Second International Conference on Environmental Pollution*, Vol. 1, p. 126. London: European Centre for Pollution Research.

[4] Paul, R., and L. Elder. 2000. *Critical Thinking—Tools for Taking Charge of Your Learning and Your Life*. Upper Saddle River, NJ: Prentice Hall.

[5] We obtained the basis for much of the information on critical thinking from the International Conferences on Critical Thinking and Educational Reform, sponsored by the Foundation and Center for Critical Thinking (http://www.criticalthinking.org). This section is adapted from *Environmental Issues: An Introduction to Sustainability* by Robert L. McConnell and Daniel C. Abel (2008, Pearson Prentice Hall, Upper Saddle River, NJ).

[6] This interpretation is disputed by many legal scholars who argue that in fact the court did not reach that conclusion.

[7] Available at http://www2.franciscan.edu/plee/adler.htm.