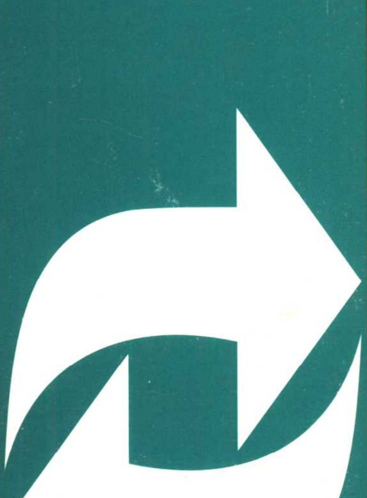
Taking SIDES

Clashing Views on Controversial Issues in Science, Technology, and Society



Thomas A. Easton

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Clashing Views on Controversial Issues in Science, Technology, and Society

Edited, Selected, and with Introductions by

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PREFACE

Those who must deal with scientific and technological issues—scientists, politicians, sociologists, business managers, and anyone who is concerned about a neighborhood dump or power plant, government intrusiveness, expensive space programs, or the morality of medical research, among many other issues—must be able to consider, evaluate, and choose among alternatives. Making choices is an essential aspect of the scientific method. It is also an inescapable feature of every public debate over a scientific or technological issue, for there can be no debate if there are no alternatives.

The ability to evaluate and to select among alternatives—as well as to know when the data do not permit selection—is called critical thinking. It is essential not only in science and technology but in every other aspect of life as well. *Taking Sides: Clashing Views on Controversial Issues in Science, Technology, and Society* is designed to stimulate and cultivate this ability by holding up for consideration 19 issues that have provoked substantial debate. Each of these issues has at least two sides, usually more. However, each issue is expressed in terms of a single question in order to draw the lines of debate more clearly. The ideas and answers that emerge from the clash of opposing points of view should be more complex than those offered by the students before the reading assignment.

The issues in this book were chosen because they are currently of particular concern to both science and society. They touch on the nature of science and research, the relationship between science and society, the uses of technology, and the potential threats that technological advances can pose to human survival. And they come from a variety of fields, including computer and space science, biology, environmentalism, law enforcement, and public health.

Organization of the book For each issue, I have provided an *issue introduction,* which provides some historical background and discusses why the issue is important. I then present two selections, one pro and one con, in which the authors make their cases. Each issue concludes with a *postscript* that brings the issue up to date and adds other voices and viewpoints.

Which answer to the issue question—yes or no—is the correct answer? Perhaps neither. Perhaps both. Students should read, think about, and discuss the readings and then come to their own conclusions without letting my or their instructor's opinions (which perhaps show at least some of the time!) dictate theirs. The additional readings mentioned in both the introductions and the postscripts should prove helpful. It is worth stressing that the issues covered in this book are all *live* issues; that is, the debates they represent are active and ongoing.

The list of contributors at the back of this volume provides information about the authors of the 38 selections reprinted in this book.

A word to the instructor An *Instructor's Manual With Test Questions* (multiple-choice and essay) is available through the publisher for the instructor using *Taking Sides* in the classroom. It includes suggestions for stimulating in-class discussion for each issue. A general guidebook, *Using Taking Sides in the Classroom,* which discusses methods and techniques for integrating the pro-con approach into any classroom setting, is also available.

Acknowledgments Of immense assistance in the preparation of this book were Mimi Egan, publisher for the Taking Sides series, and the libraries of the University of Maine at Orono and at Augusta, Colby College, and Thomas College. I am also grateful for the existence of computers, modems, information services, and photocopiers.

Special thanks are due to John Quigg of Thomas College.

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INTRODUCTION

Analyzing Issues in Science and Technology

Thomas A. Easton

INTRODUCTION

As civilization approaches the dawn of the twenty-first century, it cannot escape science and technology. Their fruits—the clothes we wear, the foods we eat, the tools we use—surround us. Science and technology evoke in people both hope and dread for the future, for although new discoveries can lead to cures for diseases and other problems, new insights into the wonders of nature, and new toys (among other things), the past has shown that technological developments can also have unforeseen and terrible consequences.

