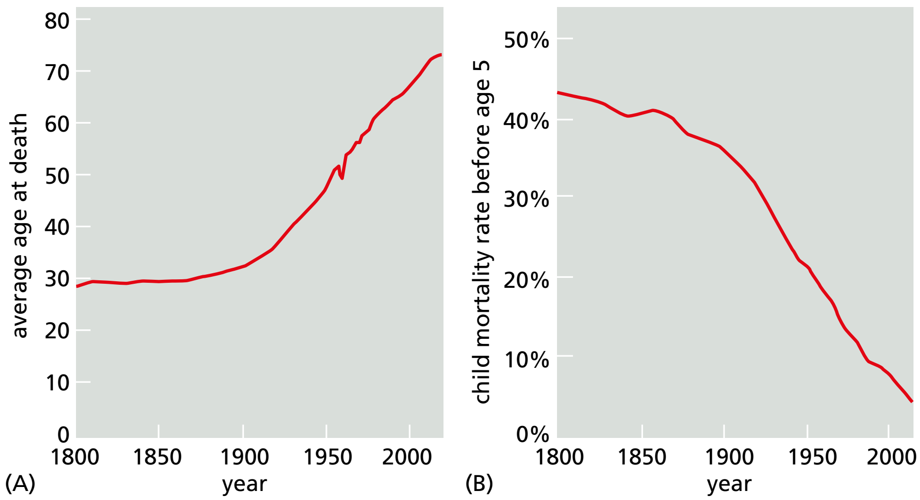
Why Trust Science?

A brief essay to help spread an understanding of how scientific knowledge is produced, while suggesting a new focus for science education at all levels.

The products of science, and the efforts of scientists, enrich our everyday lives. Perhaps you stumbled across this essay while searching the internet for a class assignment or for something interesting to read. Before 1990, the internet did not even exist. Yet now we use it for everything from watching videos and listening to music to ordering meals and staying in touch with family and friends.

The internet is just one example of how science and technology have changed the way we live. Think of electricity, cars, and computers—not to mention the medical advances that allow us to live twice as long as our ancestors did just a couple hundred years ago.

Most of us don't spend a lot of time thinking about these things, because we don't really have to. We trust that technologies will



Robust and reliable science has improved human health. Life expectancy has more than doubled in the past 200 years and child mortality has dropped dramatically. Innovations based on scientific investigation—including sanitation, vaccines, antibiotics, and disease treatments—account for most of these improvements. (From Our world in data.org).

work. We trust that when we plug in our phone, the battery will charge. We trust that when we hop in the car, the engine will convert the chemical energy contained in gasoline or a battery into the kinetic energy of motion.

But why do we trust in these technologies that—to be honest—most of us can't even begin to fully understand? How many of us know how a smart phone or a car engine or a rechargeable battery work? Have you ever finished watching the safety video on a plane and wondered how a jumbo jet that weighs hundreds of tons can possibly get off the ground and take to the skies?

Very few of us are experts on any of these things. Even so, we trust that we can recharge our phones at the end of the day and that planes don't inexplicably drop from the sky. We trust that these things will work because we can trust the engineering that produced them: the technological advances that were enabled by principles derived from extensive observation and experimentation. In other words, we trust in the underlying science.

> …are the scientific claims we read about always accurate and true?

But is all science equally trustworthy? Many of the stories we hear on the news or encounter on the internet begin with the phrase: "a new study shows…" But are the scientific claims we read about always accurate and true? If not, how do we know which studies are robust and reliable—and which might be improperly designed or even fully fictitious—especially when we lack the expertise to analyze the experiment and data ourselves?

In this essay, we address the question of why we can trust science—and how we can identify which scientific claims we can trust. We begin by explaining how scientists work together, as part of a larger scientific community, to generate knowledge that is reliable. We describe how the scientific process builds a consensus, and how new evidence can change the ways that scientists—and, ultimately, the rest of us—see the world. Last, but not least, we explain how, as informed citizens, we can all become "competent outsiders" who are equipped to evaluate scientific claims and are able to separate science facts from science fiction.

Science Creates Knowledge Through a Community Effort

When you picture a scientist, what comes to mind? Maybe you imagine a chemist working long, lonely hours at a laboratory bench, a whiteboard covered with equations and beakers boiling in the background. Or maybe you think of someone like Gregor Mendel, the Austrian monk who is sometimes described as the father of genetics, alone in his abbey garden, meticulously examining generation after generation of his carefully bred pea plants.

