Understanding Science

What has science done for you lately?

Plenty. If you think science doesn't matter much to you, think again. Science affects us all, every day of the year, from the moment we wake up, all day long, and through the night. Your digital alarm clock, the weather report, the asphalt you drive on, the bus you ride in, your decision to eat a baked potato instead of fries, your cell phone, the antibiotics that treat your sore throat, the clean water that comes from your faucet, and the light that you turn off at the end of the day have all been brought to you courtesy of science. The modern world would not be modern at all without the understandings and technology enabled by science.

Science affects us all, every day of the year.

To make it clear how deeply science is interwoven with our lives, just try imagining a day without scientific progress. Just for starters, without modern science, there would be:

- **no way to use electricity.** From Ben Franklin's studies of static and lightning in the 1700s, to Alessandro Volta's first battery, to the key discovery of the relationship between electricity and magnetism, science has steadily built up our understanding of electricity, which today carries our voices over telephone lines, brings entertainment to our televisions, and keeps the lights on.

- **no plastic.** The first completely synthetic plastic was made by a chemist in the early 1900s, and since then, chemistry has developed a wide variety of plastics suited for all sorts of jobs, from blocking bullets to making slicker dental floss.

Bus photo provided by SunLine Transit Agency; shopping photo by USDA; faucet photo by CDC; medicine photo by National Institute of General Medical Sciences; light bulb photo by U.S. Climate Change Technology Program; phone photo by Maine.gov; photo of powerlines provided by Warren Gretz/NREL.

- **no modern agriculture.** Science has transformed the way we eat today. In the 1940s, biologists began developing high-yield varieties of corn, wheat, and rice, which, when paired with new fertilizers and pesticides developed by chemists, dramatically increased the amount of food that could be harvested from a single field, ushering in the Green Revolution. These science-based technologies triggered striking changes in agriculture, massively increasing the amount of food available to feed the world and simultaneously transforming the economic structure of agricultural practices.

- **no modern medicine.** In the late 1700s, Edward Jenner first convincingly showed that vaccination worked. In the 1800s, scientists and doctors established the theory that many diseases are caused by germs. And in the 1920s, a biologist discovered the first antibiotic. From the eradication of smallpox, to the prevention of nutritional deficiencies, to successful treatments for once deadly infections, the impact of modern medicine on global health has been powerful. In fact, without science, many people alive today would have instead died of diseases that are now easily treated.

Scientific knowledge can improve the quality of life at many different levels—from the routine workings of our everyday lives to global issues. Science informs public policy and personal decisions on energy, conservation, agriculture, health, transportation, communication, defense, economics, leisure, and exploration. It's almost impossible to overstate how many aspects of modern life are impacted by scientific knowledge. Here we'll discuss just a few of these examples.

Photo of soybean crop provided by Dave Warren/USDA; smallpox vaccine photo provided by James Gathany/CDC.

Fueling technology

Basic science fuels advances in technology, and technological innovations affect our lives in many ways everyday. Because of science, we have complex devices like cars, X-ray machines, computers, and phones. But the technologies that science has inspired include more than just hi-tech machines. The notion of technology includes any sort of designed innovation. Whether a flu vaccine, the technique and tools to perform open heart surgery, or a new system of crop rotation, it's all technology. Even simple things that one might easily take for granted are, in fact, science-based technologies: the plastic that makes up a sandwich bag, the genetically-modified canola oil in which your fries were cooked, the ink in your ballpoint pen, a tablet of ibuprofen—it's all here because of science.