Those consequences do *not* belong to science, for science is nothing more than a systematic approach to gaining knowledge about the world. Technology is the application of knowledge to accomplish things that otherwise could not be accomplished. Technological developments do not just lead to devices such as hammers, computers, and jet aircraft, but also to management systems, institutions, and even political philosophies. And it is, of course, such *uses* of knowledge that affect people's lives for good and ill.

It cannot be said that the use of technology affects people "for good *or* ill." As Emmanuel Mesthene said in 1969, technology is neither an unalloyed blessing nor an unmitigated curse.[1] Every new technology offers both new benefits and new problems, and the two sorts of consequences cannot be separated from each other. Automobiles, for example, provide rapid, convenient personal transportation, but precisely because of that benefit, they also cause suburban development, urban sprawl, crowded highways, and air pollution.

OPTIMISTS VS. PESSIMISTS

The inescapable pairing of good and bad consequences helps to account for why so many issues of science and technology stir debate in our society. Optimists tend to focus on the benefits of technology and to be confident that society will be able to cope with any problems that arise. Pessimists tend to fear the problems and to believe that the costs of technology will outweigh any possible benefits.

Sometimes the costs of new technologies are immediate and tangible. When new devices fail or new drugs prove to have unforeseen side effects, people can die. Sometimes the costs are less obvious. John McDermott, one of Mesthene's opponents, expressed confidence that technology led to the centralization of power in the hands of an educated elite; to his mind, technology was therefore antidemocratic.[2]

The proponents of technology answer that a machine's failure is a sign that it needs to be fixed, not banned. If a drug has side effects, it may need to be refined, or its list of permitted recipients may have to be better defined (the banned tranquilizer thalidomide, for example, is notorious for causing birth defects when taken early in pregnancy; it is apparently quite safe for men and nonpregnant women). And although several technologies that were developed in the 1960s seemed quite undemocratic at the time, one of them —computers—developed in a very different direction. Early on, computers were huge, expensive machines operated by an elite, but it was not long before they became so small, relatively inexpensive, and "user-friendly" that the general public gained access to them. Proponents lauded this as a true case of technological "power to the people."

CERTAINTY VS. UNCERTAINTY

Another source of debate over science and technology is uncertainty. Science is, by its very nature, uncertain. Its truths are provisional, open to revision.

Unfortunately, people are often told by politicians, religious leaders, and newspaper columnists that truth is certain. By this view, if someone admits uncertainty, then their position can be considered weak and they need not be heeded. This is, of course, an open invitation for demagogues to prey upon people's fears of disaster or side effects (which are always a possibility with new technology) or upon the wish to be told that greenhouse warming and ozone depletion are mere figments of the scientific imagination (they have yet to be proven beyond a doubt).

NATURAL VS. UNNATURAL

Still another source of controversy is rooted in the tendency of new ideas —in science and technology as well as in politics, history, literary criticism, and so on—to clash with preexisting beliefs or values. These clashes become most public when they pit science against religion and "family values." The battle between evolution and creationism, for example, still stirs passions a century and a half after naturalist Charles Darwin first said that human beings had nonhuman predecessors. It is nearly as provocative to some to suggest that homosexuality is a natural variant of human behavior (rather than a conscious choice), or that there might be a genetic component to intelligence or aggressiveness, or that the traditional mode of human reproduction might be supplemented with in vitro fertilization, embryo cloning, surrogate mother arrangements, and even genetic engineering.

Many new developments are rejected as "unnatural." For many people, "natural" means any device or procedure to which they have become accustomed. Very few realize how "unnatural" such seemingly ordinary things as circumcision, horseshoes, and baseball are.

However, humans do embrace change and are forever creating variations on religions, languages, politics, and tools. Innovation is as natural to a person as building dams is to a beaver.

PUBLIC VS. PRIVATE: WHO PAYS, AND WHY?

