Science, Pseudoscience, and Not Science: How Do They Differ?

2

"There are more things in heaven and earth, Horatio, than you have ever dreamed of in your philosophy."

William Shakespeare, in *Hamlet*

Many news stories related to health and the environment introduce and describe scientific concepts which may be unfamiliar to the reader. Often, the stories draw conclusions based on the scientific or technical concepts that were presented, with the result that the reader is left to rely on a correct interpretation of the concept by the writer. Similarly, many marketing and advertising claims for health-related products rely on anecdotal evidence, rather than on the outcomes of controlled research.

In this chapter, we hope to provide you with the tools to examine stories and claims systematically so that you will become a skeptical and literate consumer of scientific information. That skill should help in real-life situations when you try to evaluate competing claims for optimal diets or nutrition, immunization programs, and even politically charged issues.

2.1 Introduction

Which of these statements are true?

"You should live a chemical-free life."

"Eating seeds is great because every seed is packed with the nutritional energy needed to create a full-grown plant."

"Use only organic beauty products because what goes on your skin enters your bloodstream."

"Why would you inject three diseases like measles, mumps, and rubella (German measles) vaccine into an infant?"

G.R. Baran et al., *Healthcare and Biomedical Technology in the 21st Century: An Introduction for Non-Science Majors*, DOI 10.1007/978-1-4614-8541-4_2,

"Cancer rates are increasing because of the chemicals and growth stimulants we feed animals."
"You should only feed your family food that contains no pesticides or food additives."

It's likely that you have heard at least one of these statements (or one very much like it) at some point in your life and accepted it without much thought because…it sounded right, or "truthy," as the comedian Steven Colbert would say. Did you then act on this so-called advice? If the answer is yes, then you have just provided an unfortunate example of the small role of science in public life.

2.2 Popular Views and Public Perception of Science

What is the usual, commonly held impression of science, scientists, and engineers? If you've known anyone who entered these professions, you probably remember someone "geeky" and studious; the television series "The Big Bang Theory" portrays a group of physicists who fit this popular image of scientists. No wonder that many nonscientists find it difficult to imagine that scientists and engineers actually have something to contribute to daily life!

The news cycle is now on 24 h a day, 7 days a week. We are bombarded by "news" from traditional newspapers, traditional network news programs, cable network news channels, tweets, blogs, e-mail, texts, etc. The concept of news as information is giving way to news as entertainment, and consumers now have so many choices that it is possible to consciously or subconsciously filter out stories that don't fit in with a certain worldview or attitude.

At one time, in the 1960s, physics and engineering were at the top of the news; this was the period when the Western nations worried about the Soviet Union and its space program and atomic bombs, when children in grade school and high school practiced what to do in case of nuclear attack (the trick was to hide under your desk!), and when the Soviets sent up the first orbiting satellite called Sputnik, politicians were ready to fund a variety of science programs. That's when the National Aeronautics and Space Administration (NASA) was organized and President Kennedy called for the USA to land a man on the moon.

Even as scientists and engineers were hailed as heroes when the lunar landing was successful, the more common portrayal of scientists in the media was decidedly one-dimensional and often portrayed scientists as deranged and up to no good. A mad scientist was responsible for creating Frankenstein; another crazed scientist (played brilliantly by Peter Sellars) was responsible for creating instruments of death and destruction in the 1964 movie Dr. Strangelove, which had the subtitle "how I stopped worrying and loved the bomb."

Scientists also seemed to disappoint the public and reporters: where were all those flying cars that were promised? Maybe they didn't quite promise them, but that's what the newspaper stories said. Engineers were supposed to design all sorts of gadgets that would make our lives fun, and instead we get to read about the search somewhere in Switzerland for the Higgs Boson, whatever that is. If scientists and engineers were so wrong about all their promises and predictions, then maybe the nonbelievers in climate are right and there is no threat after all!

Science stories seem to contain words like "wacky," "breakthrough," "scare," and "wasteful" and often have a sensational tone to them; these words don't seem to indicate objectivity on the part of the reporter. One topic has certainly emerged and captured the public's interest: health. Newspapers and television news and entertainment programs routinely feature stories about cancer survival, diet, obesity, new drugs, new kinds of surgeries, and dietary supplements. Dr. Oz has a television show where he talks about medicine in language the ordinary person can understand and a website where he promotes food supplements that can energize you and revitalize your immune system. Another physician, Dr. Joel Fuhrman, is featured on hour-long PBS television programs where he discusses nutrition-based treatments for obesity and chronic diseases. Because these two folks have an M.D. following their names, many people listen…and buy those dietary supplements.

A newspaper headline once stated that bananas are as good as drugs for treating HIV. It completely misinterpreted the results of a study reported in the Journal of Biological Chemistry in 2010. The original article stated that a lectin (type of sugar) found in bananas could interfere with the HIV virus entering cells. However, nowhere in the body of the article was it suggested that eating bananas was an effective treatment for HIV infections.

Still other issues are debated during political elections. Should more nuclear plants, solar cell factories, or wind farms be constructed? Should the government fund research for more energy-efficient cars, or is that a waste of taxpayer money? Should the government fund research that uses embryonic stem cells, or is that morally reprehensible? Is the "fracking" technology for releasing and collecting natural gas safe for the environment? We vote and decide which politicians get elected to make decisions about our future. However, we often don't know what their positions are on these important science-related issues. During the US presidential election in 2012, not a single scientific or technologic issue was debated; yes, the topic of an oil pipeline from Canada to the USA was brought up, but only as it related to "energy independence from the Middle East" and "job creation," not as part of a debate about a sensible energy policy.

Advances in science and technology are single-handedly responsible for the rapid rise in our standard of living over the past 200 years, and politicians and public policy figures all agree that science and technology are keys to future economic development and jobs. However, there seems to be a disconnect between relying on science and technology on the one hand and at the same time minimizing the roles of scientists and engineers in making big decisions. There are so many socio-scientific issues to consider: will additional taxes on high-sugar-content soft drinks influence obesity rates, should the type of materials used to manufacture baby bottles be regulated, should we be teaching evolution or creationism in public classrooms, and should decisions on these topics be made on an emotional basis or on an informed, rational basis?

How can one decide what is true and factual and what is invented or exaggerated by the media to sell advertising? Reading this chapter should help you to separate fact from fiction and turn you into an informed consumer and citizen [1]. We will try to bridge the gap between scientists and nonscientists, so well articulated by C.P. Snow (a physicist, chemist, and writer of some two dozen works of fiction and nonfiction) in his Rede lecture "The Two Cultures" [2]. He and others have lamented the education our secondary and high school students receive, with no realistic discussion of the scientific method, no preparation for how to interpret statistics, to estimate risk, or to evaluate the complexities associated with health and medicine. Instead, science is often taught as a series of individual facts that are barely comprehensible, as if to discourage the greater majority of students from an active and lifelong participation in scientific debates of crucial importance to their lives and futures.

2.3 Student Attitudes About Science

There is disturbing evidence about the state of knowledge regarding science and technology in the US surveys of children in elementary school and in middle school which indicate that kids are excited about science and very much enjoy the hands-on types of science experiences they have as a part of their education, many of which involve animals or the environment: guinea pigs, goldfish, and what can you find in the local pond or stream. Freshmen in high school still maintain a generally high degree of interest in science, but unfortunately, this interest significantly diminishes during the high school years, with physics and chemistry in particular becoming less and less popular.

Gender differences in attitudes to science also appear, though these differences are themselves variable depending on local cultural attitudes. Interestingly, in a science test given to 15-year-old students in 65 countries, girls outperformed boys in Eastern and Southern Europe and in the Middle East; in Western Europe and in the USA, boys outperformed girls [3]. Female students in US high schools seem to enjoy and elect to participate in biology courses, but shun math and physics; it is unfortunate that the early enthusiasm for science and technology shared equally by both boys and girls in elementary education is somehow lost in girls as they continue through high school. Many high school students of both sexes appear to develop a dismissive attitude toward science, reasoning that because the subject matter is of no interest to them, there is no need to learn it and that there will be no further exposure to science in college or in later life. The false notion that geometry, algebra, and calculus have no purpose for a nonscience major in college also becomes widespread. Along with this rejection of science and technology, students lose an ability to interact critically with scientific information. As the science educator Hodson wrote:

> To be fully scientifically literate, students need to be able to distinguish among good science, bad science, and nonscience, make critical judgments about what to believe, and use scientific information and knowledge to inform decision making at the personal, employment, and community level. In other words, they need to be critical consumers of science. This entails recognizing that scientific text is a cultural artifact, and so may carry implicit messages relating to interests, values, power, class, gender, ethnicity, and sexual orientation [4].

It's also curious and alarming that many students believe in certain pseudosciences, and these beliefs appear to persist into adulthood. How many "educated" people are there who believe that ghosts exist, that astrology can explain personalities and predict the future, that aliens regularly visit earth, that wearing jewelry made of certain crystals or metals has an effect on health, or that breaking a mirror brings bad luck (Fig. 2.1)? And even though surveys conducted by the National Science Foundation suggest that Americans are scientifically literate, the 2010 Science and Engineering Indicators report excluded questions about evolution and

Fig. 2.1 Astrology and new-age crystal therapy hold a fascination for many credulous people, even though no reliable evidence has been presented to support claims of effectiveness

the Big Bang; in other words, we don’t really know what Americans think about those two topics [5]. Apparently, the National Science Board thought that Americans would be confused because some of them hold religious beliefs that don’t allow them to think independently about scientific evidence.

In order to understand how science differs from pseudoscience, we will first discuss what the scientific method is, how engineers work, and the critical importance of using evidence to support claims made on scientific or technological topics.

2.4 How Science Is “Done”

It’s useful to know what the scientific process is, and how scientists and engineers arrive at conclusions, in order to be able to recognize silly or misleading claims and statements. If you adopt some of this thinking and analytical style, you’ll be able to make better decisions for yourself, your friends, and family members. You’ll learn how to analyze advertising that relies on some random bit of science, how to evaluate many socio-scientific issues that arise during election campaigns, and how to make sense of fad diets claims and food supplement commercials.

Before analyzing the statements listed at the beginning of this chapter and other “controversial” topics, let’s discuss how science is done. Let’s move away for the moment from emphasizing scientific and technical knowledge that can be memorized (e.g., what is the chemical symbol for arsenic?) to accepting that science is a process fundamentally grounded in asking questions. As questions are asked, evidence-based answers are given; and because not everyone agrees with the answers, a debate begins. This is, fundamentally, what the scientific process is all about: question, answer, debate, verify, and ask further questions.

Science is different from engineering; science attempts to provide answers about events in the natural world, while engineers often use scientific knowledge to modify the world to solve practical problems. How is science done? *Not* as it is done in most high schools.

Students in high school are instructed to follow a certain procedure while performing an experiment. Almost everyone knows what the result will be (they would have heard about it from students in another class); all the chemicals, materials, and equipment for the experiment are listed in the instructions and are conveniently provided. At the end of the experiment, the student is required to write a report that summarizes the activity and explains the result in a way that reinforces a concept found in the book or presented during lecture. In school, there is always a “right” answer, and all other answers are “wrong.” That makes grading the report easy.

Does this sound familiar? Do you think that this is the way science is really done? If you think yes, that could explain why you never wanted to be a scientist; after all, why would anyone pursue such a boring, predetermined, repetitive profession? Fortunately, and in point of fact, this is not the way scientists practice their profession.