Courtesy of Lizzy Mwamburi

If so, you might be surprised to learn that science—particularly modern science—is very much a team sport. In any field of science, from astronomy to zoology, researchers work with one another within the broader scientific community. These investigators share their data in publications and debate their findings at conferences. They write research proposals that are reviewed by their scientific peers. They give lectures where others scrutinize and evaluate everything from their methods to how they interpret their results. They collaborate with colleagues—and interact with competitors—who are all part of a vast network of scientists based at institutions around the world, including many in the global south and the developing world. As Ludwik Fleck—a Polish microbiologist who also studied the sociology of science—put it, "A truly isolated investigator is impossible… Thinking is a collective activity."

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In response to these collective critiques, investigators devise even more rigorous strategies for testing their theories and concepts. Scientists—both the original discoverers and those outside the group—then adjust their hypotheses to best accommodate all of the available data. If two heads are better than one, when it comes to science, hundreds and maybe even thousands of investigators will often put their heads together to ponder a problem and experimentally test—and retest—the proposed solution. In this manner, the scientific community strives to come to a consensus.

Of course, scientists, like anyone, can make mistakes. But, as a group, scientists are professionals who have dedicated their lives to trying to understand the world in which we live. So we should value their training and expertise in the same way that we put our trust in the mechanics, pilots, and air traffic controllers who work together to ensure that our flights take off and land safely. Scientists are trained to examine everything they see with an analytical eye. So when we have questions that, by nature, require methodical and rigorous investigation, it only makes sense that we should turn to scientists to help us find the answers.

Science is Self-Correcting Because Scientists Are Critical of Their Own Work

When we first learn about "the scientific method," we are told that a scientist makes observations and then develops a hypothesis—a proposal explaining those observations—that can be tested by some sort of experiment. If the results support the hypothesis, the hypothesis is confirmed and the investigator can then conduct additional research to further refine his or her model.

But that picture is vastly oversimplified. In reality, hypotheses are proposals that are formulated to be disproven. Scientists are trained to be skeptical—even (or especially) of their own hypotheses. Good scientists operate with the knowledge that their initial ideas or models may require revision or even outright rejection. Some might even argue that a major goal of science is to eliminate erroneous notions, irreproducible results, and incorrect interpretations. Because science advances through a rigorous community-based testing of hypotheses, it effectively corrects its own mistakes. A rigorous system of checks and balances is "baked in" to the scientific method, steering us away from misinformation and toward an increasingly accurate and reliable understanding of the world.

A rigorous system of checks and balances is "baked in" to the scientific method.

Courtesy of Ashrafi Hossain

A healthy application of skepticism allows science to progress. But it only does so because, as a community, scientists share a similar set of values. In his book *Science and Human Values*, Jacob Bronowski, a physicist and philosopher, noted: "Science confronts the work of one [investigator] with that of another and grafts each on each; it cannot survive without justice and honor and respect. Only by these means can science pursue its steadfast object, to explore truth."

Shared Practices Increase the Accuracy of Scientific Findings

Shared values alone are not enough to make science self-correcting. Over time, the scientific community has developed a set of critical practices that facilitate the constant vetting of knowledge necessary for science to progress. These practices enable investigators to "check their work" by identifying potential problems in their theories and experiments, allowing them to pursue the necessary corrections.

1. **Independent replication.** When investigators publish their work, they provide comprehensive descriptions of the experimental procedures they followed. Many publications include a list of all the materials that were used, as well as where the ingredients were purchased, how they were prepared, and even what lot numbers appear on the side of the bottle! This excruciating level of detail is designed to allow others in the community to reproduce the original experiment (or conduct one that is very similar). In this way, scientists can readily corroborate or add to each others' results—or identify a problem with the original study.

2. **Randomized controlled trials.** To determine if a new drug or vaccine (or even a high-school science curriculum) is more effective than the one that's currently in use, scientists compare what happens to a group of people who receive the new intervention to a "control" group that does not. To make sure that these two groups don't differ in some significant way (for example, one containing people that are all decades older than in the other), such studies randomly assign the participants to each group: some to receive the experimental treatment and others to receive either the conventional, current treatment or a placebo – an inactive substance or a sham (or "dummy") treatment. These randomized controlled trials represent the gold standard approach to determining, with certainty, whether a new treatment is both effective and safe.

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3. **Blinded analysis.** When scientists design and conduct their experiments, what prevents them from (either purposefully or unintentionally) selectively reporting the data that support their hypotheses? To prevent such bias from creeping in, scientists can use a "blinded analysis" to avoid "seeing the answers" ahead of time. For example, in a clinical trial to test the effectiveness of a drug or vaccine, the investigators conducting the study typically do not know which participants receive the treatment and which get a placebo. Very often, the participants themselves don't know, either—ensuring that nobody involved in the study can inadvertently sway the results.

4. **Statistical Validation.** Scientific data will always exhibit some degree of variability, so researchers use statistical analyses to

assess how likely it is that a particular result is "real," as opposed to something that could have happened by chance. To avoid being misled, good scientists design their experiments with all the appropriate controls, replicate samples, and a total sample size that is large enough to assure them that their results are meaningful and not simply due to random luck.