Finally, conflict frequently arises over the function of science in society. Traditionally, scientists have seen themselves as engaged solely in the pursuit of knowledge, solving the puzzles set before them by nature with little concern for whether or not the solutions to those puzzles might prove helpful to human enterprises such as war, health care, and commerce. Yet, again and again, the solutions discovered by scientists have proved useful—they have even founded entire industries.

Not surprisingly, society has come to expect science to be useful. When asked to fund research, society feels that it has the right to target research on issues of social concern, to demand results of immediate value, and to forbid research it deems dangerous or disruptive. And society's control of the purse strings gives its demands a certain undeniable persuasiveness.

PUBLIC POLICY

The question of how to target research is only one way in which science and technology intersect the realm of public policy. Here the question becomes, How should society allocate its resources in general? Toward education or prisons? Health care or welfare? Research or trade? Encouraging new technologies or cleaning up after old ones? The problem is that money is limited—there is not enough to finance every researcher who proposes to solve some social problem. Faced with competing worthy goals, society must make choices. Society must also run the risk that the choices made will turn out to be foolish.

THE PURPOSE OF THIS BOOK

Is there any prospect that the debates over the proper function of science, the acceptability of new technologies, or the truth of forecasts of disaster will soon fall quiet? Surely not, for some issues will likely never die, and there will always be new issues to debate afresh. (For example, think of the population debate, which has been argued ever since Thomas Malthus's 1789 "Essay on the Principle of Population," and then consider the debate over the manned exploration of space and whether or not it is worthwhile for society to spend resources in this way.)

Since almost all technological controversies will affect the conditions of our daily lives, learning about some of the current controversies and beginning to think critically about them is of great importance if we are to be informed and involved citizens.

Individuals may be able to affect the terms of the inevitable debates by first examining the nature of science and a few of the current controversies over issues of science and technology. After all, if one does not know what science, the scientific mode of thought, and their strengths and limitations are, one cannot think critically and constructively about any issue with a scientific or technological component. Nor can one hope to make informed choices among competing scientific or technological priorities.

WOMEN AND MINORITIES IN SCIENCE

There are some issues in the area of science, technology, and society that, even though they are of vital importance, you will not find directly debated in this volume. An example of such an issue might be, "Should there be more women and minorities in science?" However, this is not a debate because no one seriously responds to this question in the negative. Nonetheless, you should keep such considerations in mind as you read the issues in this book. And you should consider how the problems of discrimination and prejudice (based on race or class or gender) are played out in some of these debates—the debate on the information revolution and the debate on the use of humans as "experimental animals" would be two examples.

Every spring the American Association for the Advancement of Science publishes a special issue of its journal *Science* that deals with women in science. The March 13, 1992, issue dealt with obstacles in women's way. The April 16, 1993, issue dealt with the culture of science; its lead article was "Is There a 'Female Style' in Science?" And the March 11, 1994, issue focused on international comparisons of men and women working in science.

Also, every fall *Science* has a special issue on minorities in science. The November 13, 1992, issue dealt with the "pipeline problem," or the diversion of minority science students into other lines of study and work. And the November 12, 1993, issue focused on expanding minority representation in science careers.

These special issues contain a wealth of statistical information, interviews, and analyses invaluable to anyone considering whether or not to pursue a career in science. There are also, of course, vast amounts of other material available. See, for example, *Women's Work: Choice, Chance or Socialization? Insights from Psychologists and Other Researchers,* by Nancy Johnson Smith and Sylva K. Leduc (Detselig Enterprises, 1992).

THE SOUL OF SCIENCE

The standard picture of science—a world of observations, hypotheses, experiments, theories, sterile white coats, laboratories, and cold, unfeeling logic—is a myth. This image has more to do with the way science is presented by both scientists and the media than with the way scientists actually perform their work. In practice, scientists are often less orderly, less logical, and more prone to very human conflicts of personality than most people suspect.

The myth remains because it helps to organize science. It provides labels and a framework for what a scientist does; it may thus be especially valuable to student scientists who are still learning the ropes. In addition, the image embodies certain important ideals of scientific thought. These ideals make the scientific approach the most powerful and reliable guide to truth about the world that human beings have yet devised.