2.4.1 How Scientific Ideas Beget Scientific Research

Science and technology are professions that demand creativity, and the best scientists are those who are most creative (just as the best writers and artists are usually those who are most creative). A scientist begins work by puzzling over a question; the question may have been assigned by a supervisor or may be one that the scientist has thought of independently. Many scientific questions are based on anecdotal evidence, an informal observation that has not been systematically tested (e.g., people taking the high blood pressure drug Rogaine™ started regrowing hair). The better the scientist, the better the question, because let’s face it, some questions are not worth worrying about. As the exact form of the question is formulated, the scientist may do a few experiments to test out his thinking and consult the scientific literature to see if anyone else has worked on a similar problem. It is typical of good science that doing experiments and collecting data are done not to come up with an answer or explanation, but to help decide between any number of competing possible explanations or hypotheses. To be valid, scientific hypotheses must be testable and falsifiable (proven false). A hypothesis is testable if it can be supported or rejected by carefully designed experiments or nonexperimental studies. A hypothesis is falsifiable if it can potentially be ruled out by data to show that the hypothesis does not explain the observations. Statements of opinion and conjectures based on supernatural or mystical explanations that cannot be tested or refuted fall outside the realm of scientific explanation.

Scientists conduct experiments to test hypotheses, but unless experiments are well-planned, the data they yield may be worthless. It is important to use the principles of sound “Experimental Design” when planning, conducting, and analyzing an experiment. We will discuss in some detail the types of experiments (or clinical trials) that involve human or animal subjects in the chapter on “Evaluating and Approving New Drugs and Devices,” but here it is worthwhile to introduce some general concepts and ideas that are pertinent to virtually all types of experimentation.

Experiments involve variables: an independent variable or factor is a quantity or value that is set by the experimenter. For example, in an experiment to determine the effect of caffeine on blood pressure, the independent variable could be the amount of caffeine in milligrams consumed within a certain time period. The dependent variable would be the outcome measure; in this case it could be the blood pressure measured 1 h after consumption of caffeine.

In most experiments, it is necessary to have a control group against which the other measurements will be compared; in this experiment, the control group of individuals would be a group that consumes water instead of caffiene, but whose blood pressure is also measured. Because the person constructing the experiment would want to ensure that the control and experimental groups were not somehow self-selected (groups of caffeine-loving individuals all volunteering for the caffeinated group), individuals would be assigned to the control or experimental group at random, perhaps using a random number generator to facilitate the assignments.

Then, when blood pressure is measured, the experimenter would want to ensure that no bias creeps in and would perform the measurements blindly (i.e., would measure blood pressure without knowing if that particular individual had been in the control or in the experimental, caffeine-ingesting group). The experimenter would also realize that measurements themselves involve errors; a systematic error affects the accuracy of the measurement and could result from the measuring instrument not being properly calibrated or by the person making the measurement not knowing how to read the dial indicator. A random error affecting the precision of the measurement would also exist, for example, if the blood pressure value fluctuated during measurement. The effect of random errors can be reduced by replicating the measurement many times.

The common characteristics of "good" experiments include control groups, randomized participating individuals, or specimens, and the data recorder is blinded so that an expectation of a certain result cannot affect the measurement. The precision and accuracy of the measurement technique is known and reported, and an adequate number of replications are performed to reduce the effects of random error. Finally, statistical analyses are performed to determine if differences in results between the control group and the experimental group (or between experimental groups if more than one is involved) are due to a "real" effect of the independent variable or if the differences could be due to chance alone.

The result of all this thinking or experimentation is usually a hypothesis that the scientist formulates as a preferred explanation (Fig. 2.2). Most scientists take pride in coming up with simple explanations or hypotheses (they refer to them as "elegant"). The principle called Occam's razor states that everything else being equal, the simplest explanation is probably the correct one (the razor shaves away unnecessary complications). For example, if you hear hoofbeats, it's likely that horses are galloping by, not zebras; it is more likely that NASA landed a man on the moon than it all being an elaborate hoax and so on and so forth. Think of Occam's razor when you hear wild explanations of how diet pills can make you lose a lot of weight quickly without reducing your food intake or increasing your exercise levels!

Osborne and Dillon list a few examples of great questions that led to experimentation or data collecting, illustrating that the best scientists did not start by collecting all necessary data, but rather used superior intuition to first propose a hypothesis [6]:

– Wegener suggested that because the coastlines of several continents seemed to match or fit together (e.g., western coast of Africa and eastern coast of South America), all continents were joined together at one time and had separated in the process called continental drift (Fig. 2.3). At the time this suggestion was

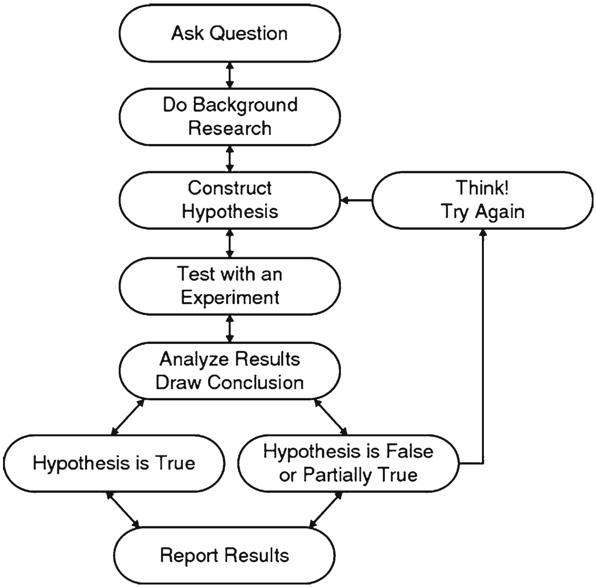

Fig. 2.2 Flow diagram of the scientific method. Copyright Springer Science + Business Media Dordrecht

made (1912), there was no explanation of how this could have happened; only later did seismologic experiments show there are two kinds of earth's crust and provided the evidence validating the theory.

– Louis Pasteur thought that diseases were caused by organisms too small to be seen with the naked eye (the germ theory of disease), that killing such organisms would lessen the chance of milk or wine spoiling (Pasteurization), and that weak forms of disease could be used as immunizing agents against stronger forms of that disease. He was proven right when he "put his money where his mouth was"; he publicly immunized 25 sheep against anthrax and left 25 sheep nonimmunized. All 25 nonimmunized sheep died from anthrax, while only one immunized sheep died. Pasteur later went on to develop a vaccine against rabies.
– Charles Darwin noticed that finches (a type of bird) on isolated islands near South America had substantially different characteristics that depended on the food supply on any given island (e.g., short beaks for eating seeds, long beaks for catching insects). Because all the finches had originally come from the same location (South America), Darwin hypothesized that the birds had evolved characteristics needed for survival on their island homes. This was the beginning of his formulation of the theory of natural selection, a radical departure from accepted dogma, which was that at the moment of creation, all species had been made at the same time. At first he was unsure of proposing this alternative explanation, and he continued thinking and gathering additional data. It was another 20 years before he felt confident enough to publish "The Origin of Species."
– Copernicus showed in a book published in 1543 that the motion of heavenly bodies made sense even if the earth was not the center of the galaxy (the geocentric theory was the accepted version of the solar system at that time). Unfortunately, he had no

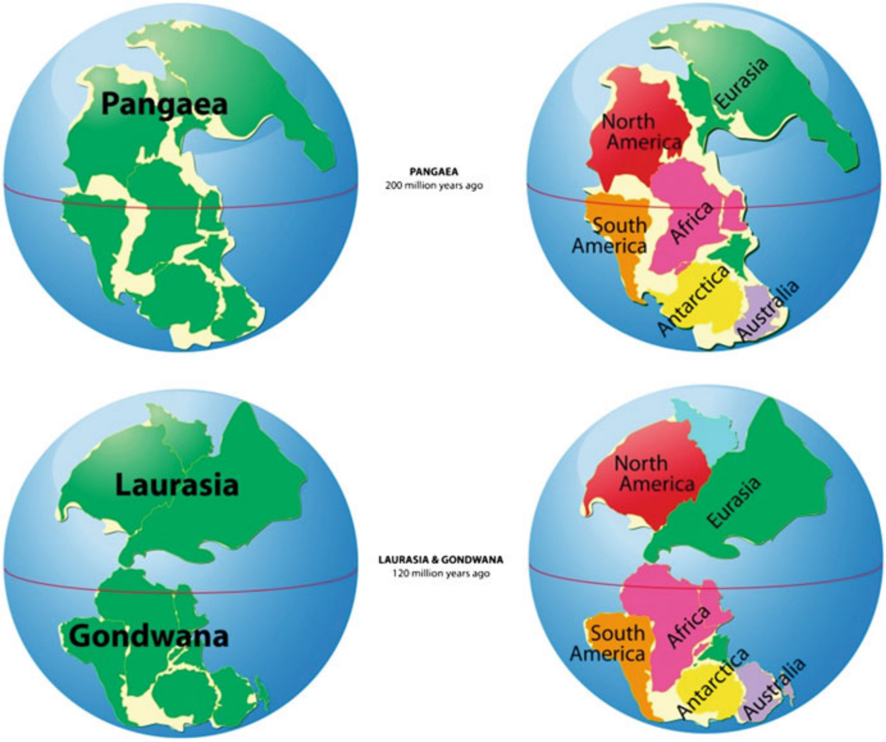

Fig. 2.3 Map showing how all the earth's continents once fit together. At one point, this was only a hypothesis; additional data later confirmed the validity of the hypothesis, lending it the status of a theory

data supporting the idea that the sun was the center of our solar system (heliocentric theory). It took an additional 200 years and work by Tycho Brahe, Johannes Kepler, Galileo, and eventually Isaac Newton before Copernicus's theory was accepted.

During the time a scientist is searching for data to support a hypothesis or to confirm a theory, many complications can occur. Experiments will fail or provide unexpected data that don't fit the scientist's concept; the theory/question is revised and more thinking and experimentation is done. This process of analysis, experimentation, revision of concept, experimentation again, changing the conditions of experiment, etc. is a very different one than that done in high school. There is another critical difference: no one knows the "correct" answer! It's entirely possible to construct an experiment and get a wrong answer, and it happens all the time. This is very central to the way a scientist conducts business, because it's not the way most people are trained to think; it's more comfortable to do an experiment and to accept the answer as the "truth."

Scientists often make their name by proving other scientists wrong by obtaining new data that disproves an established theory or by offering a new interpretation of existing data. They argue about how to interpret evidence all the time in what has been called a process of "organized skepticism" which is the strongest guarantee

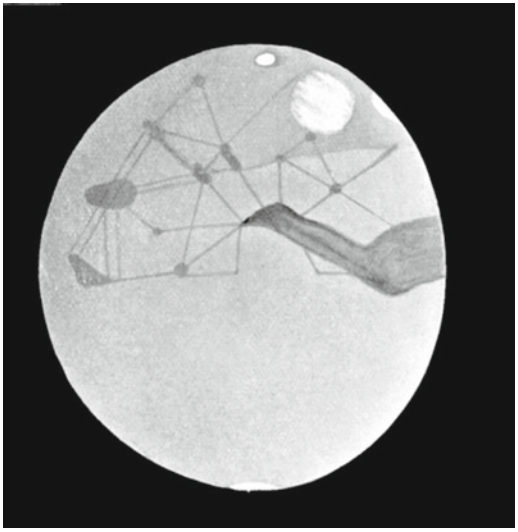

Fig. 2.4 Martian "canals" sketched following astronomic observations. Copyright Springer Science + Business Media, LLC

that the shelf life of any bogus or mistaken explanation or theory will be short indeed. There are many scientific theories that were accepted and popular at one time or another, but were proven wrong as more data became available:

- The existence of a planet called "Vulcan" was believed to be responsible for variations in the orbit of the planet Mercury; many astronomers even claimed to have seen it! This theory was abandoned in 1915.
- The Theory of Spontaneous Generation, formulated by Aristotle, stated that life could start from mud when it was exposed to light. The theory was based on observations of barnacles that seemed to form spontaneously on ship hulls and maggots that would crawl out of a corpse. The theory still had believers in the 1700s!
- Geologic features (Fig. 2.4) observed by astronomers on the surface of the planet Mars led some to theorize that these were canals built by some advanced alien life form; the theory was finally put to rest in the 1960s when NASA sent satellites flying over Mars which transmitted pictures back showing that the features were streaks of dust.