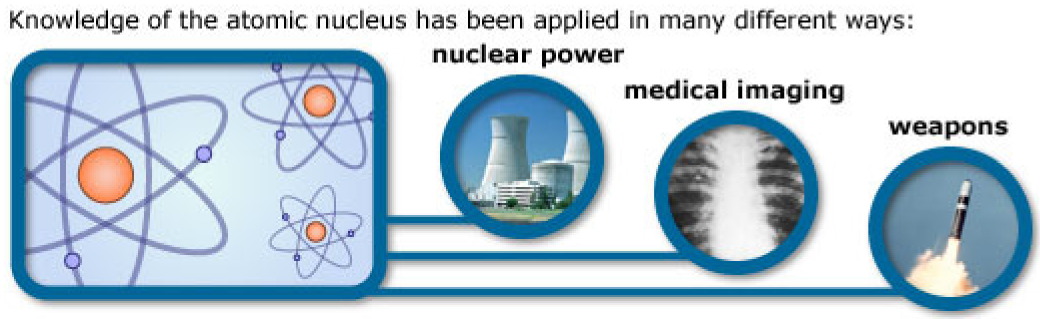
While images of big, complex innovation, might be the first to spring to mind when you think of technology ...

... it can also be the smaller, simpler, science-based innovations that we take for granted.

Though the impact of technology on our lives is often clearly positive (e.g., it's hard to argue with the benefits of being able to effectively mend a broken bone), in some cases the payoffs are less clear-cut. It's important to remember that science builds knowledge about the world, but that people decide how that knowledge should be used. For example, science helped us understand that much of an atom's mass is in its dense nucleus, which stores enormous amounts of energy that can be released by breaking up the nucleus. That knowledge itself is neutral, but people have chosen to apply it in many different ways:

- **Energy.** Our understanding of this basic atomic structure has been used as the basis of nuclear power plants, which themselves have many societal benefits (e.g., nuclear power does not rely on non-renewable, polluting fossil fuels) and costs (e.g., nuclear power produces radioactive waste, which must be carefully stored for long periods of time).
- **Medicine.** That understanding has also been used in many modern medical applications (e.g., in radiation therapy for cancer and in medical imaging, which can trace the damage caused by a heart attack or Alzheimer's disease).
- **Defense.** During World War II, that knowledge also clued scientists and politicians in to the fact that atomic energy could be used to make weapons. Once a political decision was made to pursue atomic weapons, scientists worked to develop other scientific knowledge that would enable this technology to be built.

Computer chip photo provided by NASA; lab research photo provided by James Gathany/CDC; International Space Station photo provided by NASA; ibuprofen image comes from Bright_Star's flickr page (CC BY-NC-ND 2.0); canola oil image comes from adpowers's flickr page (CC BY 2.0); pen tip image comes from Tzatziki's flickr page (CC BY-NC-SA 2.0).



So scientific knowledge allows new technologies to be built, and those technologies, in turn, impact society at many levels. For example, the advent of atomic weapons has influenced the way that World War II ended, its aftermath, and the power plays between nations right up until today.

Rancho Seco nuclear reactor photo provided by Warren Gretz; x-ray photo provided by CDC/Libero Ajello; missile photo provided by DOE.

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Science and technology on fast forward

Science and technology feed off of one another, propelling both forward. Scientific knowledge allows us to build new technologies, which often allow us to make new observations about the world, which, in turn, allow us to build even more scientific knowledge, which then inspires another technology … and so on. As an example, we'll start with a single scientific idea and trace its applications and impact through several different fields of science and technology, from the discovery of electrons in the 1800s to modern forensics and DNA fingerprinting …

From cathodes to crystallography

A cathode ray tube from the early 1900s.

We pick up our story in the late 1800s with a bit of technology that no one much understood at the time, but which was poised to change the face of science: the cathode ray tube (node A in the diagram below). This was a sealed glass tube emptied of almost all air—but when an electric current was passed through the tube, it no longer seemed empty. Rays of eerie light shot across the tube. In 1897, physicists would discover that these cathode rays were actually streams of electrons (B). The discovery of the electron would, in turn, lead to the discovery of the atomic nucleus in 1910 (C). On the technological front, the cathode ray tube would slowly evolve into the television (which is constructed from a cathode ray tube with the electron beam deflected in ways that produce an image on a screen) and, eventually, into many sorts of image monitors (D and E). But that's not all …