THE IDEALS OF SCIENCE: SKEPTICISM, COMMUNICATION, AND REPRODUCIBILITY

The soul of science is a very simple idea: *Check it out.* Years ago, scholars believed that speaking the truth simply required prefacing a statement with "According to" and some ancient authority, such as Aristotle, or a holy text, such as the Bible. If someone with a suitably illustrious reputation had once said something was so, it was so.

This attitude is the opposite of everything that modern science stands for. Scientific knowledge is based not on authority but on reality. Scientists take nothing on faith; they are *skeptical.* When a scientist wants to know something, he or she does not look it up in the library or take another's word for it. Scientists go into the laboratory, or the forest, or the desert—wherever they can find the phenomena they wish to know about—and they "ask" those phenomena directly. They look for answers in nature. And if they think they know the answer already, it is not of books that they ask, "Are we right?" but of nature. This is the point of scientific experiments—they are how scientists ask nature whether or not their ideas check out.

The concept of "check it out" is, however, an ideal. No one can possibly check everything out for himself or herself. Even scientists, in practice, look up information in books and rely on authorities. But the authorities they rely on are other scientists who have studied nature and reported what they learned. And, in principle, everything those authorities report can be checked. Experiments performed in the lab or in the field can be repeated. New theoretical or computer models can be designed. Information that is in the books can be confirmed.

In fact, a good part of the "scientific method" is designed to make it possible for any scientist's findings or conclusions to be confirmed. For example, scientists do not say, "Vitamin D is essential for strong bones. Believe me. I know." They say, "I know that vitamin D is essential for proper bone formation because I raised rats without vitamin D in their diet, and their bones became soft and crooked. When I gave them vitamin D, their bones hardened and straightened. Here is the kind of rat I used, the kind of food I fed them, the amount of vitamin D I gave them. Go and do likewise, and you will see what I saw."

Communication is therefore an essential part of modern science. That is, in order to function as a scientist, you must not keep secrets. You must tell others not just what you have learned but how you learned it. You must spell out your methods in enough detail to let others repeat your work.

Scientific knowledge is thus *reproducible* knowledge. Strictly speaking, if a person says, "I can see it, but you cannot," that person is not a scientist. Scientific knowledge exists for everyone. Anyone who takes the time to learn the proper techniques can confirm any scientific finding.

THE STANDARD MODEL OF THE SCIENTIFIC METHOD

As it is usually presented, the scientific method has five major components: *observation*, *generalization* (identifying a pattern), stating a *hypothesis* (a tentative extension of the pattern or explanation for why the pattern exists), *experimentation* (testing that explanation), and *communication* of the test results to other members of the scientific community, usually by publishing the findings. How each of these components contributes to the scientific method is discussed below.

Observation

The basic units of science—and the only real facts that the scientist knows—are the individual *observations*. Using them, scientists look for patterns, suggest explanations, and devise tests for their ideas. Observations can be casual or they may be more deliberate.

Generalization

After making observations, a scientist tries to discern a pattern among them. A statement of such a pattern is a *generalization*. Cautious experimenters do not jump to conclusions. When they think they see a pattern, they often make a few more observations just to be sure the pattern holds up. This practice of strengthening or confirming findings by replicating them is a very important part of the scientific process.

The Hypothesis

A tentative explanation suggesting why a particular pattern exists is called a *hypothesis*. The mark of a good hypothesis is that it is *testable*. But there is no way to test a guess about past events and patterns and to be sure of absolute truth in the results, so a simple, direct hypothesis is needed. The scientist says, in effect, "I have an idea that X is true. I cannot test X easily or reliably. But if X *is* true, then so is Y. And I can test Y." Unfortunately, tests can fail even when the hypothesis is perfectly correct.

Many philosophers of science insist on *falsification* as a crucial aspect of the scientific method. That is, when a test of a hypothesis shows the hypothesis to be false, the hypothesis must be rejected and replaced with another. This is not to be confused with the falsification, or misrepresentation, of research data and results, which is a form of scientific misconduct.