2.4.2 Collecting More Data to Validate a Theory: Who Pays for Science and Engineering Research

As the scientist gains confidence in a theory, depending on the scope of the question and the required amount of additional data needed to answer new related questions, funding is often needed in order to pay for supplies, equipment, and technical support to search for more confirmatory data to support a more expanded theory. The request for funding takes the form of a proposal, in which the scientist describes (with as much specific detail as possible given page limits) the fundamental idea or question, the reason or reasons why it is important to answer the question, what others have done to answer this or a similar question, what preliminary work the scientist has done to answer the question, and the plans the scientist has for further work. (A portion of a real proposal is included in Appendix A.) In order to show a command of the subject matter and to indicate that a great deal of work has already been done, the scientist might propose one or more hypotheses in the proposal. A hypothesis is essentially the best-guess prediction of how the proposed experiments will work out and is based on the current evidence. So, the hypothesis continues to be tested by the experiments proposed by the scientist. It is also true that sometimes a hypothesis is not needed, and with the development of specialized computer algorithms and rapid access to huge amounts of data, it is possible to mine data for correlations without the initial formulation of a hypothesis. At any rate, the hypothesis is tested, and if not supported, it is revised again and again until a conclusion can be drawn that provides at least a partial answer to the initial question.

This proposal, along with several others submitted by other scientists, is evaluated by a group of peers, i.e., other scientists familiar with the field, and given a score. The score is supposed to be related to the originality of the question, the importance of the question, the justification provided for the plans to answer the question, consideration of alternative answers, and finally the plans themselves. The reviewers often evaluate the proposal based on questions such as is the proposed explanation novel, is the hypothesis properly stated, are the experiments properly designed to test the hypothesis, and is the scientific team qualified to conduct this type of research. If the score is good enough, the scientist may receive a grant for a period of a few years to fund the research. Note please that the proposal is reviewed by other scientists who look forward to pointing out what if anything is wrong and silly about the idea and experiments!

Over the next year or two, the scientist will usually choose to disclose the results of experiments in the form of presentations at scientific meetings or publications in peer-reviewed journals and start building a case for a conclusion (answer to the question). If the results or "facts" that the scientist obtains are reproducible, observable natural occurrences, they constitute the evidence the scientist uses to support his/her interpretation of events. Sometimes, the scientist is compelled to draw an inference, which is a conclusion based on the facts but not specifically tested (e.g., if someone walks into your home wearing a wet raincoat, you infer that it is raining outdoors, even though you may not have seen it for yourself).

2.4.3 Announcing Research Results: Scrutiny by Peers

Disclosure of findings from scientific studies will often occur in the form of a manuscript submitted for publication in a scientific journal. High-quality journals will insist on peer review of the submission, which means that two or three other scientists will be asked to read the manuscript and provide a recommendation as to its worthiness for publication as part of a painful exercise called the "peer-review process" (Fig. 2.5). The review is usually done "blind," meaning that the submitting

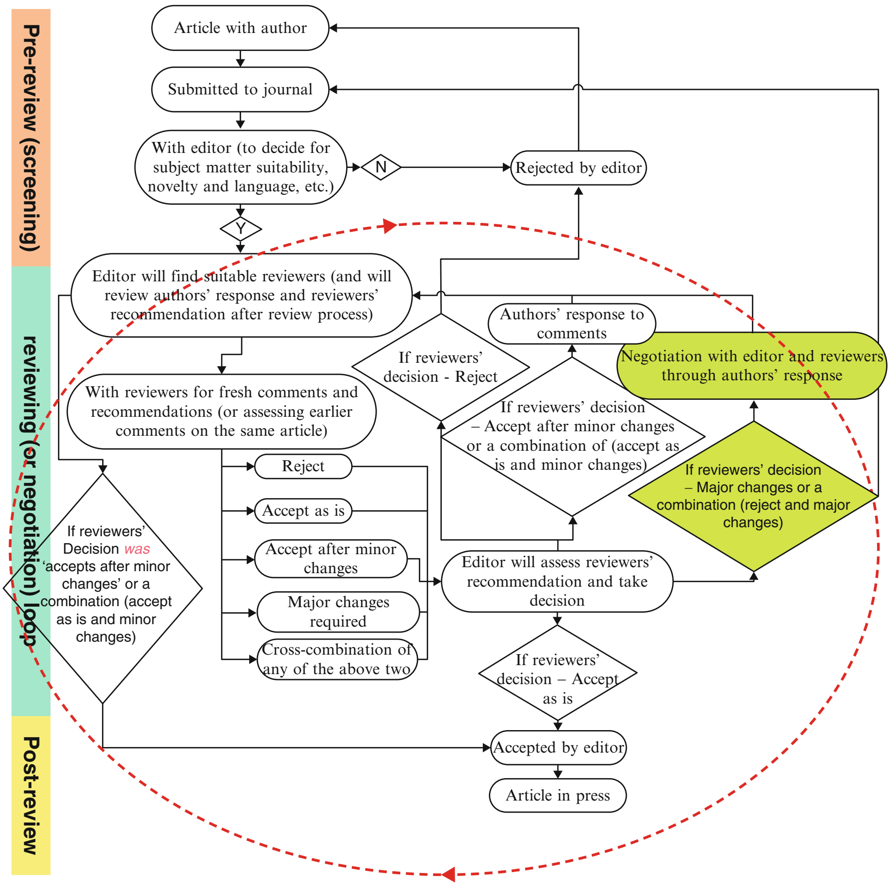

Fig. 2.5 A flow diagram of the peer-review process. The process acts as a safeguard against publication and dissemination of faulty or misinterpreted data. Copyrighted by Springer Science + Business Media B.V.

author does not know who the reviewers will be and often the name and affiliation of the author will be masked from the reviewers. The author will also be asked to disclose any financial considerations that might pose a conflict of interest; for example, a study describing the design of a new hip implant could be influenced by the author owning stock in the company selling the implants.

By the way, this kind of disclosure of a potential conflict of interest is peculiar to scientists. As was documented in the 2010 Oscar-winning movie "Inside Job," economists often write articles without disclosing their work for mutual funds or other investment companies.

The reviewers will consider the quality of the experiments, and their interpretation, realizing all the time that the data *suggest* the answer to a question; data are not absolute facts that state how things are. If the peer review is favorable, the manuscript is published.

Now the real action begins. If the manuscript reports a truly significant or exciting find or explanation (e.g., a cure for the common cold), other scientists get involved. First, questions are asked for more detail about the experiments, and other scientists will try to repeat the experiments to see if they obtain the same results; they will try to replicate the reported experimental results. If not, then the value of the original manuscript is called into question, and an argument begins. The argument may begin even if the experimental results agree, but a different explanation for the observation can be offered by other scientists.

2.4.4 Theories and Laws

At this point you should have recognized one of the main characteristics of the work of science: there is much review and much argument, and it is only after that review and argument is completed that an explanation rises to the level of a theory. And, even after a theory is generally accepted (e.g., the Theory of Relativity), it continues to receive scrutiny because scientists are skeptical by nature. No scientific theory is proven once and for all, and independent testing continuously tests the theory. Remember that no scientific theory can be tested in every possible situation and, as a result, a theory supported by current data is accepted until and unless further testing and data show otherwise.

A famous case in 1989–1990 illustrates this point. At that time, two chemists (Pons and Fleischmann) from the University of Utah claimed to have discovered the phenomenon of "cold fusion," i.e., the ability to fuse two atoms of hydrogen into a single atom of helium. This was tremendously exciting because it was done in an ordinary test tube, and energy was released! Their work suggested the promise of clean, renewable energy everyone had been waiting for. Because of the significance of this discovery, other scientists wanted to learn the details; however, Pons and Fleischmann kept postponing the release of information on the details of their experiments and, eventually, were found out to be sloppy experimentalists at best and frauds at worst.

So, to summarize and define some terms, a theory is an often complex explanation of phenomena that is based on the best available evidence. The evidence offered in support of a theory has been subjected to critical analysis and review by all interested scientists and usually represents the consensus of the scientific community at any given time. Nevertheless, this explanation keeps being retested, and it may be that testing is never completed, e.g., the phenomenon occurred over a time scale not possibly reproducible. For example, how can we do an experiment that replicates the formation of the universe as explained by the Big Bang Theory? Nonetheless, and this is significant to repeat, a theory is based on the best interpretation of the evidence at any given time. Furthermore, a consensus represents the best interpretation of existing data by the scientific community as a whole and does not necessarily mean that all scientists agree with that interpretation at all times. In fact, sometimes those few scientists, who may genuinely disagree with the consensus of the scientific community, may over time be able to change that consensus by presenting new findings or interpretations to falsify the existing theory.

If a theory is an explanation, how can we take advantage of the explanation to invent a better device or develop a new technology? If a law can be formulated, which describes relationships between various bodies and substances in a mathematical way, and these relationships can be confirmed by observation, then the law will provide guidance for utilizing the explanation contained in a theory. For example, Newton's second law of motion states that $F = ma$, or that the force exerted by a moving object is equal to the mass of the object multiplied by its acceleration. Notice that although this law does not explain why this is true (and it is true, because it has been confirmed by thousands of experiments), it is still a quite useful thing because it becomes a tool to make predictions. For example, an engineer who knows the weight of a bullet and the speed with which it travels can use Newton's second law of motion to calculate the force that bullet would deliver on impact and design a bulletproof vest. Newton's second law also predicts that when catching a fast-moving baseball that would normally hit a baseball glove with a great deal of force, pulling the glove away at the moment the ball hits the glove will reduce the relative acceleration of the ball and reduce the force felt by the fielder's hand.

A scientific law is not necessarily a stronger interpretation of the evidence as compared to a scientific theory, but rather a scientific law has a mathematical form to it while a scientific theory may not.

It is this constant process of review, argumentation, and retesting, all done publically and resulting in the formulation of theories or laws, that distinguishes claims made by science from claims that are belief based without an underpinning of observation or experimental validation. This quote by Carl Sagan may help you understand these issues better: "To be accepted, new ideas must survive the most rigorous standards of evidence and scrutiny."

Cobern and Loving provide an elegant explanation of what science is and what it involves [7]:

> Science is about natural phenomena and the explanations that science offers are naturalistic. The explanations are testable against other natural phenomena, or against other explanations (test of a theory). Science is about explaining, not only about describing. Science also assumes that it is possible to learn about nature, that there is order in nature, and that there is cause and effect in nature.

Science involves criticism, review, and argument, all conducted publically and accepting revisions of explanations and theories. Not all opinions matter, even though that may not seem "fair"; opinions have to be based on relevant and appropriate observations (Fig. 2.6).