In 1895, the German physicist Wilhem Roentgen noticed that his cathode ray tube seemed to be producing some other sort of ray in addition to the lights inside the tube. These new rays were invisible but caused a screen in his laboratory to light up. He tried to block the rays, but they passed right through paper, copper, and aluminum, but not lead. And not bone. Roentgen noticed that the rays revealed the faint shadow of the bones in his hand! Roentgen had discovered X-rays, a form of electromagnetic radiation (F). This discovery would, of course, shortly lead to the invention of the X-ray machine (G), which would in turn, evolve into the CT scan machine (H)—both of which would become essential to non-invasive medical diagnoses. And the CT scanner itself would soon be adopted by other branches of science—for neurological research, archaeology, and paleontology, in which CT scans are used to study the interiors of fossils (I). Additionally, the discovery of X-rays would eventually lead to the development of X-ray telescopes to detect radiation emitted by objects in deep space (J). And these telescopes would, in turn, shed light on black holes, supernovas, and the origins of the universe (K). But that's not all …

The discovery of X-rays also pointed William and William Bragg (a father-son team) in 1913 and 1914 to the idea that X-rays could be used to figure out the arrangements of atoms in a crystal (L). This works a bit like trying to figure out the size and shape of a building based on the shadow it casts: you can work backwards from the shape of the shadow to make a guess at the building's dimensions. When X-rays are passed through a crystal, some of the X-rays are bent or spread out (i.e., diffracted) by the atoms in the crystal. You can then extrapolate backwards from the locations of the deflected X-rays to figure out the relative locations of the crystal atoms. This technique is known as X-ray crystallography, and it has profoundly influenced the course of science by providing snapshots of molecular structures.

Perhaps most notably, Rosalind Franklin used X-ray crystallography to help uncover the structure of the key molecule of life: DNA. In 1952, Franklin, like James Watson

Cathode ray tube photo provided by Henk Dijkstra © The Cathode Ray Tube site.

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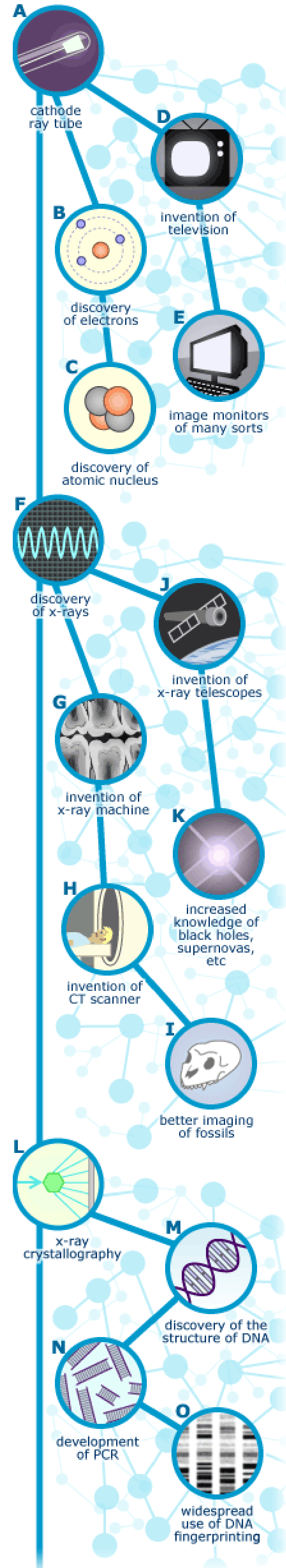
and Francis Crick, was working on the structure of DNA—but from a different angle. Franklin was painstakingly producing diffracted images of DNA, while Watson and Crick were trying out different structures using tinker-toy models of the component molecules. In fact, Franklin had already proposed a double helical form for the molecule when, in 1953, a colleague showed Franklin's most telling image to Watson. That picture convinced Watson and Crick that the molecule was a double helix and pointed to the arrangement of atoms within that helix. Over the next few weeks, the famous pair would use their models to correctly work out the chemical details of DNA (M).

The impact of the discovery of DNA's structure on scientific research, medicine, agriculture, conservation, and other social issues has been wide-ranging—so much so, that it is difficult to pick out which threads of influence to follow. To choose just one, understanding the structure of DNA (along with many other inputs) eventually allowed biologists to develop a quick and easy method for copying very small amounts of DNA, known as PCR—the polymerase chain reaction (N). This technique (developed in the 1980s), in turn, allowed the development of DNA fingerprinting technologies, which have become an important part of modern criminal investigations (O).