In terms of the X and Y hypotheses mentioned above, if it has been found that Y is not true, can we say that X is false too? Perhaps, but bear in mind that X was not tested. Y was tested, and Y is the hypothesis that the idea of falsification says must be replaced, perhaps with hypothesis Z.

The Experiment

The *experiment* is the most formal part of the scientific process. The concept, however, is very simple: an experiment is a test of a hypothesis. It is what a scientist does to check an idea out. It may involve giving a new drug to a sick patient or testing a new process to preserve apples, tomatoes, and lettuce.

If the experiment does not falsify the hypothesis, that does not mean that the hypothesis is true. It simply means that the scientist has not yet come up with a test that falsifies the hypothesis. As the number of times and the number of different tests that fail to falsify a hypothesis increase, the likelihood that the hypothesis is true also increases. However, because it is impossible to conceive of and perform all the possible tests of a hypothesis, the scientist can never *prove* that it is true.

Consider the hypothesis that all cats are black. If you see a black cat, you do not really know anything at all about the color of all cats. But if you see a white cat, you certainly know that not all cats are black. You would have to look at every cat on Earth to prove the hypothesis, but only one (of a color other than black) to disprove it. This is why philosophers of science often say that *science is the art of disproving,* not proving. If a hypothesis withstands many attempts to disprove it, then it may be a good explanation of the phenomenon in question. If it fails just one test, though, it is clearly wrong and must be replaced with a new hypothesis.

Researchers who study what scientists actually do point out that most scientists do not act in accord with this reasoning. Almost all scientists, when they come up with what strikes them as a good explanation of a phenomenon or pattern, do *not* try to disprove the hypothesis. Instead, they design experiments to *confirm* it. If an experiment fails to confirm the hypothesis, then the researchers try another experiment, not another hypothesis.

The logical weakness in this approach is obvious, but it does not keep researchers from holding onto their ideas as long as possible. Sometimes they hold on so long, even without confirming the hypothesis, that they wind up looking ridiculous. Other times the confirmations add up over the years, and any attempts to disprove the hypothesis fail to do so. The hypothesis may then be elevated to the rank of a theory, principle, or law. *Theories* are explanations of how things work (the theory of evolution *by means of* natural selection, for example). *Principles* and *laws* tend to be statements of things that invariably happen, such as the law of gravity (masses attract each other, or what goes up must come down) or the gas law (if you increase the pressure on an enclosed gas, the volume will decrease and the temperature will increase).

Communication

Each scientist is obligated to share her or his hypotheses, methods, and findings with the rest of the scientific community. This sharing serves two purposes. First, it supports the basic ideal of skepticism by making it possible for others to say, "Oh, yeah? Let me check that." It tells the skeptics where to look to see what the scientist saw and what techniques and tools to use.

Second, communication allows others to use in their work what has already been discovered. This is essential because science is a cooperative endeavor. People who work thousands of miles apart build with and upon each other's discoveries—some of the most exciting discoveries have involved bringing together information from very different fields.

Scientific cooperation stretches across time as well. Every generation of scientists both uses and adds to what previous generations have discovered. As Sir Isaac Newton said in 1675, in a letter to fellow scientist Robert Hooke, "If I have seen further than [other men], it is by standing upon the shoulders of Giants."

The communication of science begins with a process called "peer review," which typically has three stages. The first stage occurs when a scientist seeks funding—from government agencies, foundations, or other sources—to carry out a research program. He or she must prepare a report describing the intended work, laying out the background, hypotheses, planned experiments, expected results, and even the broader impacts on other fields. Committees of other scientists then go over the report to determine whether or not the applicant knows his or her area, has the necessary abilities, and is realistic in his or her plans.

Once the scientist has acquired funding, has done the work, and has written a report of the results, that report will be submitted to a scientific journal, which begins the second stage. Before publishing the report, the journal's editors will show it to other workers in the same or related fields and ask them whether or not the work was done adequately, the conclusions are justified, and the report should be published.

The third stage of peer review happens after publication, when the broader scientific community can judge the work.