It is important to remember the point made in this last paragraph: although everybody is entitled to their own opinion, when it comes to science, not everyone's opinion is relevant, and irrelevant opinions should not be considered in deciding issues that are fact based. Debates and arguments between scientists are not settled by a vote, but by who has the best factual evidence and interpretation of that evidence. As Senator Moynihan once said, "Everyone is entitled to their own opinion, but not to their own facts."

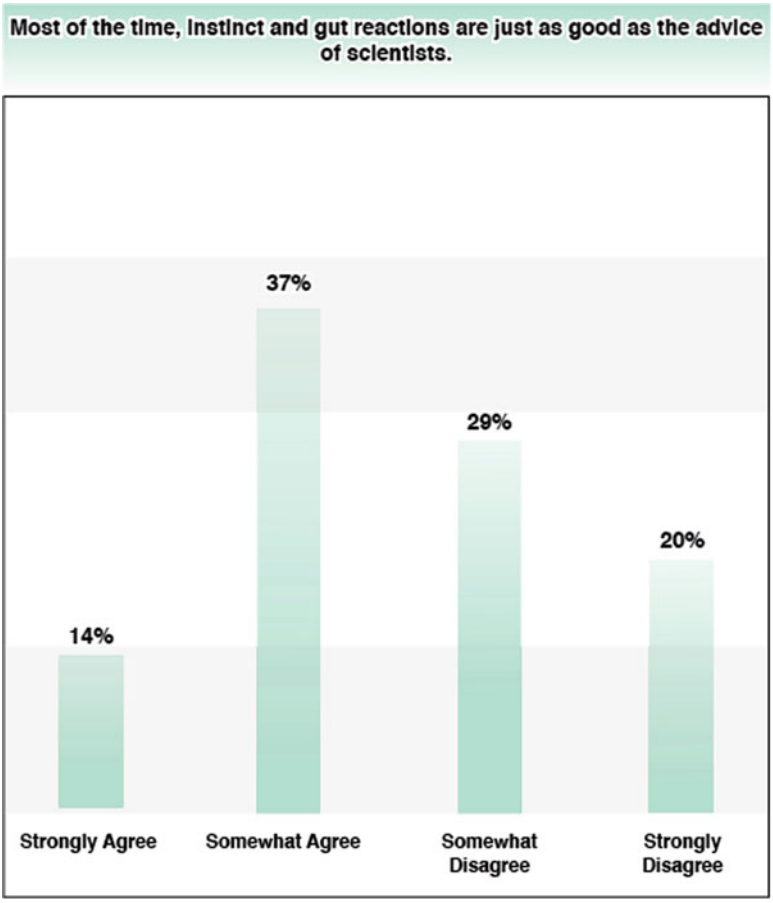

Fig. 2.6 The general public appears to be unaware that scientific advice and opinions are based on training and informed observation and as such are fundamentally different than other uninformed opinions. Data from a University of Texas/Texas Tribune poll of October 2012

2.4.5 What Can Go Wrong in the Scientific Process

Now that we have discussed the ways in which scientists and engineers work hard to devise experiments and theories, and to reach conclusions that will eventually lead to laws that enable design of safe buildings, airplanes, and artificial hearts, it's time to confess that mistakes can be made. Scientists and engineers are human and are influenced by all the same psychological factors that influence everyone else. Furthermore, the scientific process is a human activity and, like most other human activities, can be distorted by many societal factors. Let's see what some of these distorting factors are.

2.4.5.1 Data Distortion

Humans tend to be (and want to be) consistent. That tendency is also responsible for the difficulty we often have giving up a strongly held opinion or reversing an attitude. So, if, for example, a scientist has a strong certainty that a particular bacterium is responsible for a particular disease, there may be a tendency to have more faith in data supporting that opinion than in contradictory data. If a physician comes to think that the patient has a cyst in her breast, then it will be difficult to suddenly reclassify the lump as cancerous.

Once a person makes a decision, he or she is often bound to that decision, and it becomes difficult to revise. This pattern of behavior is common to organizations too, and there have been many large projects that continue to remain active even after it becomes clear to outsiders that the cost are unjustified or the initial design was flawed. There is a particular kind of fantastic optimism that causes project leaders to claim that there will no longer be cost overruns and that the machine will finally work! For example, the US F-35 Joint Strike Fighter program is beset by significant problems. More than 2,400 F-35s were to be bought through 2037, but the total cost of acquisition is now nearly $400 billion, up 42 % from the estimate in 2007; the price per plane has doubled since project development began in 2001. Cost overruns now total $1 billion. On top of it all, the plane's performance was described as "mixed" in 2011. The project continues nevertheless.

Humans (scientists too!) tend to accept or reject evidence based on preconceptions. These preconceptions were likely developed with a good-sized helping of "scientific intuition." It turns out that most people like to think that they have a good sense of intuition, because we all suffer from the human tendency to remember times when our intuition was correct rather than the times when we were dead wrong. Just think of how many times you've played the same lottery number….

This erroneous belief in the power of intuition has many examples. For example, many folks believe that personal interviews are the best way to establish who should be offered a particular position. However, it has been shown that in most circumstances an interview is useless for many reasons [8]. First, an applicant who has a nice personality and is pleasant looking will benefit from the "halo effect" and will be considered to have all the necessary skills for the job regardless of objective measures such as background or experience. Second, the interview is biased by the "primacy" and "contrast" effects; all things being equal, the most recent interviewee is remembered best, and the candidate following a "bad" one will be evaluated too highly, while a candidate following an "excellent" one will be evaluate too harshly [9].

By the way, the halo effect is used to good purpose by the advertising industry; a pleasing name on a product carries over to a pleasing overall impression of the product itself. Do the names Corvette, Viper, Sting Ray, and Jaguar not convey a certain characteristic of the automobiles just because of their names?

Missing or negative data are ignored in favor of data that confirm beliefs or that preserve consistency. It has been shown that the likelihood that a peer reviewer will recommend publication of some manuscript is related to the likelihood of the submitted paper confirming the reviewer's own body of work [10]. Practitioners and believers of holistic medicine often claim that "it's the patient's own fault" if a treatment doesn't work.

On the other hand, evidence may also be overamplified, meaning that even though there may be insufficient evidence, there is nevertheless pressure to proceed to a conclusion. It is sometimes difficult to recognize that evidence is lacking, because people (scientists too!) like to tell stories about what is happening and want to see a cause and effect relationship even when there is none; are you familiar with the phrase "jumping to a conclusion"? That's why it is good scientific practice to first form a hypothesis (make a prediction) and then systematically test the hypothesis with experiment.

Another example of the human desire to tell stories and of our need for consistency is the tendency to see patterns where there are none (or for a scientist to see a connection where there is none). How many of you believe in a "hot streak" even if there is no way that the outcome of a previous event (e.g., a basketball shot going in) could have an effect on the next attempt? Still another sports-related example is the so-called Sports Illustrated cover jinx, which claims that if an athlete or a team is featured on the cover, inevitably the team will suffer a loss or losses, and the athlete will go "cold," i.e., stop performing well. In fact, the jinx is just a manifestation of what is called "reverting to the mean." The team's or athlete's performance is typified by some average performance; an above-average performance is the reason to make the cover, but at some point the team or athlete will have to perform below average, hence the jinx.

But we are programmed to preferentially perceive and pay attention to the outlier and provide exceptional characteristics (good or bad) to the person, fact, or thing that stands out. In part, this habit of ours is what is responsible for ethnic or racial stereotyping. Because members of minority groups stand out more, we endow them with more dramatic traits. If we are member of the majority and meet another who is not, then any characteristics we notice will be exaggerated. So, for example, members of a white majority would often tend to exaggerate the athletic ability (positive characteristic) and the generally lower economic status (negative characteristic) of the black minority.

The tendency to exaggerate is itself even more exaggerated in group settings, when individuals' behavior is influenced by the presence of others; this is called "Groupthink." It turns out that in a group, the thinking and attitudes of the members do not move toward the average attitude, but instead the average attitude becomes more pronounced, more radical. Groupthink is always more extreme than "individual think." This phenomenon could explain the polarization going on in American politics today, when it seems that the divide between the "left" and the "right" is wider than ever, with no apparent common ground in sight.

Because humans are inherently biased, there is a risk that the missing information will be replaced with a biased explanation. One way to avoid this trap is to establish a causal story by gathering what is called covariational information. In this approach, data are obtained while searching for the presence or absence of an effect both when the proposed cause is either present or absent. The questions asked are two: (1) Is there an effect in the presence of the proposed cause? and (2) is there an effect in the absence of the proposed cause?

To borrow an example from Brem and Riss, let's consider the claim that welfare recipients have difficulty getting off welfare because they lack job skills [11]. The explanation (story) might say that job skills improve one's chances of landing a paying job and allows the person to get off welfare. This explanation sounds reasonable and may even be true! But recall the existence of bias…in decades past, explanations involving the role of a "spirit" were assumed to be reasonable. The role of evidence in evaluating the claim made earlier would consist of comparing welfare recipients with job training against welfare recipients without job training. If we find those with training spend less time on welfare than those without, that finding constitutes evidence for the claim. If we also find that those with training obtain well-paying jobs and that those with well-paying jobs are less likely to return to welfare, that is evidence for the mechanism. In real life, of course, these are complex issues, but published research does suggest that if welfare recipients are shown that they can be successful in the labor market (i.e., providing them with job skills), they will show an increased tendency to seek work.

What do you think: *how could you evaluate claims that eating more than two helpings of fried foods per day increases blood cholesterol*?

2.4.5.2 Other Forms of Bias

It may surprise you to hear that scientists can be biased. Indeed, one of the forms of bias talked about today is based on gender. There are many more male scientists in senior positions than female scientists. Surveys indicate that men and women receive the same number of doctoral degrees in biology, yet at universities, only about 15 % of professors (the highest academic rank) are female. These ratios are somewhat different in other scientific fields; a 2008 survey in the UK found that 25 % of men were employed in science, engineering, and technology versus 4 % of women in those same fields.

There are many potentially accurate explanations for this phenomenon. For example, women have been historically dissuaded from pursuing mathematics and the physical sciences, and indeed there are more women in biologically-intensive science careers when compared to physical sciences-intensive careers. The advancement of women in their careers can be impeded by their traditional child-rearing roles, which can interfere with the single-minded dedication needed at the start of an academic career, when fresh assistant professors are busily pursuing tenure. Whatever the reasons are, folks at various national-level organizations are concerned that large numbers of potentially productive scientists and engineers are being lost to other professions.

What do you think: why are fewer women than men drawn to science and technology careers?

In this chapter, we are more concerned with examining bias and the effects of this slanted gender distribution on scientific practice, rather than on the roots of this form of bias. Two examples serve to illustrate these points. Until recently, the role of men as hunter gatherers was given primacy in studies of the social evolution of mankind; it is only within the past 25 years or so that the role of women as gatherers and toolmakers has been recognized and their importance accented. In another instance, craniologists (folks who measure the size of the skull) used to maintain that the ratio of men's skulls to their body mass "proved" men to be more intelligent than women. A later reexamination of the data showed that the skulls selected for measurement were not randomly selected, and if they had been, the opposite conclusion would have been reached using that line of reasoning (women are more intelligent than men). Other examples of bias include racial bias: claims that whites are more intelligent than blacks, that society could be improved by selective breeding, and that restricting immigration from southern Europe (e.g., Italy) would improve American society's genetic pool.

It is important to understand that bias not only may be used to promote the idea of someone's inferiority, it could also be used at times to promote the concept of a particular ethnic groups superiority in one field or another. In all such instances, extremely careful examination of data to search for evidence of bias would be called for.