As shown by the flowchart above, scientific knowledge (like the discovery of X-rays) and technologies (like the invention of PCR) are deeply interwoven and feed off one another. In this case, tracing the influence of a single technology, the cathode ray tube, over the course of a century has taken us on a journey spanning ancient fossils, supernovas, the invention of television, the atomic nucleus, and DNA fingerprinting. And even this complex network is incomplete. Understanding DNA's structure, for example, led to many more advances besides just the development of PCR. And similarly, the invention of the CT scanner relied on much more scientific knowledge than just an understanding of how X-ray machines work. Scientific knowledge and technology form a maze of connections in which every idea is connected to every other idea through a winding path.



Making strides in medicine

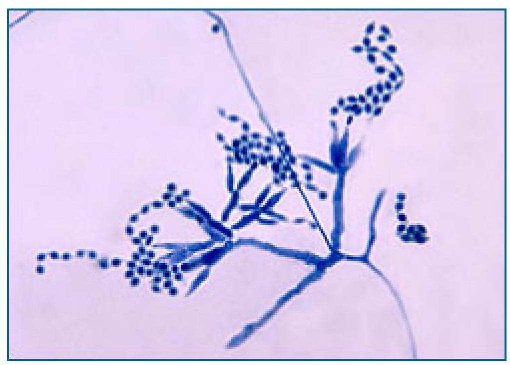
A century ago, a diagnosis of juvenile diabetes was an almost certain death sentence. Children affected by diabetes rarely lived more than a few years. However, thanks to the discovery of insulin in the early 1920s, along with subsequent scientific breakthroughs in genetic engineering that allowed insulin to be mass-produced, that statistic has completely turned around: diabetics now live long lives.

Diabetes is just one of many diseases and health concerns for which science has helped develop treatments, preventions, or cures. Without science, we wouldn't know how to make an X-ray machine, how to build an artificial knee, how to prevent nutritional deficiencies, how to ward off cholera and malaria, or even, at the most basic level, that hand-washing can prevent the spread of germs. In many thousands of ways, science has supplied us with tools to improve human health—not the least of which has been medications to treat diseases …

MOLDY MIRACLE DRUGS

At his lab bench in 1928, biologist Alexander Fleming found that his research had gone bad—moldy, in fact. One of his plates of bacterial colonies had picked up the tiny spores of a mold floating through the air and was now growing a fuzzy head of white fluff. Instead of tossing the contaminated plate, Fleming took a close look and noticed that the white fluff was having a surprisingly powerful effect. The mold, of course, was *Penicillium*, and it was not only slowing the bacteria—it was actually causing them to explode! Fleming immediately began experiments and soon showed that the mold was able to kill many bacterial strains, including those that cause strep throat, staph infections, pneumonia, syphilis, and gonorrhea. And unlike other bacterial treatments available at the time (like mercury and arsenic), penicillin was non-toxic, exclusively attacking bacteria and leaving the body's own cells alone. It would take another decade for scientists to develop the means of producing and purifying the drug efficiently, but when they did, it was a breakthrough, arriving just in time to treat wounded World War II soldiers.

Alexander Fleming



One species of *Penicillium* is used in the production of the antibiotic penicillin, but others are important in cheese-making. Another, like the one pictured here, causes an AIDS-related illness.

Before long, other compounds like penicillin were discovered, ushering in the age of antibiotics and saving millions of lives. Unfortunately, it would not last long. Antibiotic-resistant bacteria rapidly evolved and were first documented just four years after penicillin became widely available. Over the last 20 years, antibiotic resistance has become an increasingly serious problem. Now, medical doctors are again looking towards scientific research with the hope that the lab bench will once more provide them with a silver bullet to fight bacterial infections.

Alexander Fleming photo courtesy of the National Library of Medicine; *Penicillium* photo courtesy of the CDC/ Dr. Libero Ajello.