5. **Peer review.** Everything that scientists do is subject to review by fellow scientists. Before they even begin their research, investigators typically submit requests for funding to pay for their experiments, explaining what they intend to do and how they intend to do it. These applications are evaluated by other researchers to ensure that only well-designed projects will receive financial backing. The articles that scientists write to describe their research are similarly assessed before being published in "peer-reviewed" journals. In this process, scientists with the required expertise (whose identities are generally not revealed to the study's authors) give feedback on the paper before it is accepted for publication. Last but not least, once research papers are published, all of the information they present is subject to critique by the broader scientific community.

Although individual scientists may get things wrong, community-driven corrections allow the field to progress toward an ever-greater understanding.

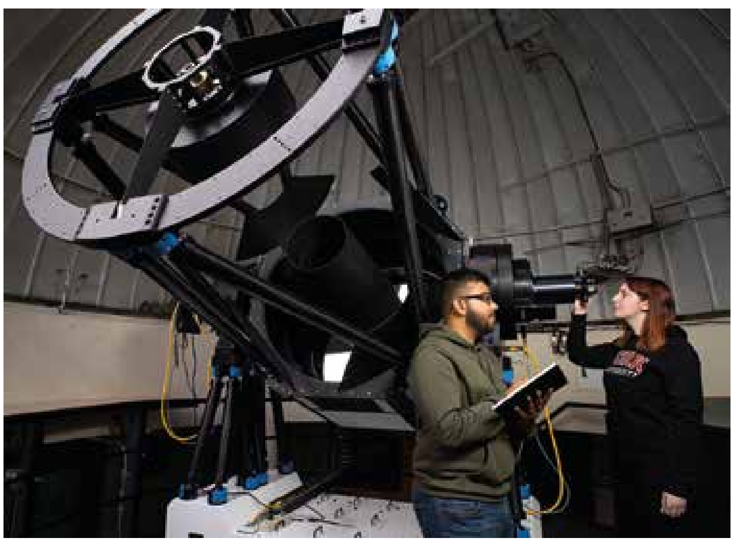
By publishing their results and subjecting their methods and analyses to critical review, scientists facilitate the exchange of ideas, challenge hypotheses and interpretations, and encourage each other to continually reassess their theories and refine their conclusions. Thus, although individual scientists may get things wrong, community-driven corrections allow the field to progress toward an ever-greater understanding.

Only the claims that have passed the rigorous testing of community-wide experimentation and critque are accepted as provisionally valid, thereby moving us toward a consensus that is reliable and in which we can trust. As scientist and historian Naomi Oreskes says in her book *Why Trust Science:* "…the basis for our trust is not in scientists—as wise or upright individuals—but in science as a social process that rigorously vets claims."

Science Is a System for Understanding the World that Generates Testable Predictions

Science does not progress by simply confirming the same information, under the same set of circumstances, again and again. The beauty of the scientific enterprise is that it uses past observations and experiments to predict how the natural world will behave in the future. It does so by producing models: conceptual frameworks for how things work. These models are then tested repeatedly by investigators in other labs—and even in other fields of science—to determine whether they always hold true. New experiments may confirm a model, lead to its alteration in small or large ways, or prompt its rejection and replacement with one that better accommodates all of the data.

In this way, science has produced a vast web of interconnected, well-established knowledge that allows us not only to describe or account for the things we observe today—but to predict what will happen tomorrow, next Tuesday, and 100 years from now. In the late 1600s, Sir Isaac Newton came up with his laws of motion to explain how physical forces affect the movement of objects. These laws are still valid today. Anywhere on the planet, we can use them to gauge how fast to run to intercept a pass, or how to nail a kickflip on a skateboard. But the same laws also apply in space, where they can predict, with almost uncanny accuracy, when the next solar eclipse will take place, how much fuel a rocket ship needs to get to Mars, or whether detonating a precisely targeted explosion will provide enough force to alter the path of an asteroid that might otherwise collide with the Earth in five months, five years, or five centuries.