Bias does not only occur as the result of gender or race. In some cases, it can occur for political reasons. In the Stalinist Soviet Union (1921–1953), Trofim Lysenko was director of Soviet biology and developed a theory of genetics that claimed an "environmentally acquired inheritance," rather than the more widely accepted genetic theory derived from the work of Mendel. This theory coincided with the communist thinking of that time, which was that organisms (including people) could be easily and quickly remade under controlled environmental conditions. Lysenko's theory became popular in the Soviet Union and formed the basis of its agricultural policy in the mid- and late 1940s. Scientists who dissented from this prevailing theory were imprisoned! Because the theory was based on questionable and even fraudulent data, crop yields in the Soviet Union plummeted, causing severe hardships. Tragically, Lysenko's theory was also responsible for helping justify Mao Tse-Tung's great leap forward in China in 1958, a disastrous experiment believed to have caused the deaths of 20–40 million people from starvation.

Although it is doubtful that scientific fraud on this scale is practiced today, it is important to know that it can occur on a smaller scale, as the result of what may be called the "my-side" bias. That is, a scientist examining data may be tempted to exclude data that does not support his/her working hypothesis and may instead be tempted to interpret the data to support his/her working hypothesis. Studies of human behavior have shown that we all practice the "my-side" bias on a daily basis, though perhaps not scientifically, when we often choose to hear or see only those events and things that coincide with our view of the world.

In keeping with the theme of bias in science, some folks maintain that the science and health technology we have is biased in favor of the West. That is, because most scientists and healthcare professionals are trained and do research in Western Europe or the USA, the current scientific understanding has a bias against those who have not been dominant in science. To reverse this discrimination, some argue that more indigenous or native or traditional notions of science should be included in science curricula. And in fact, there is no reason to exclude multicultural knowledge about the real world, as it has been accumulated over many years and served the needs of various indigenous peoples. However, while recognizing and appreciating the bounty of experience-derived knowledge, we should not confuse folklore with science. The folklore we celebrate enabled a culture to develop new technologies and to survive by successfully solving everyday problems, but it does not bear scrutiny through our definition of the scientific method. That is, traditional or indigenous or aboriginal notions of science and technology should be probed to discover does the technology have a theoretical background, does the theory permit updating and revision, is systematic experimentation part of the development of the knowledge, is the knowledge formalized, and can further research be done on it? Much of the folklore accumulated by native people is generally useful only in the contextual framework of the life of those people and past times; it loses applicability when it enters a setting that is different from where and when it was developed. For example, the use of certain plants to cure or aid those who are ill will work only where those plants grow; knowledge of the key ingredient is lacking, so the knowledge cannot be spread universally. Often too the knowledge has been protected, available only to certain practitioners and their acolytes, and not generally available for all to read, see, and discuss, i.e., not conformable to our definition of science.

2.4.6 Pseudoscience

The strength of the scientific approach relies on the continued scrutiny of data and interpretations of those data and in the peer-review approach to reviewing manuscripts and research. Above all, however, it is the acceptance of the idea that our current understanding of things may be wrong, and if new knowledge is acquired, theories are amended. There is no system of beliefs that is able to make such a claim and that is where science and religion diverge.

You may recall that at the beginning of this chapter, a series of provocative statements were made. If you spend enough time in the early morning hours watching cable television, particularly the infomercial variety of programs, you may encounter even more such statements. Some promise to cure an affliction like baldness, psoriasis, or dementia; others promote all-natural new treatments that are only available by mail order or strange combinations of ingredients only recently discovered to help resolve various health problems (Fig. 2.7).

Some of the ads may seem comical, but you surely think that they must be at least somewhat effective, otherwise no one would be buying television time to advertise. So how should listeners react, who presumably want to find an effective remedy (but not fall victim to misleading advertising such as shown in Fig. 2.8)?

There are explanations for why many of these claims “sound” reasonable, and we can think of reasonable rules that can be followed in examining them. First, news of newly discovered cures are often exaggerated for purposes of a sensational headline, and many of such stories are based (loosely) on very early studies that have not been tested by other scientists. Second, be wary of trying unproven remedies if the advertising is suggesting that since nothing else has worked, what do you have to lose? You could lose even more good health, your time, and certainly some of your money. Patients and their families who may be desperate for a cure are

Fig. 2.7 At one time, there were fraudsters selling snake oil as a cure-all in the American west. Snake oil has been replaced by food supplements, cures for baldness, aids for impotence, or pills for extra energy as the next must-have curative substance

Fig. 2.8 People like to believe in miracle cures

particularly vulnerable and sometimes travel to clinics around the world where licensing and truth in advertising laws are poorly enforced [10]. Third, the reason that dramatic claims of cures are made is because we know that dramatic and sensational news is most easily remembered. Finally, testimonials (when truthful) are only provided by people whom the treatments helped. Recall that in the absence of a controlled study, it is not possible to determine if these improvements came as the result of the placebo effect or not, and in any case, there are no testimonials from people for whom the treatments did *not* help.

As noted above, scientists tend to be very skeptical of even their own claims, and a good helping of skepticism is helpful; remember that extraordinary claims require extraordinary proof, that any causal claim must have relied also on a control group, and that the burden of proof is on the person seeking to overturn the accepted treatment mode.

A few years ago there was a lot of discussion about a compound called beta-carotene that was found in fruits and vegetables. Several laboratory studies, animal studies, and results of observations showed that this compound was protective against cancer. Then, the results of three clinical trials were published, which showed that the compound did *not* work as promised. Infomercials marketing beta-carotene diet supplements would show a stack of laboratory studies on one side, and three clinical studies on the other, and ask "which do you believe?" In this case, the consensus of the scientific community was that the clinical trials had the last word, and while eating fruits and vegetables is definitely a good idea for many health reasons, it does not help to protect against cancer [12].

Regardless of all that we are taught and have read about science and engineering, various pseudosciences maintain their popularity in our society: acupuncture, astrology, homeopathy, etc. All these schemes have advocates who provide testimonials as to the effectiveness of these treatments or beliefs. A survey conducted in 2007 by the National Institutes of Health (NIH) reported that 38 % of Americans use some form of complementary and alternative medicine (CAM). The NIH, under pressure from politicians who believe in alternative medicine, has formed an organization called the National Center for Complementary and Alternative Medicine. The objectives of this institute include the study of alternative medical practice such as the use of herbal medications, dietary supplements, probiotics (e.g., yoghurt), meditation, yoga, spinal manipulation, qigong, tai chi, movement therapies such as Pilates and Rolfing, energy field manipulation such as Reiki and magnet therapy, Ayurvedic medicine, and traditional Chinese medicine. It is of interest to note that on its web page, the NCCAM states that "rigorous, well-designed clinical trials for many CAM therapies are often lacking; therefore, the safety and effectiveness of many CAM therapies are uncertain." Also, "information provided by NCCAM is not meant to take the place of your primary health care provider's medical expertise." There are a number of other warnings about credentials of CAM practitioners, including the fact that dietary supplements have not been tested on pregnant women, that the mechanisms of action of the supplements are unknown, and that standards for ensuring dosage and purity of botanicals and dietary supplements do not exist.

Let's consider acupuncture (Fig. 2.9). A frequent comment made about this practice is "we know it works from thousands of years of experience." The "acupoints" that are described as areas with concentrations of nerve endings and blood vessels have never been found by any microscopic or biochemical techniques. A study reported that during acupuncture, certain brain activity was reduced, which corresponded to lower pain perception in the volunteers taking part in the study. What does that mean, exactly? Was the effect causal or coincidental or was it due to the placebo effect? Many reviewers of homeopathic practice believe that the placebo

Fig. 2.9 The process of acupuncture. Scientific studies have shown that acupuncture does not work

effect is responsible for the outcomes of treatment and that studies purporting to show it to be effective are improperly designed and do not use the proper controls.

Homeopathy is a type of treatment that is reputed to be effective for treating

What do you think: *what questions should be asked when considering an alternative medical approach*?

a number of ailments including arthritis, asthma, depression, headaches, and insomnia. Testimony for its effectiveness is available from the many celebrities who are users, including Paul McCartney, Tina Turner, and Jennifer Aniston, though within the traditional medical community it is considered to be quackery. It has evolved into an industry including a professional trade association (The Society of Homeopaths), whose members are trained in preparing the medications. Homeopaths believe that by choosing a substance that causes the same symptoms as the disease afflicting the patient, and having the patient ingest a very dilute preparation of that substance, the patient will recover. For example, if the patient has a runny nose, the homeopath might take some onion juice (which also causes a runny nose), dilute it in water, and shake the solution in a special way called succession. The dilution of the active ingredient is extreme:

a common dilution is called 30C, which is achieved by taking a drop of the active substance, diluting it in 100 drops of water, then taking one drop of the first dilution and diluting it again in 100 drops of water, and so on until the dilution has been made 30 times. What are the chances of any of the active substance still remaining? Homeopaths claim that the water “remembers” the active substance even though none may be left and that the memory of the substance is more potent than the substance in its original strength [13]. Again, no scientific proof of any of these claims is provided by their proponents.

So how can you tell science apart from pseudoscience? The answer lies not so much in the specific topic under discussion, but rather in what type of work or process was involved in formulating the new explanation or theory. If the answers to these questions is “no,” it is likely that the explanation is pseudoscientific.

– Was the scientific method used?
– Were hypotheses constructed and carefully tested?
– Are mechanisms proposed that explain the phenomenon?
– Did statistical methods and analyses provide evidence of patterns or estimates of certainty or is the idea presented as dogma and unchangeable?
– Were alternative explanations considered and evaluated?
– Has the explanation developed and changed over time as new evidence became available?

2.5 Engineering Methods

At this point it may be relevant to introduce the distinction between science and engineering. After all, almost all the medical devices we will discuss in this book have been designed and manufactured by engineers (Fig. 2.10).

It is interesting that the word engineer may be used both as a noun and as a verb. When used as a verb, e.g., “he engineered a solution,” it conveys the idea that someone used their skill, experience, and knowledge to find a more or less perfect answer to some problem. It implies that there was some estimation, guesswork, and trial and error involved. Aren’t these actions consistent with what we believe indigenous and ancient peoples had to do? In fact, this behavior to some degree still characterizes the practice of engineering. The engineering method is “the strategy for causing the best change in a poorly understood situation within the available resources” [14]. Consider some of the famous engineering projects: building the Suez canal, tunneling under the English channel to provide a train link between England and France, and the man into space program. All these problems were initially poorly defined, the resources that would be needed had not been accurately estimated, the length of time needed to achieve the goal was unknown, and the side effects of achieving the goal could not be imagined. President John F. Kennedy called for the USA to land a man on the moon within 10 years, but no one at the time had any idea of how to do that exactly. Also, the materials, electronic components, and available resources all changed throughout the duration of the project. Engineers solved that

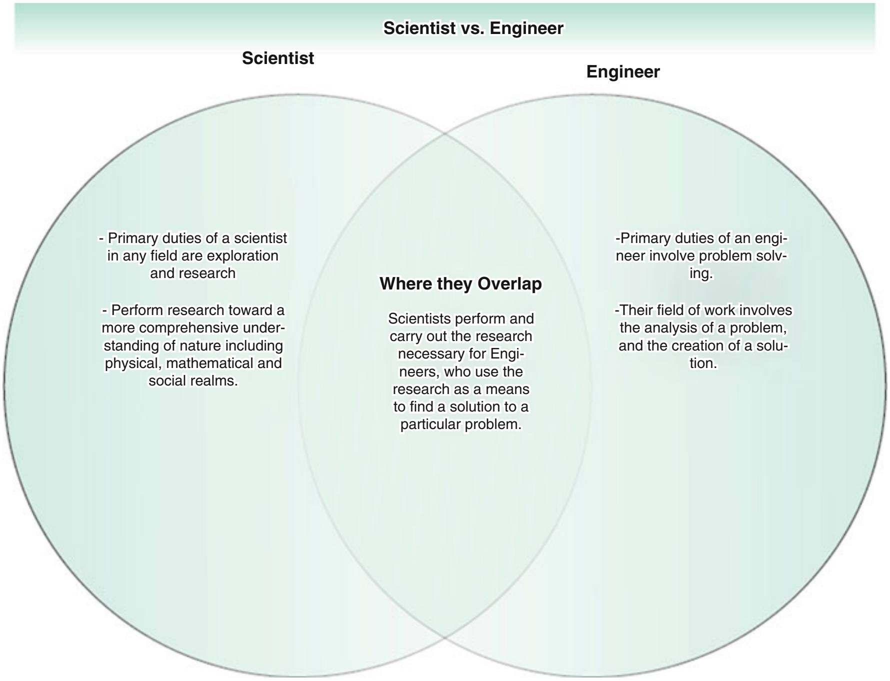

Fig. 2.10 Scientists and engineers have somewhat different perspectives and interests, but their work is complementary

problem, because seeking the best solution while surrounded by uncertainty and change is the engineer's specialty.