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Getting personal

You may not be an expert on microbiology, geology, or climatology, but even so, scientific knowledge may factor into your everyday decision-making. Science has implications for issues we face everyday—and while science doesn't dictate which choice is the right one, it does give us important background knowledge to inform our decisions. Here are just a few examples of everyday decisions informed by science:

To wash or not to wash. One hundred and seventy years ago, hand-washing wasn't an everyday ritual—even for doctors working in both the morgue and the maternity ward! However, since then, biologists have developed the germ theory of disease, and research has shown that hand-washing prevents the spread of infection. A 2005 study found that promoting hand-washing among children in low-income areas could reduce the incidence of diseases like pneumonia by fifty percent! Though washing one's hands might seem like a simple habit today, it is so commonplace only because scientific knowledge has emphasized its benefits.

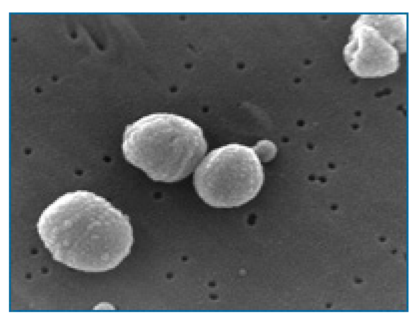
Which fish? Will you have the local tilapia or the orange roughy? Taste certainly factors into this decision, as does cost. But what about science? Conservation biology tells us that the orange roughy's population has been decimated by the seafood industry. Even more worrisome, biologists have figured out that the fish lives to be 100 years old and doesn't begin to reproduce until it's 20 years old, making it difficult for the population to recover from over-fishing. Tilapia, on the other hand, is farmed specifically for human consumption and is not threatened. Which will you choose?

The orange roughy (top) and tilapia (bottom) available on the same menu have very different conservation statuses.

Dodging disaster. Everyone needs a place to call home, but where will yours be? If you're considering a house in earthquake country, you might want to take a cue from seismologists and geologists: not all soil types are the same. Scientists have determined that some areas within earthquake zones are unusually dangerous and damage-prone because of the possibility of liquefaction—a phenomenon in which shaking causes soil particles to flow past one another easily, like a liquid. In this case, science can point you towards a more stable and safe home.

Damage due to liquefaction after an earthquake in Niigata, Japan in 1964.

Am I better yet? You're over your strep throat and feeling well again, so is it time to ditch the antibiotics? Well, you could, but evolutionary biology suggests that stopping a course of antibiotics early encourages the evolution of antibiotic resistant bacteria, by allowing those bacteria not quite killed off by the incomplete dose of antibiotics to preferentially survive and reproduce. Those mildly resistant bacteria could come back to haunt you or infect someone else, and if they do, your original antibiotic may not work against the new strain.



Streptococcus bacteria

Petroleum preferences. You're in the market for a new car—but which one? There are many considerations, including mileage. A car that gets better mileage means that you'll pay less for gas. But geology can shed even more light on the issue. The petroleum necessary to make gas is a limited resource. The Earth only has so much oil and geologists estimate that we have already tapped much of that. The more petroleum we use, the harder it becomes to find. The harder petroleum is to find, the more expensive each barrel of oil becomes, and the more you'll be paying at the gas pump! A car that conserves gas might be more expensive now, but could end up paying off in the long run.

A plug-in hybrid electric vehicle that can run off of electricity generated by renewable sources.

Hand washing photo provided by CDC/Kelly Thomas; orange roughy photo by W. Savary from the FDA Regulatory Fish Encyclopedia; tilapia photo by B. Tenge from the FDA Regulatory Fish Encyclopedia; liquefaction photo provided by Earthquake Engineering Research Center; Streptococcus bacteria provided by CDC/Janice Carr; plug-in hybrid electric car photo by Mike Linenberger/NREL.

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Shaping society

Just as it shapes your personal decision-making, scientific knowledge also helps inform regulatory decision-making and policy—and the results of these decisions are everywhere. In fact, they are so ubiquitous that you probably never even stop to think about them. Why is your quart of milk decorated with a nutrition label? Why do schools check students' vaccination records? Why aren't your new kitchen tiles made of asbestos? Why is it illegal to pour your used motor oil down a storm drain? Because of science, of course. Science informs policies that promote our health, safety, and environmental stewardship.