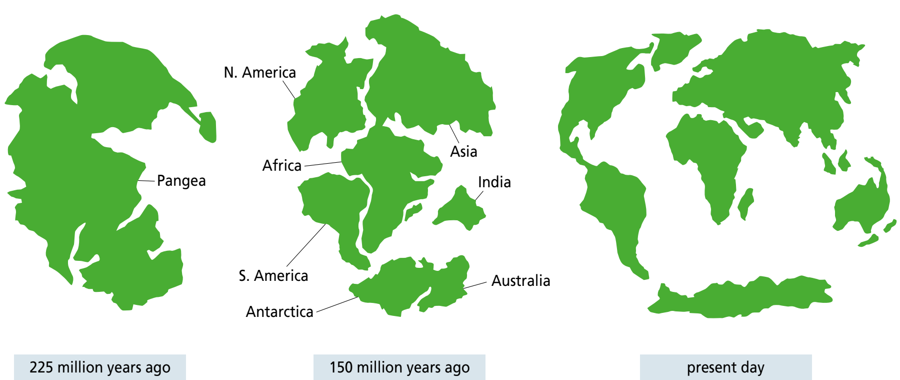


Courtesy of York University (Toronto, Canada)

Scientific Thinking Is Continually Refined by New Evidence, and It Can Sometimes Produce a Major Change in How We View the World

It's clear that science is an iterative, never-ending process of exploration and analysis in which even popular ideas are continuously re-evaluated as scientists make new observations and gather fresh evidence. As the methods available to make these observations become ever more powerful, they not only fuel new discoveries, but allow older ideas to be revisited with fresh eyes. In some cases, the new evidence can totally upend the way we see the world.

In the early 20th century, for example, scientists had a handful of theories regarding the movement of the continents on earth. One held that they formed early in geological history and remained right where they arose. Another proposed that the young earth had contracted as it cooled, causing its surface to buckle and fold like the skin of a dried up raisin. Those wrinkles, it was thought, caused the land to shift up or down, forming the ridges of mountain ranges and the sunken depths of the ocean floors.



The theory of plate tectonics reveals how the continents are currently thought to have moved over time. Although the concept of continental drift was proposed more than a century ago, it took decades of observation, and the development of new technologies, to amass the evidence needed to confirm the bold and startling concept—initially thought to be impossible—that the continents are slowly creeping across the Earth's surface.

Then, in the early 1900s, a German meteorologist, Alfred Wegener was contemplating how, on a world map, the contours of South America and Africa looked like they fit together, like the pieces of a jigsaw puzzle. He made the astounding proposal that all of Earth's continents were moving laterally across its surface, and that they had once been part of a single large mass, called Pangea, that gradually pulled apart over hundreds of millions of years.

But solid evidence that the ground upon which we stand is not as stable as it seems would not come until the 1950s, when geologists used sonar to map the ocean floor. Instead of the smooth surface that they expected, they discovered mountain ranges and trenches that were formed as the seafloor spread. Through the 1960s, scientists continued to survey the ocean floor, studying the way that magnetic materials aligned as ancient rocks were formed. The data they collected showed that not only have the continents shifted relative to one another, but so have massive slabs of the Earth's crust—the so-called "tectonic plates" upon which the planet's continents and its oceans all ride. This slow creep, about as fast as your fingernails grow, can now be directly measured using the Global Positioning System (GPS). And continued observation and study of this phenomenon is critical: it is the movement of tectonic plates that gives rise to volcanoes and to earthquakes.

Courtesy of Tom Mumford, Univ. of Washington Friday Harbor Labs

Most Scientific Knowledge Builds Gradually Toward a Reliable Consensus

Although the process of scientific inquiry occasionally leads to dramatic changes in our understanding of the natural world, as it did for the tectonic plate finding, most changes in scientific knowledge are much more gradual. As more and more studies are conducted, the community moves toward a deeper understanding of a problem or question, one small step at a time.

Consider the idea that diseases can be caused by microorganisms. In the 18th and 19th centuries, curious physicians and scientists with access to a microscope reported detecting germs (then called animalcules or "little animals") in infected wounds or blood samples collected from people with the plague and other awful diseases. But were these tiny creatures the cause of the illness?

The German doctor Robert Koch was the first to link a specific microorganism with a specific disease. He began his work studying anthrax, a disease that affected livestock as well as humans. Examining the blackened blood of diseased cows and sheep, Koch could see what appeared to be tiny sticks or threads. The same little sticks were never found in the blood of healthy animals. Koch then dipped a small sliver of wood into the blood from a diseased animal and used it to inoculate a mouse. When that mouse succumbed to anthrax, Koch found that its blood was also teeming with the suspicious sticks.

The discovery that a particular type of rod-shaped microbe causes anthrax. This photograph, taken through a microscope by Robert Koch, was published in 1877.

Even then, Koch couldn't be sure that there wasn't something else in his sample that was causing the disease. So he came up with a technique for growing microbes in a culture dish so they would form individual colonies, each of which contained a pure population of only one type of germ. This careful, step-by-step approach allowed him to prove that a specific microbe, which he collected and then cultured in the lab, could cause a specific, deadly disease.