It is certainly possible for these standard peer review mechanisms to fail. By their nature, these mechanisms are more likely to approve ideas that do not contradict what the reviewers think they already know. Yet, unconventional ideas are not necessarily wrong, as German geophysicist Alfred Wegener proved when he tried to gain acceptance for his idea of continental drift in the early twentieth century. At the time, geologists believed that the crust of the Earth—which is solid rock, after all—did not behave like liquid. Yet, Wegener was proposing that the continents floated about like icebergs in the sea, bumping into each other, tearing apart (to produce matching profiles like those of South America and Africa), and bumping again. It was not until the 1960s that most geologists accepted his ideas as genuine insights instead of harebrained delusions.

THE NEED FOR CONTROLS

Many years ago, I read a description of a "wish machine." It consisted of an ordinary stereo amplifier with two unusual attachments. The wires that would normally be connected to a microphone were connected instead to a pair of copper plates. The wires that would normally be connected to a speaker were connected instead to a whip antenna of the sort usually seen on cars.

To use this device, one put a picture of some desired item between the copper plates. It could be, for instance, a photo of a person with whom one wanted a date, a lottery ticket, or a college that one wished to attend. One test case used a photo of a pest-infested cornfield. The user then wished fervently for the date, the winning lottery ticket, a college acceptance, or whatever else one craved. In the test case, the testers wished that all the pests in the cornfield would drop dead.

Supposedly, the wish would be picked up by the copper plates, amplified by the stereo amplifier, and then sent via the whip antenna to wherever wish orders go. Whoever or whatever fills those orders would get the message and grant the wish. Well, in the test case, when the testers checked the cornfield after using the machine, there was no longer any sign of pests. What's more, the process seemed to work equally well whether the amplifier was plugged in or not.

You are probably now feeling very much like a scientist—skeptical. The true, dedicated scientist, however, does not stop with saying, "Oh, yeah? Tell me another one!" Instead, he or she says, "Let's check this out."[3]

Where must the scientist begin? The standard model of the scientific method says that the first step is observation. Here, our observations (as well as our necessary generalization) are simply the description of the wish machine and the claims for its effectiveness. Perhaps we even have the device itself.

What is our hypothesis? We have two choices, one consistent with the claims for the device and one denying those claims: the wish machine always works, or the wish machine never works. Both are equally testable and equally falsifiable.

How do we test the hypothesis? Set up the wish machine, and perform the experiment of making a wish. If the wish comes true, the device works. If the wish does not come true, the device does not work.

Can it really be that simple? In essence, yes. But in fact, no.

Even if you do not believe that wishing can make something happen, sometimes wishes do come true by sheer coincidence. Therefore, even if the wish machine is as nonsensical as most people think it is, sometimes it will *seem* to work. We therefore need a way to shield against the misleading effects of coincidence.

Coincidence is not, of course, the only source of error we need to watch out for. For instance, there is a very human tendency to interpret events in such a way as to agree with our preexisting beliefs, or our prejudices. If we believe in wishes, we therefore need a way to guard against our willingness to interpret near misses as not quite misses at all. There is also a human tendency not to look for mistakes when the results agree with our prejudices. The cornfield, for instance, might not have been as badly infested as the testers said it was, or a farmer might have sprayed it with pesticide between checks, or the testers may have accidentally checked the wrong field. The point is that correlation does not necessarily reflect cause. In other words, although an event seems to occur as the result of another, there may be other factors at work that negate the relationship.

We also need to check whether or not the wish machine does indeed work equally well when the amplifier is unplugged as when it is plugged in, and then we must guard against the tendency to wish harder when we know that it is plugged in. Furthermore, we would like to know whether or not placing a photo between the copper plates makes any difference, and then we must guard against the tendency to wish harder when we know that the wish matches the photo.

Coincidence is easy to protect against. All that is necessary is to repeat the experiment enough times to be sure that we are not seeing flukes. This is one major purpose of replication. Our willingness to shade the results in our favor can be defeated by having another scientist judge the results of our wishing experiments. And our eagerness to overlook errors that produce favorable results can be defeated by taking great care to avoid any errors at all; peer reviewers also help by pointing out such problems.