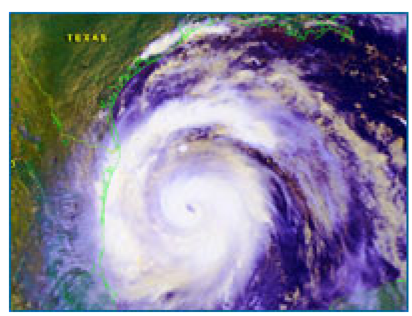
Policies that you confront every day are informed by science.

Science doesn't dictate policy, but it does give us a "how-to" manual for reaching the outcomes that we decide we want. For example:

- **Want to get rid of polio?** In the 1940s and 50s, American society got behind efforts to prevent and treat polio by donating to the organization called the March of Dimes. Through the March of Dimes, that societal concern financed research on polio vaccines. Science provided us with the vaccine that made prevention possible, and it also gave us an understanding of polio transmission that shaped our approach to administering the vaccine. If we wanted to truly eradicate the disease, only a massive vaccination effort would do the trick. Today, a polio vaccination is a routine requirement for enrolling in public school in the U.S. In 1988, a set of international health organizations launched a global eradication program based on widespread vaccination—and the battle continues. As of January 2007, polio had been beaten back to just four countries.

A child in India is given an oral polio vaccine.

- **Want to get warning of natural disasters?** Though we can't yet predict earthquakes, science does have effective ways of predicting when and where hurricanes might strike land. Society has put that knowledge to good use. The National Weather Service continually collects data about meteorological patterns and analyzes those data based on our scientific understanding of weather systems. They may then issue a hurricane warning, which gives citizens time to get to safety and allows community organizers to prepare for evacuations and emergencies.



A satellite image of Hurricane Emily approaching Mexico.

Polio vaccination photo provided by WHO/P. Virot; hurricane image from the National Climatic Data Center.

- **Want to repair our ozone layer?** The ozone layer shields us from damaging ultraviolet rays, but in 1985, we discovered a chink in that armor—a hole in the ozone layer over Antarctica. If things went unchecked, science predicted dire outcomes: possible increases in DNA damage and skin cancer rates, along with unpredictable changes in the global food web caused by die-off of UV-sensitive plankton. Luckily, science was also ready with an explanation and a potential solution. The culprit seemed to be chlorofluorocarbons (CFCs), human-made chemicals used for air conditioning and aerosol propellants, which, chemists showed, could destroy ozone molecules. Society took science to heart, and in 1990, policy makers from 93 countries gathered in London to sign a treaty, agreeing to phase-out CFCs by 2000.

Science doesn't tell us that we *ought* to prevent disease, provide advanced warning in case of disaster, or protect our planet. People make those decisions based on their own values, but once a decision is made, we can use scientific knowledge to figure out how to accomplish that goal and what its likely ramifications will be.

Scientific knowledge informs public policies and regulations that promote our health, safety, and environmental stewardship.

Find out how scientific research can shape public policy around the globe and help protect the environment. Explore Ozone depletion: Uncovering the hidden hazard of hairspray.

Visit the Visionlearning website for a case study on how scientific research influenced regulations and policies regarding smoking.

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What science has done for you lately

In this section, we've seen that science touches many aspects of our lives: from the mundane (e.g., the plastic lid on your morning coffee) to the world-changing (e.g., the eradication of smallpox). And while some of the impacts of science on society may not be clear boons, many are. Without science, we would not have even basic knowledge about promoting health, safety, and environmental stewardship. This knowledge informs both our personal and societal decision-making. Scientific knowledge also forms the basis for technological advancement. From a simple light bulb, to a complex computer, to genetically engineered rice—they are all man-made technologies based on basic scientific knowledge.

Here, we've seen how scientific knowledge affects your life everyday, often without much notice. But this doesn't mean that you have to accept whatever scientific information the media throw your way. In the next section, you'll learn how to become a critical consumer of scientific information and how an understanding of science can change the way you look at the world …