Using a similar approach, Koch discovered the microbe that causes tuberculosis (TB)—one that is distinct from the little sticks that cause anthrax. For this work, Koch was awarded a Nobel prize in 1905. And many other discoveries followed suit. Only decades later would the same sort of sleuthing lead to the isolation of the virus that causes flu. Viruses are even harder to study than bacteria because they are too small to be seen using a light microscope. Thus, when clinicians looked at nasal swabs from people sick with flu, they could not see an obvious culprit. But in 1933, researchers in the UK took "throat washings" gargled up by their sick colleague and ran it through a fine filter that would remove larger objects, including cells. What remained was a fluid that contained something so tiny that it was invisible, yet so infectious that when it was dripped into the nostril of a ferret, it gave the animal all the symptoms of flu—including a stuffy nose, sneezing, and fever. These experiments, which showed that filtered phlegm from a sick person but not from a healthy one could spread disease, pointed researchers toward the virus responsible for the repeated influenza epidemics that had killed many millions of people across the globe.

Today, clinicians and researchers can collect samples from people with an unknown illness and use powerful DNA technologies to quickly screen them for genes that are associated with hundreds of known disease-causing viruses, bacteria, parasites, and fungi. Such an approach led to the rapid isolation and identification of the virus responsible for COVID. Determining what sort of germ causes an infection is the first step toward developing vaccines and treatments that can slow or prevent the disease. In the case of COVID, the initial discovery of the virus was rapidly followed by studies of how it gets into host cells and how it is transmitted from person to person—findings that were quickly confirmed by multiple laboratories around the world. This understanding drove the development and administration of a novel vaccine to billions of people less than a year after the first reports of infection. Such rapid progress from a basic discovery to a clinical benefit shows that—even with checks and balances in place (including controlled, blinded trials and peer review)—science can sometimes reach a consensus in record time.

Understanding the Scientific Process Can Help Us Differentiate Between Misinformation and Legitimate Science

Thanks to the explosive expansion of the internet and the inescapable spread of social media, most of us now have virtually unlimited access to a tidal wave of information—as well as misinformation. Today, anyone can promote products or ideas to hundreds or thousands or even millions of people with the click of a button. Sadly, a great deal of this information is not accurate. People with a large number of online followers, but little scientific background, can publicize dubious or unconfirmed studies – or even fabricate them out of thin air. Some advocate sincere but unscientific or disproven beliefs, like the link between autism and childhood vaccines. Others foster falsehoods for financial gain, like oil company lobbyists who deny the role that fossil fuels are playing in global climate change. In this informational free-for-all, false claims often become quickly sensationalized and disseminated to millions of people.

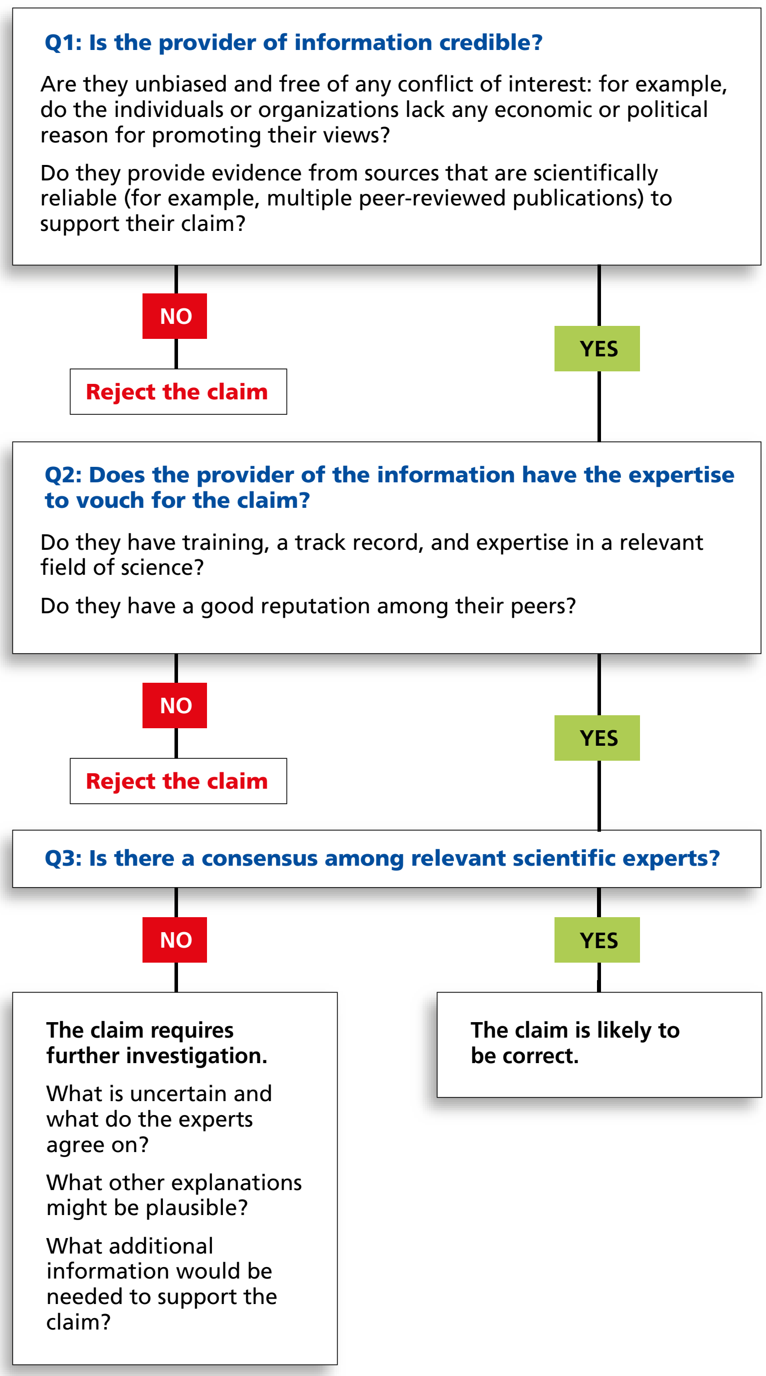
> Given that we can't be experts in most fields of science, how can we determine whether a particular study or story is trustworthy?