Other sources of error are harder to avoid, but scientists have developed a number of helpful *control* techniques. One technique is called "blinding." In essence, blinding requires setting up the experiment in such a way that the critical aspects are hidden from either the test subjects, the scientist who is physically performing the experiment, or both. This helps to prevent individuals' expectations from influencing the outcome of the experiment.

In the pharmaceutical industry, blinding is used whenever a new drug is tested. The basic process goes like this: A number of patients with the affliction that the drug is supposed to affect are selected. Half of them—chosen randomly to avoid any unconscious bias that might put sicker patients in one group[4]—are given the drug. The others are given a dummy pill, or a sugar pill, also known as a *placebo*. In all other respects, the two groups are treated exactly the same.

Although, placebos are not supposed to have any effect on patients, they can sometimes have real medical effects, apparently because people tend to believe their doctors when they say that a pill will cure them. That is, when we put faith in our doctors, our minds do their best to bring our bodies into line with whatever the doctors tell us. This mind-over-body effect is called the "placebo effect." To guard against the placebo effect, experimenters employ either single-blind or double-blind techniques.

Single-Blind With this approach, the researchers do not tell the patients what pill they are getting. The patients are therefore "blinded" to what is going on. Both placebo and drug then gain equal advantage from the placebo effect. If the drug seems to work better or worse than the placebo, then the researchers can be sure of a real difference between the two.

Double-Blind If the researchers know what pill they are handing out, they can give subtle, unconscious cues that let the patients know whether they are receiving the drug or the placebo. The researchers may also interpret any changes in the symptoms of the patients who receive the drug as being caused by the drug. It is therefore best to keep the researchers in the dark too; and when both researchers and patients are blind to the truth, the experiment is said to be "double-blind." Drug trials often use pills that differ only in color or in the number on the bottle, and the code is not broken until all the test results are in. This way nobody knows who gets what until the knowledge can no longer make a difference.

Obviously, the double-blind approach can work only when there are human beings on both sides of the experiment, as experimenter and as experimental subject. When the object of the experiment is an inanimate object (such as the wish machine), only the single-blind approach is possible.

With suitable precautions against coincidence, self-delusion, wishful thinking, bias, and other sources of error, the wish machine could be convincingly tested. Yet, it cannot be perfectly tested, for perhaps it only works sometimes, such as when the aurora glows green over Copenhagen, in months without an *r*, or when certain people use it. It is impossible to rule out all the possibilities, although we can rule out enough to be pretty confident that the gadget is pure nonsense.

Similar precautions are essential in every scientific field, for the same sources of error lie in wait wherever experiments are done, and they serve very much the same function. However, no controls and no peer review system, no matter how elaborate, can completely protect a scientist—or science—from error. Here, as well as in the logical impossibility of proof (remember, experiments only fail to disprove) and science's dependence on the progressive growth of knowledge, lies the uncertainty that is the hallmark of science. Yet, it is also a hallmark of science that its methods guarantee that uncertainty will be reduced (not eliminated). Frauds and errors will be detected and corrected. Limited understandings of truth will be extended.

Those who bear this in mind will be better equipped to deal with issues of certainty and risk.

NOTES

1. Mesthene's essay, "The Role of Technology in Society," *Technology and Culture* (vol. 10, no. 4, 1969), is reprinted in A. H. Teich, ed., *Technology and the Future*, 6th ed. (St. Martin's Press, 1993).

2. McDermott's essay, "Technology: The Opiate of the Intellectuals," *The New York Review of Books* (July 31, 1969), is reprinted in A. H. Teich, ed., *Technology and the Future*, 6th ed. (St. Martin's Press, 1993).

3. Must we, really? After all, we can be quite sure that the wish machine does not work because, if it did, it would likely be on the market. Casinos would then be unable to make a profit for their backers, deadly diseases would be eradicated, and so on.

4. Or patients that are taller, shorter, male, female, homosexual, heterosexual, black, white—there is no telling what differences might affect the test results. Drug (and other) researchers therefore take great pains to be sure groups of experimental subjects are alike in every way but the one way being tested.