The work of an engineer involves design: a new biomaterial put together from available raw materials, a new type of engine, and a new kind of scaffolding for rebuilding a broken bone. At the outset of all exercises in design, the engineer, or more likely the engineering team, has a sense of how to start or pick up a series of hints as to how to find a solution. They also have a set of tools: equations that describe the behavior of some mechanical or electrical system or software that permits rapid calculations to be made. Recall that scientists proceed to gain new knowledge by thinking of new theories or explanations and conducting experiments to test those theories or hypotheses; engineers also have a set of procedures they follow that are somewhat different from those used by scientists.

Engineers will follow the general principles of first, proposing several design solutions. Then, they will estimate the needed resources and compare with the resources that are available. They will then seek to identify the best estimate design and discard the alternatives, and proceed to solve the problem by successive approximations, getting closer with each attempt. The "weakest link" will be identified, and a safety factor developed that will depend on the confidence in the design, the expected lifetime, and the cost of failure. Everything that is learned in the course of solving the problem will be expressed quantitatively, including graphs, tables, and mathematical equations.

Perhaps now it is clear why the engineering approach is so absolutely useful for solving healthcare problems; they are poorly understood, the outlook for stable resources is dim, and new knowledge is constantly being provided by scientists… exactly the environment familiar to engineers.

2.6 Science and Religion (Nonscience)

Because science is a discipline that depends on evidence and religion mostly relies on belief in the absence of physical evidence, conflicts between science and religion are almost inevitable. On occasion, the conflicts become obvious, particularly during a political race or when curriculum choices for public K through 12 education are being debated. In recent years, a good example of the different approach to teaching science offered by strict religious followers has been the discussion about the teaching of theory of evolution versus creationism (a variety of creationism is called "intelligent design"). In general, the followers of creationism believe that the origin of the universe is due to a Creator (or "intelligent designer"), that the theory of evolution is inadequate in explaining the variety of life forms on our planet, that adaptive change only occurs within tightly defined limits, that apes and human do not share a common ancestor, and that the earth is between 6,000 and 10,000 years old. In North, Central, and South America and in Western Europe, these beliefs correspond to a literal interpretation of the Judaeo–Christian bible. Most adherents of orthodox Islam also believe that the origin of the universe is due to a Creator and that apes and humans do not share a common ancestor. However, followers of other religions, e.g., Hinduism, often have radically different views of the origins of the world.

The arguments proposed by creationists include suggestions that creationism is actually more aligned with the requirements of science than is evolution; for example, if evolution is valid, why can't we observe event or processes that support it? Why are there gaps in the fossil record that could show us the transitional species predicted by evolution? Is not the wealth of species and nature observable to us today not a commonsense affirmation of a sublime and powerful Creator? Isn't evolution just a theory anyway?

Let's examine some of these arguments. Taking the last one first, it is a common mistake for nonscientists to minimize the amount of supporting data, other theories, and logic required for a hypothesis to rise to the level of a theory. Scientists, as we have already discussed, are inherently skeptical, argumentative, and tentative and would never claim that a theory has been proven true once and for all. Rather, they argue that the overwhelming weight of available evidence and the interpretation of that evidence support the present formulation of the theory, *until proven otherwise*. Scientists regard this attitude with pride, not as evidence of weakness.

The issue of the missing fossil record is due to a fundamental misunderstanding of the evolutionary theory. Creationists note that the fossils for "missing link," the jump between apelike and man, have not been found. Evolutionary biologists

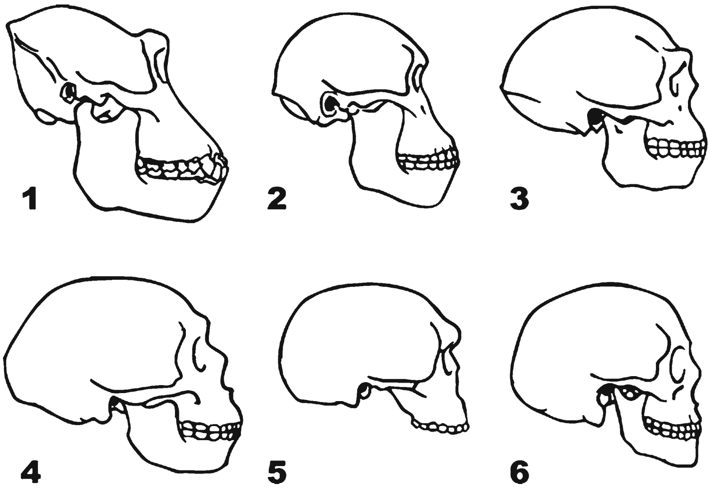

Fig. 2.11 Reconstructions of human skull development with time based on the fossil record

respond by emphasizing that evolution progresses not up a ladder with distinct steps, but rather with many branches splitting off, and species sharing a common ancestor (i.e., man and ape) have gone on along different branches. Also, the conditions for fossil preservation are not easily met. Consider how many hundreds of millions of animals have inhabited our planet; should we not be inundated with fossils if it were that easy to preserve a fossil? The large number of animals that lived in muddy environments, and whose bones were covered and preserved in sediment, are most likely to leave us with fossils, and in addition humans did not live in such environment, and there were few of them to leave a fossil record. However, we have been able to find skulls and other bones of the ancestors of present-day mankind, and those fossils have been used to construct a map of how we evolved (Fig. 2.11).

It turns out that we can in fact observe processes that are indicative of evolution, which is after all a theory stating that the organisms who survive are those best adapted to the environment. A survey of animals on isolated islands, e.g., the Galapagos and others, will show that individual islands are populated by a very non-diverse number of species, all surviving because they are well adapted to their environment. The larger the island, and the greater the variety of habitat, the larger the diversity of species. The ability to analyze DNA has now clearly shown that many genetic mutations have spread in the last few thousand years and have changed the way people digest food, store fat, grow hair, and fight disease. Examining the physiology of Tibetans living at higher elevations, for example, shows that some Tibetans have much greater oxygen-carrying ability in their blood than others and that women with this ability had more surviving children than women with lower oxygen-carrying ability. Therefore, evolution favors those better at surviving a low-oxygen environment in the Himalayan mountains. We have all heard about bacteria that have mutated and are able to resist antibiotics; evolution explains that bacteria able to adapt to antibiotics survive and pass on that characteristic to their progeny, while those bacteria unable to withstand antibiotic challenge die off.

Although some creationists abide by a strict interpretation of the Judaeo–Christian bible, believing that the Creator had completed work within 6 days and the world is only a few thousand years old, others have an amended philosophy called intelligent design (ID). Unlike creationists, proponents of ID do not dismiss radioactive carbon dating (used to establish that many fossils are millions of years old) as a trick, accept the age of the earth as being approximately 4.5 billion years, agree that some evolution occurs, and that natural selection has a role in determining which species survive and transmittal of successful traits. However, they argue that all this is evidence of the intervention and participation by a Creator, not simply evolutionary biology. Nevertheless, ID is inconsistent with our current scientific understanding of the natural world on a number of fundamental issues, including the central role of randomness in natural evolution, and has been declared as a variation of creationist conjecture by the US federal courts.

This is not to suggest that religious belief is necessarily incompatible with scientific method. There have been many active, prominent scientists who were devout Christians and practiced both their faith and profession without apparent contradiction. Francis Collins (director of the National Institutes of Health), William Phillips (corecipient of the 1997 Nobel Prize for Physics), and most interestingly Georges Lemaitre (Belgian priest who proposed the Big Bang Theory) are just some examples. Peter Higgs, the physicist who predicted the existence of a subatomic particle now called the Higgs boson and a nonbeliever himself, has been quoted as saying that:

> The growth of our understanding of the world through science weakens some of the motivation which makes people believers. But that's not the same as saying they're incompatible. It's just that I think some of the traditional reasons for belief, going back thousands of years, are rather undermined.…Anybody who is convinced but not a dogmatic believer can continue to hold his belief [15].

Should creationists and proponents of intelligent design be allowed to have their own opinion? Yes, of course; and if they wish, they should discuss it and attempt to convince others that their view is correct. Should creationism and intelligent design be taught as and considered to be as scientifically and objectively valid as evolution? No, of course not! Those beliefs do not rise to the standard demanded of science. They have no research agenda, because anything not explainable is ascribed to a supernatural authority. Creationism and intelligent design do not propose new research, nor are they capable of modification or falsifiable as new knowledge is uncovered. These attitudes seek to overturn accepted explanations of natural events rather than changing their own underlying principles.

The argument over what (creationism vs. evolution) can or should be taught in public schools has been played out in the courts in the USA. In 1925, the State of Tennessee sued a high school teacher named John Thomas Scopes for violating the state's Butler act, which made it illegal to teach evolution in schools. The Scopes trial was sensational and followed by newspapers from all parts of the USA. Scopes was found guilty and fined $100, but the conviction was later overturned on a technicality. A movie "Inherit the Wind" was made about the Scopes trial.

In approximately ten subsequent law cases, in states ranging from Arkansas to California to Louisiana to Minnesota to Pennsylvania, the courts have consistently ruled that the state may not require that teaching be tailored to the principles of a particular religion, that teaching evolution does not limit the free exercise of religion, that a "balanced treatment" teaching both evolution and creationism was not constitutional, that a school district may prohibit a teacher from teaching creationism as science, and that teachers could not be told to read a disclaimer before teaching about evolution. In the most recent case in 2005 in York County Pennsylvania, the judge ruled that the school district's attempt to maintain an "intelligent design" teaching policy in the schools was unconstitutional.

2.7 Science and Politics

Just as science topics sometimes run afoul of strict religious doctrines, so do politicians on occasion decide that scientific opinions conflict with political or economic necessity. It is sometimes believed that this occurs because few scientists or scientifically trained individuals choose to run for political office. And it is true that there are very few practicing scientists in the US Congress; in 2011, there was 1 physicist, 1 chemist, 1 microbiologist, 6 engineers, and 22 people with medical training among the 435 members of the House of Representatives. As has been mentioned once already, in the 2012 presidential campaign, there were no scientific policy issues questioned or debated.