We all need to think critically when we read or see stories on the web, on social media, or in the popular press. However, given that we can't be experts in most fields of science, how can we determine whether a particular study or story is trustworthy? How can we inoculate ourselves against being fooled by scientific untruths or misrepresentations? Researchers devoted to promoting science literacy have devised a three-step process for separating science fact from science fiction.

The first and perhaps most critical step involves evaluating the source of the claim. Who is providing or promoting the information? Do they have economic or political reasons to spread these views? What, if anything, might they be selling?

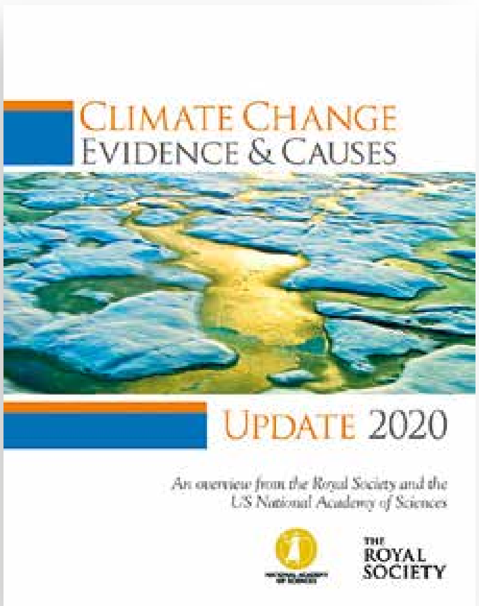
Next, it is important to ask whether the source of the information has the expertise and credentials needed to validate their assertion. Do they have the appropriate training (an MD or PhD degree, for example) and do they conduct research in that particular field? Even highly respected scientists can be wrong when they venture too far from their areas of expertise. Not long ago, small groups of distinguished physicists insisted that it was uncertain that smoking caused cancer, cast doubt that acid rain was caused by power plant emissions, and (until their dying breaths!) opposed the idea that greenhouse gases cause climate change.

Having an advanced degree is clearly not necessarily a guarantee that someone will act ethically. The physicists just mentioned were heavily supported by financial backing from the industries that benefited from their “expert” testimonials. Therefore, another point to consider is whether the experts in question are generally respected by their



A simple, three-step process can be used to evaluate scientific information. This "fast and frugal" method uses three filters to differentiate between claims that are not supported by science and those that are. (Adapted from Jonathan Osborne and Daniel Pimentel, *Science* 378: 246-248, 2022).

scientific peers. During the early days of the COVID-19 pandemic, for example, a small but vocal group of physicians advocated the use of ivermectin (a horse de-worming drug) to prevent infection—a strategy that is not only ineffective, but can be harmful. Some of these clinicians had previously been criticized by their peers in the medical community for promoting other unproven and ineffective treatments. Yet they continued to publicize their unsupported claims, which were then amplified by influencers with no scientific or medical training at all.



A scientific consensus on human-induced climate change. This summary report was produced jointly by the science academies of the US and UK.

But what happens if the source of the story seems credible? At that point, it's time to assess whether a scientific consensus exists. This can sometimes be more challenging to discern. A good place to start might be the website of a reliable organization, such as a respected news outlet or the National Academy of Sciences (in the United States) or the Royal Society (in the United Kingdom). In the case of climate change, for example, the community of climatologists speaks with a broad consensus when it concludes that human activity is contributing to global warming.

False or exaggerated claims are often made about products targeted to health and wellness—even beauty. Billions of dollars are made each year through the sale of supplements and treatments that, at best, do nothing. The problem is that a rigorous scientific study of these products would be prohibitively expensive and almost impossible to conduct: volunteers can't be sequestered in a laboratory where their diets and behaviors can be meticulously monitored for years or even decades. But huge profits can be made by selling supplements that are supposedly "backed by science." The so-called experts promoting these products might even insist that they have been "proven 100% effective." Of course, any claims that offer absolute certainty should always be viewed with suspicion. One does not have to be an expert in any field of science to know that such a declaration is—literally—too good to be true!

Ensuring that Science Remains Trustworthy Requires Constant Vigilance

By now it should be clear that the entire scientific enterprise is built on trust. Integrity is so essential to science that Albert Einstein once remarked: "Most people say that it is the intellect which makes a great scientist. They are wrong: it is character." Scientists trust one another to adhere to the standards and practices that the community has established to enable all researchers to rely on—and build on—each other's findings. This confidence is a foundational component of the iterative process of investigation that allows scientists to come to a consensus and provide us with knowledge that we can trust.

Albert Einstein once remarked: "Most people say that it is the intellect which makes a great scientist. They are wrong: it is character."

At the same time, scientists have an obligation to be open and honest with all of us. Much of the authoritative research we encounter in the news is supported by our taxes. And lives can depend on whether scientific studies are conducted rigorously and presented accurately. Scientists therefore have an ethical responsibility to communicate their findings in a clear and straightforward manner, to honestly explain what their conclusions mean (and what they don't mean), and to make their data as available as they can for public scrutiny.

This policy of openness did not arise spontaneously. The worldwide institution of science, as a whole, has long worked to establish a system of values and incentives that strongly encourage investigators to be meticulous with their methodology and scrupulous when it comes to sharing their results. Thus, the scientific community actively discourages various forms of "bad behavior," including the publication of fraudulent or misleading data and the promotion of unverified research. Such misconduct can waste precious resources and limited funding, erode public trust, hamper discovery, and lead us farther from the truth—thereby undermining the primary objective of scientific research.

Maintaining the cultural values of science requires a continuous input of energy and attention. Leading

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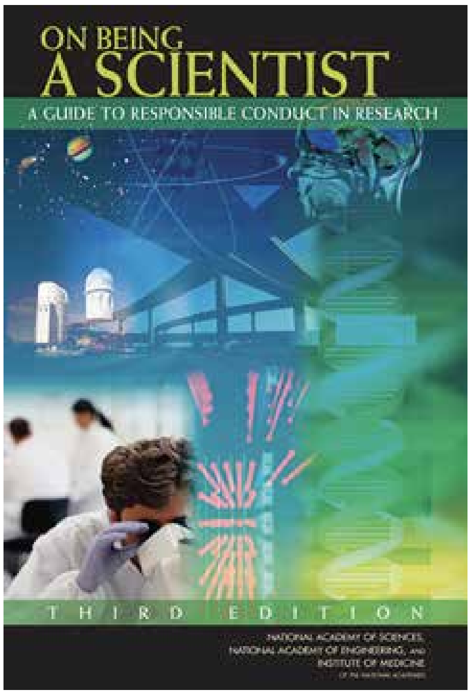
the way are venerable scientific academies, including the Royal Society in the UK (established in 1660), the US National Academy of Sciences (signed into existence by President Abraham Lincoln), and The World Academy of Sciences (a global science academy based in Trieste, Italy, working to advance science and engineering for sustainable prosperity in the developing world). Institutions like these shore up the pillars of science by educating future generations of scientists and instilling in them the community values and practices that are required for science to remain healthy.



Scientific academies educate young scientists about proper scientific practice and also strive to protect the scientific enterprise. The US National Academies produced this guide, which can be downloaded for free, to describe what responsible conduct in science looks like and to encourage good practice for scientists-in-training.

By describing clearly how researchers can act responsibly and ethically, and outlining some of the pitfalls that scientists-in-training may face, these institutions encourage the practice of sound science and help to root out scientific malpractice. Consider, for example, the publication *On Being a Scientist*. Featuring examples based on real-world experiences, this guide allows students to think through case studies that mirror dilemmas they may face in their own careers and exposes them to issues that are central to maintaining the standards and practices of the scientific profession.

But reading exhaustive and extensive reports on scientific integrity is not enough. Students learn to do good science by example. As bioethicist Paul Root Wolpe writes: “Behaving ethically is the principal way that mentors transfer the ethical standards of their profession to their trainees. All the formal ethics training in the world cannot compensate for an unethical mentor.” Senior scientists must therefore practice the type of upstanding behavior that they wish to propagate.