On the other hand, having a certain background is no guarantee of being open to scientific ways of thinking. In 2012, representative Paul Broun of Georgia, who is a physician, referred to evolution, embryology, and the Big Bang Theory as all coming "straight from the pit of Hell" [16]. Congressman Akins from Missouri (another member of the House Science and Technology Policy Committee at the time the statement was made) stated in the summer of 2012 that women who are raped cannot get pregnant and that therefore rape should not be grounds for abortion; his belief in the immorality of abortion probably influenced him to make a groundless and false statement about a scientific issue.

In 2009, there was a terrible earthquake in L'Aquila, Italy, as a result of which one small village was devastated and 297 people died. Italian seismologists had warned that the town lay on a fault line, and tremors were felt in the days prior to the main earthquake. The scientists stated in the days before the earthquake that a major earthquake was unlikely, but did not discount the possibility. In 2012, the scientists were put on trial for being "falsely reassuring," convicted, and sentenced to 6 years in jail [17]. It appeared that the local government was trying to find a scapegoat for the disorganized renovation efforts following the earthquake, because given the state of the art in earthquake science, no one is capable of predicting the magnitude of an earthquake!

President George W. Bush instituted a program called the President's Emergency Plan for AIDS Relief (PEPFAR), identifying $15 billion to be spent in 2003–2008 to combat the spread of AIDS primarily in Africa. However, because of the influence of Christian conservatives, the legislation creating PEPFAR included the mandatory provision that none of the money would go to charitable groups that enable abortion. Unfortunately, because many charitable groups include contraception, birth control, and abortion counseling among their activities, they could not be funded, in part because the PEPFAR program promotes abstinence as a birth control and HIV control measure. Although portions of these provisions were repealed in 2009 by President Obama, confusion still exists among the many charitable organizations working in Africa, with the result that they do not apply for funding.

The junior senator from Florida, Marco Rubio, identified by some political pundits as a potential nominee for president by the Republican Party for the 2016, was asked in an interview how old he thought the earth is (Senator Rubio is also a member of the Senate's committee on Science and Transportation). He answered by stating that he was not qualified to answer that question because he was not a scientist, that it was one of the great mysteries, and that it is currently a dispute among theologians [18]. What sort of worldview does this influential and potentially powerful political figure have if he states that the age of the earth is a theological question? Is it not a scientific question that has been settled a long time ago?

These examples of political influence on issues that ought to be discussed and decided based on evidence suggest that American voters should insist that candidates for political office should clearly express their views on issues such as teaching evolution and climate change so that the public can judge the suitability of these candidate for becoming policy makers. Of course, American voters themselves should also be better educated about science and public policy or at least apply scientific reasoning skills to complex problems.

2.8 Scientifically Based Arguments

It is likely that you will witness arguments on scientific topics, whether it be on television news covering political or school board meetings, at the supermarket when debating the safety of genetically engineered foods, or at the preschool when parents discuss the pros and cons of immunization.

To illustrate how disagreements may be settled in a rational and scientific manner, let's consider climate change, a topic that is currently controversial. Essentially, the argument is between those who claim that the earth's climate is showing signs of warming and that greenhouse gas emissions resulting from human activity significantly contribute to this trend and those who tend to dismiss such claims as alarmist, deny the trend, or attribute the trend to natural causes. How should this question be argued?

The first structure of an argument is the claim. At this time, in 2012, all relevant international scientific bodies agree that there is a significant man-made contribution to global warming. Parenthetically, it should be noted that the USA and China, who are the largest producers of greenhouse gases, do not view the potential damage caused by global warming as seriously as do other nations in Western Europe, India, and Japan. Various groups affiliated with carbon energy producers (e.g., large oil companies) make the claim that there is no global warming and that, even if there is such warming, industrial processes play no role in that process.

The next step in constructing an argument is to present data, i.e., evidence in support of the claim. Evidence cited by deniers of climate change includes indications that global warming has not occurred over the past 10 years, that the warming that has occurred over the past 22 years is smaller than predicted by current models, and that the carbon dioxide emitted by fossil-fuel burning industry is not a pollutant but is in fact good for agriculture. Scientists have been accused of colluding to alarm the public because they obtain grants to study the phenomenon and deniers of climate change also claim that some government bureaucrats wish to use the fear of global warming as an excuse to raise taxes.

On the opposite side of the argument, scientists show data that the polar ice caps are shrinking, land surface air temperature is increasing, sea surface temperatures (measured since 1850) are increasing, air temperature over oceans is increasing, ocean heat content is increasing, the sea level is rising, the increased carbon dioxide levels is acidifying the oceans, specific humidity is increasing, and for more than 19 consecutive years, there has been a loss of ice from glaciers worldwide.

After data are presented, a scientific argument will proceed to a step called a “warrant” that explains or justifies the relationship between the data and the claim. Global warming naysayers point to the discrepancies between models of climate change and actual changes in temperature, suggesting that the models are erroneous. However, we don’t know if the discrepancy falls within the margin of error permitted by the model. The naysayers also point out the “positive” aspects of global warming, i.e., that additional carbon dioxide released to the atmosphere will allow more plant life, and the nations that have affordable energy from fossil fuel are more prosperous than those without.

In order to still better examine the data and conclusions drawn, we proceed to the “qualifier” portion of the scientific argument to help us decide if the conclusions are reliable. Unfortunately, within the context of this book, we cannot examine in detail the data themselves, nor read the very large body of literature published in this area.

Instead, we will turn to the “backing” for the argument, where we examine additional assumptions that support the validity of the argument. It turns out that most of the folks who publically denounce global warming as a hoax are not climate scientists. Although an opinion piece on January 27, 2012 published in the Wall Street Journal disputing the evidence for man-made global warming was signed by 16 scientists, it was later pointed out that the signers had no expertise in climate science, that two had once to worked for Exxon, and that six others worked for think tanks funded by industries including Exxon. Subsequently, on February 1, 2012, the Wall Street Journal published a letter by 40 other scientists including prominent climate change experts who pointed out that 97 % of researchers who actively publish on climate science agree that climate change is real.

So we may summarize as follows: the consensus of the scientific community as expressed in the opinion of scientific societies and national academies of sciences in developed countries is that global warming is occurring and that the man-made contribution is significant, that there are some discrepancies between the exact predictions of the computer models used to predict global warming and the measured temperatures, and that the majority of the folks arguing that global warming is a hoax publish in venues affiliated with politically conservative opinions and have a high probability of being affiliated with fossil-fuel producing industry. Similar to arguments put forward by creationists, a favorite strategy used by climate change doubters to equate the validity of both sides of the climate change debate (e.g., great majority of climate scientists on one side, a few scientists, and many business leaders on the other) is to portray the issue as "controversial" and one where there is still "doubt" about the extent (if any) of climate change. These references to controversy and doubt are meant to imply that perhaps the majority of scientists are wrong, and so it would not be prudent to act on their recommendations to reduce carbon emissions.

This systematic approach, i.e., of claim, data, warrant, qualifier, backing, and rebuttal, is the preferred method by which consensus is arrived in science. It should be readily apparent that the discussions (not just the climate) can get pretty heated on these issues!

2.9 Analyzing Pseudoscientific Claims

Let's now return to the questions asked at the beginning of this chapter.

Should you live a chemical-free life? Impossible, we are made of chemicals, we eat and breed chemicals, and we live in a world made of chemicals. Maybe you should live a synthetic chemical-free life? That has become increasingly difficult since the dawn of civilization. After all, almost everything we wear, material we use for shelter, and even our food contain synthetic components. And, most synthetic materials are perfectly safe when taken properly (e.g., artificial food coloring, artificial flavoring, anticaking additives), and some natural products are not to be consumed under any circumstance (e.g., poisonous mushrooms). As we discuss in Chap. 10, when it comes to toxins, it is all a matter of the type and concentration. In most cases our bodies can safely deal with low concentrations of most synthetic or natural compounds; higher concentrations can be harmful.

Does eating seeds provide a maximum benefit? In order for this to be true, our body would have to be able to process the raw materials in seeds in the same way that the growing plant does. The plant harnesses sunlight, water, and nutrients from the soil that are important catalysts that enable a seed to transform into a healthy and nutritious food for humans.

> Remember that dietary supplements are not regulated by the FDA, so folks who might have a financial interest in selling such supplements are free to claim all sorts of benefits without having to prove any of them! The marketing schemes are subtle and usually involve a bit of truth and a bit of science. For example, a statement can be made that "studies have shown that ingredients found in this supplement boost the immune system." Analysis of this statement would start by first asking about the study: who conducted it, what was the form in which the ingredient was provided, who were the subjects, what were the controls, and was the study replicated by others. And even if the ingredient "boosts" the immune system, that is a long way from being certain that the amount and the form of that ingredient in the supplement will be effective; chances are there are no studies supporting that exact supplement.

Furthermore, just because an ingredient found in a supplement is beneficial, what's to say that more of that ingredient in your diet will be more beneficial? The human body maintains itself in "homeostasis," a kind of equilibrium that balances all the complicated biochemical processes occurring in the body in the liver, kidneys, neural system, etc. A disturbance to that equilibrium (e.g., eating too much cabbage because it contains iron and sulfur, both ingredients that the body requires) will produce well-known and unpleasant gastric effects as the body seeks to expel the excess ingredients.

How about dietary supplements that contain plenty of antioxidants? Here's where the bit of truthful science gets in: free radicals damage DNA; this is of course bad, so eating foods with plenty of antioxidants may reduce the amount of free radicals if the body absorbs this extra amount of free radicals. Of course…free radicals are also involved in killing harmful bacteria in your body; still sure you want to get rid of them?

Antioxidants are found in fresh leafy green vegetables, and it's been found that folks who have a diet rich in such vegetables are usually in better health than those who do not. Is this adequate proof of the value of antioxidants? Here is where the issue of "confounding variables" comes in. It turns out that the folks who eat lots of fresh vegetables are typically better well-off, which implies that their overall diet is better balanced and their economic situation allows them to obtain regular healthcare. Their lives are also probably less stressful than the lives of poor people, who often do not have local sources of fresh vegetables or access to regular healthcare. In this case, therefore, all these other variables (economic status, healthcare, reduced stress) are likely to influence the state of health, and in this way they confound the simplistic interpretation that a green leafy diet alone is responsible for improved health because it eliminates free radicals. To further add to the potential confusion, it is rare that all the studies ever done on dietary ingredients agree with each other.

Use proteins or other natural ingredients in skin creams because these go into your bloodstream? In order for this to be true, the ingredients have to be able to penetrate the skin and tunnel through the walls of veins or arteries to enter the bloodstream. As discussed in Chap. 10 on Targeted Drug Delivery, only particles with low molecular weight and high lipophilicity can be absorbed into the blood stream by transdermal delivery. In fact the size of collagen and related molecules are large enough to prevent them from penetrating the skin; they simply lie on top. If the collagen is able to entrap some water, this can benefit the skin by preventing it from dehydrating. However, petroleum jelly (Vaseline™) is even better at preventing dehydration.

What are the magical ingredients of face creams? First, they often contain a vegetable protein (aloe vera, cucumber extract, etc.). The molecules that make up proteins are often long chains of different atoms bonded together, and they do not penetrate the skin. Instead, they lie on top of the skin, and as the moisture in the cream evaporates, the protein molecules shrink: that's how they produce that pleasing tightening effect on the skin, and in the process skin wrinkles are pulled together yielding a smoother complexion.