To Remain Worthy of Public Trust, Scientists Must Police Their Own Ranks to Root Out and Punish Those Who Behave Unethically

In an ideal world, no scientist would ever stray from a virtuous search for truth. Unfortunately, scientists—like all professionals—are not only human, but are under intense pressure to succeed. They must compete constantly to garner recognition, research grants, and the trainees they need to help them carry out their work. They must often work quickly to avoid being "scooped", and they seek to present their findings in the most widely read journals (a phenomenon sometimes referred to as "publish or perish"). This ever-present pressure can lead to shortcuts in the scientific process that go undetected by peer review, such as the manipulation of data or images by a member of the research team in order to create a more convincing publication. In an analysis conducted in 2009, some 2% of the scientists surveyed admitted to fabricating, falsifying, or modifying data at least once.

How can the scientific community prevent such ethical breaches? Best practices and proper conduct need to be outlined, exemplified and practiced at all levels of the scientific enterprise—from individual scientists to their institutions and funders. At the same time, all of these participants must remain ready to identify and investigate allegations of misconduct. Technology can help: software programs, for example, can facilitate detection of manipulated figures or plagiarized text.

Transgressions, when caught, must lead to formal sanctions. These can include the retraction of publications and the subsequent correction of the scientific record, suspension or removal of the perpetrators from their positions, and the revocation of their funding—either temporarily or permanently. In instances in which the misbehavior amounts to a violation of the law, the individual may even face time in prison. Such was the case for the Chinese researcher who used gene editing to irreversibly alter human embryos, a practice that is not only unethical, but—based on the current consensus of the scientific community—illegal in China and throughout the world.

In the end, the responsibility for improving the public image of science falls largely on scientists themselves. Only by energetically identifying and punishing the “bad actors,” while supporting and rewarding those who play fairly and operate with openness and honesty, can the worldwide scientific enterprise ensure that we can continue to trust in the community of scientists—and in the science they produce.

Trust in Science is Essential for Our Future as a Civilization

Science has produced such a vast array of knowledge about how the natural world operates that it not only allows humanity to foresee likely future calamities -- such as climate change or a catastrophic collision with a far-away asteroid --but to take actions today to prevent them. By producing reliable predictions about future events, science makes all of our lives safer.

At the same time, science is becoming increasingly central to so many of the concerns we currently face, from the perils of pandemics to the ethical concerns raised by the development of ever more powerful techniques for engineering genes, including our own. We have to know how to identify good science to be able to make intelligent, well-reasoned decisions on these issues that affect our personal lives -- and to protect the health, integrity, and future of society as a whole.

With this essay, we have tried to provide insights into the scientific process and how scientists, as a community, strive to uncover the truth about the world in which we live. Appreciating how the practice of science leads to new knowledge can help us all to become more critical consumers of scientific content and better informed, more confident thinkers and citizens.

Key Takeaways

Science produces reliable knowledge as a broad community effort, guided by a critical set of standards and values.

Critical scientific values include an insistence on evidence, honesty, a healthy dose of skepticism, and an openness to new interpretations and ideas.

Standards that support these values include publishing the experimental details needed for others to replicate or refute one’s findings, randomized

control trials, blinded analyses, statistical validations, and peer review.

A scientific consensus represents humanity's best approach to the truth, but it can never be 100% certain, as it must be kept open to change based on new evidence and ideas.

A good scientific explanation makes logical and testable predictions about the system being studied.

Most scientific knowledge improves gradually, with refinements that bring it ever closer to the truth.

The pervasiveness of social media has vastly expanded the influence of fake science, exposing us all to massive amounts of misinformation to tragic effect.

A solid understanding of science as a community-driven process can enable all of us to discern the truth and become "competent outsiders."

Links to selected free resources

Science, misinformation, and the role of education: "Competent outsiders" must be able to evaluate the credibility of science-based arguments. J. Osborne and D. Pimentel J, *Science* 378: 246-248, 2022 https://www.science.org/doi/10.1126/science.abq8093 A brief essay proposing a new role for science education

On Being a Scientist: A Guide to Responsible Conduct in Research, The National Academies Press, 2009. https://doi.org/10.17226/12192.
A booklet for scientists in training that emphasizes values and standards critical for the scientific community to be effective.

Science, Evolution, and Creationism. The National Academies Press, 2008. https://nap.nationalacademies.org/catalog/11876/science-evolution-and-creationism.
A booklet that emphasizes that science and religion represent two different ways of knowing about the world, and that accepting the evidence for evolution can be compatible with religious faith.

Nature of Science Lesson Sets. National Center for Science Education. https://ncse.ngo/nature-science-lesson-sets. Teaching resources that focus on “science as a way of knowing”, developed with the help of practicing science teachers.

Teaching Resources from the InterAcademy Partnership. https://www.interacademies.org/education/teaching-resources. This global effort emphasizes inquiry-based science education, with resources translated into multiple languages.

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