What about substances that are claimed to revitalize or rejuvenate or stimulate collagen production? It is true that collagen is important; after all, collagen accounts for about 25 % of all the protein in the human body. So, does it seem that your body would need help in making more collagen if it has already produced so much of it? Not likely, and the substances in facial creams have no route by which they would be incorporated into the cells that make collagen.

Vitamins, particularly vitamins A and D, are also found in facial cosmetics. Unfortunately, the amount of these vitamins it would take to do your skin any good would not be tolerated by your body [13]. Vitamin A, also known as retinol, may be found in amounts up to 2.5 % in facial creams. It is important to note that the acne-fighting ingredient retinoic acid is *not* the same thing as retinol or Vitamin A.

Other ingredients include waxes or oils. Their functions include serving as a vehicle for the fragrances, colorants, and ingredients discussed above, but they also have the important task of protecting skin from loss of moisture (drying out). One of the most effective moisture barriers is petroleum jelly, but the greasy feel of this substance makes it unpopular for direct use.

Avoid immunization because it introduces diseases into your baby's body. It is true that immunization sometimes introduces the viruses or proteins from these viruses that cause disease into the body; however, these viruses have been treated to render them very weak or more often ineffective. They still retain enough of their original character to stimulate the body to create antibodies, so that the organism will be prepared in the event of later contact with a full-strength virus. Also, even babies have an active immune system provided to them free of charge by their mothers. And while we're on this topic, there is a lot of publicity today about the "link" between immunization and autism. Some young parents are fearful of immunizing their infants against measles, mumps, and rubella (the MMR vaccine) because of a report in 1998 appearing in the UK claiming that the vaccine irritated the bowel and permitted harmful proteins to enter the blood stream and damage the brain. Fortunately, the scientific process we've been discussing took over, and when other researchers could not replicate the experimental results, the report and its author (Dr. Wakefield) were scrutinized even more closely. It turned out that his research was funded by lawyers seeking evidence to use in court cases against vaccine manufacturers and he had not disclosed this conflict of interest. He was permanently barred from practicing medicine in the UK, and the original article was retracted in 2010.

Stop feeding animals chemicals and growth stimulants because these are responsible for increasing cancer rates in humans? The rise in incidence of cancer is primarily a result of the gradual aging of the population. Cancer is typically an older person's disease, so if the percentage of the population that is older is increasing, so too is the cancer rate. There is a relationship between food and cancer to be sure, but that relationship has to do with overeating; obesity is associated with increased risks of cancer of the esophagus, breast (in postmenopausal women), endometrium (lining of the uterus), colon, rectum kidney, pancreas, thyroid, and gallbladder. So, as the number of people classified as obese increases, so too will the number of people with cancer. By the way, did you know that 35.7 % of adults and 16.9 % of children in the USA are considered to be obese (defined as having a body mass index greater than 30; overweight means having a body mass index between 25 and 30) and that if the present rate of increase continues, by the year 2030, 44 % of all adults will be considered obese? The Centers for Disease Control projects that this rise in obesity will result in as many as 7.9 million new cases of diabetes/year (compared to 1.9 million/year in 2012) and 6.8 million new cases of chronic heart disease and stroke/year, all adding $66 billion in annual medical costs.

What do you think: perhaps the most effective healthcare cost controls we can implement would be those targeting harmful behavior; if so, perhaps some of the money spent on new technology should be diverted to research on how to change people's behavior.

Table 2.1 provides a handy way of calculating your body mass index. Maintaining a normal weight by paying attention to diet may be the single most effective way (rather than use of dietary supplements) the normal individual can minimize the risk of developing illnesses such as diabetes and heart disease.

Should we avoid eating foods grown using pesticides and other additives? There is certainly nothing wrong with eating foods not grown with pesticides, but if we were to do that universally, then our food choices in the supermarket would be dramatically reduced. First, the amount of "quality" fruits and vegetables would be lowered, because many more of these items would have perished from insect pests. Second, because some additives are used to delay ripening, the available foodstuffs would have to be sourced locally, because transporting mature fruits and vegetables to the table prior to them spoiling would be difficult or impossible. Third, the additives used have been extensively studied and shown to be safe. The environmental concerns over the use of pesticides may be valid but is outside the scope of our discussion. But a related topic is the use of radiation to destroy food-borne bacteria.

> Treating food with ionizing radiation (e.g., gamma or X-ray radiation) from a small reactor has the advantage of killing bacteria, viruses, and insects that could be dangerous to humans. Every year there are reports of salmonella (a bacterium found in animal feces) poisoning that kills people consuming raw vegetables that have not been properly washed or contaminated eggs that were consumed partially uncooked. Each year, more than 300,000 people in the USA become ill from food-borne illnesses. Irradiating food would provide a more secure way of distributing non-contaminated food. Low radiation doses are used to inhibit ripening; medium doses reduce the numbers of harmful bacteria (salmonella, *E. coli*, campylobacter) in meat, poultry, and seafood; and high doses are able to sterilize packaged meat, poultry, and their products.
>
> Would you purchase and consume irradiated food? In the USA, supermarkets now stock imported foods such as fruit, spinach, flour, spices, and ground meat that have been irradiated. Although food irradiation is permitted by 50 countries, the types of food which may be treated vary from country to country. Evidence has been collected by the Food and Drug Administration for more than 40 years, and no danger to the consumer from irradiated foods has been identified.

So, when you hear claims being made that sound a bit funny or hard to believe, go ahead and exercise your brain a bit. Look into the evidence, the source of the evidence, and the type of "study" that might have been done to support the claim; does someone stand to make a profit if you believe the claim? And if you're still not sure, go ahead and ask some tough questions; you might be surprised at the answer, and it will give you all the information you need (Fig. 2.12).

Table 2.1 A way of calculating the body mass index (BMI) to estimate if an individual may be classified as obese

	Normal						Overweight					Obese										Extreme obesity		
BMI	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42
Height (ft-in.)	Weight (pounds)																							
4′10″	91	96	100	105	110	115	119	124	129	134	138	143	148	153	158	162	167	172	177	181	186	191	196	201
4′11″	94	99	104	109	114	119	124	128	133	138	143	148	153	158	163	168	173	178	183	188	193	198	203	208
5′00″	97	102	107	112	118	123	128	133	138	143	148	153	158	163	168	174	179	184	189	194	199	204	209	215
5′01″	100	106	111	116	122	127	132	137	143	148	153	158	164	169	174	180	185	190	195	201	206	211	217	222
5′02″	104	109	115	120	126	131	136	142	147	153	158	164	169	175	180	185	191	196	202	207	213	218	224	229
5′03″	107	112	118	124	130	135	141	146	152	158	163	169	174	180	186	191	197	203	208	214	220	225	231	237
5′04″	110	116	122	128	134	140	145	151	157	163	169	175	180	186	191	197	204	209	215	221	227	232	238	244
5′05″	114	120	126	132	138	144	150	156	162	168	174	180	186	192	198	204	210	216	222	228	234	240	246	252
5′06″	118	124	130	136	142	148	155	161	167	173	179	186	192	198	204	211	216	223	229	235	241	247	253	260
5′07″	121	127	134	140	146	153	159	166	172	178	185	191	198	204	211	217	223	230	236	242	249	255	261	268
5′08″	125	131	138	144	151	158	164	171	177	184	190	197	204	211	217	223	230	236	243	249	256	262	269	276
5′09″	128	135	142	149	155	162	169	176	182	189	196	203	210	216	223	230	236	243	250	257	263	270	277	284
5′10″	132	139	146	153	160	167	174	181	188	196	202	209	216	223	230	236	243	250	257	264	271	278	285	292
5′11″	136	143	150	157	165	172	179	186	193	200	208	215	222	229	236	243	250	257	265	272	279	286	293	301
6′00″	140	147	154	162	169	177	184	191	199	206	213	221	228	235	242	250	258	265	272	279	287	294	302	309
6′01″	144	151	159	166	174	182	189	197	204	212	219	227	235	242	250	257	265	276	280	288	295	302	310	318
6′02″	148	155	163	171	179	186	194	202	210	218	226	233	241	249	256	264	272	280	287	295	303	311	319	326
6′03″	152	160	168	176	184	192	200	208	216	224	232	240	248	256	264	272	279	287	296	303	311	319	327	335
6′04″	156	164	172	180	189	197	205	213	221	230	238	246	256	264	272	279	287	295	304	312	320	328	336	344

Fig. 2.12 For some reason, folks often want to believe bizarre explanations (e.g., aliens, ghosts, conspiracies) rather than assuming there is a logical and physical explanation that can be found with a little probing

2.10 Summary

Any impartial observer will admit that scientists and engineers continually discover and invent new tools that improve and influence the daily lives of humans. It is likely, given the large number of scientists and engineers being trained in developing countries and the ease with which new knowledge is distributed over the Internet, that the pace of discovery and change will increase. Employment opportunities will arise not only for folks who are practitioners of science and technology, but also for those capable of understanding and utilizing innovations in original ways. Industrialization, made possible by implementing technology, is still the best hope for the poor masses in parts of Asia, Africa, South America, and the Middle East to rise out of poverty.

The daily impact of science and technology is felt in the foods and medicines we consume, the jobs we gain (or lose), the waste we create, and medical care we receive. Scientists and engineers are thinking ahead; as C.P. Snow said, they "have the future in their bones"! Society benefits greatly from encouraging debate and dialogue, without any one particular authority prevailing in all arguments. In other words, we need informed and rational consumers and political leaders who can balance the enthusiasm of scientists and engineers with broader societal concerns. We hope that you will be such informed consumers and citizens!

2.11 Foundational Concepts

- Scientists and engineers are often perceived as "geeks" who know little about the "real" world, and their opinions on everyday matters may not be taken seriously. The popular press often misrepresents scientific findings in the interest of attention-grabbing headlines.
- The way science is done in real life, with creativity, argument, reappraisal, and uncertainty, is different from the way science is taught in school; perhaps that's why so many students don't go on to careers in science.
- The scientific method is a rigorous template for arriving at an explanation for observable natural phenomena. It relies on a fundamental knowledge base, creativity and curiosity, posing hypotheses, experimentation, data analysis, and, perhaps most important, close scrutiny by other scientists.
- Great scientists make great discoveries because of novel and intuitive explanations of well-conducted observations.
- Science is often self-correcting, because of the peer-review system in place for reviewing research proposals and publications.
- Theories are statements and explanations of phenomena made on the basis of a commonly accepted best explanation of observed phenomena; they may be changed when new observations are made or when a better-fitting explanation is provided. Laws are mathematical formulations that describe how events occur, but do not explain those events.
- There is a disproportionate amount of males in science and engineering when compared with females, and this may be the result of gender bias and other cultural factors.
- Scientists are human and are capable of bias in interpreting the results of experiments. That is why the peer-review process is so important, because it can identify this type of bias.
- Pseudoscientific claims are *not* peer reviewed and may also be distinguished from science by a lack of replicated studies, vague or nonexistent experimental design, no control groups, and fuzzy logic.
- Engineers work to provide best solutions to problems in the absence of much needed information and use successive approximations to arrive at an answer.
- Science deals with observable, verifiable, repeatable phenomena; religion relies on other-wordly explanations that cannot be tested or evaluated and has no peer-review system.
- Some politicians are strangely reluctant to base policy decisions on scientific information.
- Scientific arguments must be grounded in factual data. The strength of a scientific view or position may often be evaluated by considering the quality and objectivity of supporting data.

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