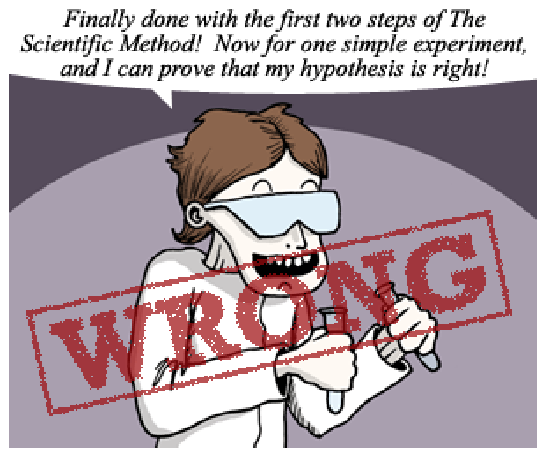
The social side of science: A human and community endeavor



The stereotypical image of a scientist is not a very social one: a geeky guy, isolated in a windowless basement lab, strictly following the rules of THE Scientific Method, until he finally makes a great discovery. No collaborators, no communication, no diversity. What's wrong with this picture? Well, several things:

1. First, as discussed in *How science works*, there is no single scientific method that can be blindly followed. The process of science is flexible and may take many possible paths.
2. Second, science is done by unique individuals — not by automated robots coldly following a routine without motivation, ambition, or creativity. Scientists are people too! Many of them care passionately about their work, and many of them are intensely creative. Their personalities, backgrounds, and goals are highly diverse.
3. And finally, science is embedded within a global scientific community. This community provides cultural norms, expectations, and accumulated knowledge, which are essential to the expansion of scientific knowledge.

In opposition to its stereotype, science much more typically works something like this: After reading up on the recent work of other scientists studying animal behavior, a scientist in Brazil gets an idea for a new bird song experiment while playing a word game with her kids. She calls a colleague in Canada to discuss the idea and to find out where she can get the recording software she will need for the experiment. She then recruits a few students and a visiting researcher from China to work on the project, and they apply for funding. After they complete the study, the team writes up the work and submits it to a journal for publication. The journal sends it out to three different scientists for review: one in Japan, one in the U.S., and one in the U.K. The reviewers like the study but suggest some changes to improve the statistical analysis. The team makes the changes and the paper is published several months later. A graduate student in France reads the paper with his lab group, emails the Brazilian researcher to learn more about her experimental procedures, and comes up with a follow-up experiment. He recruits another graduate student and a professor to work on the project with him … and so on. Compared to its stereotype, real science is more complex — but also more human.

Scientists do spend time working alone — in the field, in the lab, or at the computer — but most also collaborate on research with others. And, of course, scientists don't just do research. Most scientific work also involves reviewing other scientists' articles for journals, teaching, mentoring graduate students and younger scientists, speaking at conferences, and participating in scientific societies. So the job of being a scientist involves lots more than disappearing into a windowless lab and running an endless series of experiments!

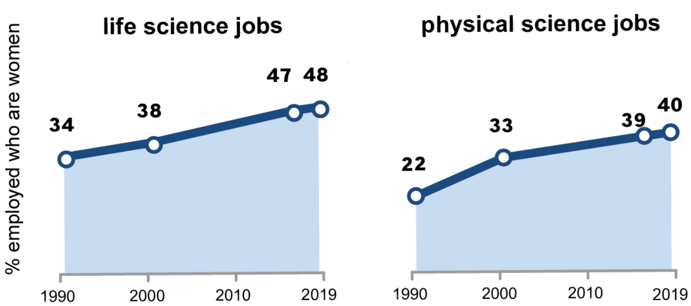
Here we'll discuss how individual scientists interact with the rest of the scientific community and how this benefits the progress of science. You can investigate:

- *The scientific community: Diversity makes the difference*
- *Science: A community enterprise*
- *Scientific culture: Great expectations*
- *The scientific community and misconduct*
- *Human endeavor, human biases*

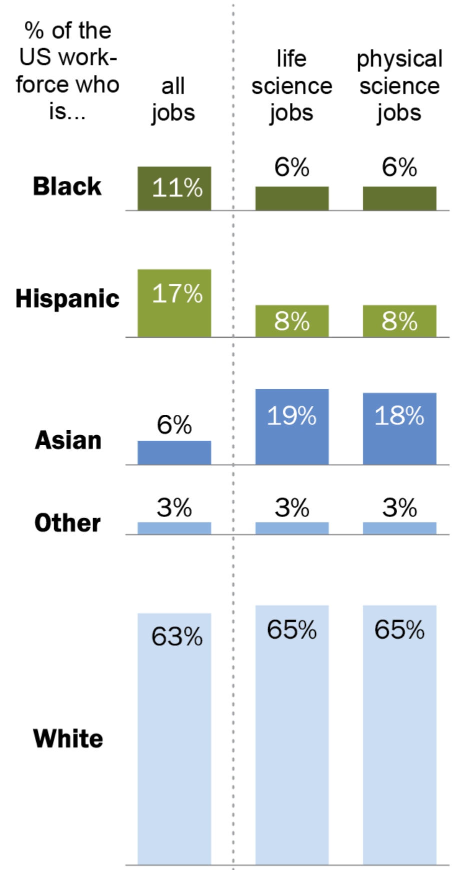
Or just flip to the next page to dive right in!

The scientific community: Diversity makes the difference

People from all over the world from all sorts of different cultures and backgrounds are a part of the scientific community, and science benefits from these different perspectives and contributions. At many points in history, Western science *has* been the exclusive domain of white men, but that is changing … slowly. For example, since people who identify as women represent about 50% of the U.S. population, they *should* make up 50% of scientists, too; over the past 30 years, women have come to hold a larger share of jobs in the life and physical sciences in the U.S. – though not half yet. And while Hispanic and Black people make up a significant percentage of the life and physical science workforce in the U.S. today, they still face barriers that lead to underrepresentation and are paid less than white and Asian workers.[1] Many people are working on a variety of fronts to expand access and stamp out exclusion, but there is a long way still to go.[2]



The percent of the life and physical science workforce who identify as women has increased over the last 30 years. Source: Pew Research Center, April, 2021, "STEM Jobs See Uneven Progress in Increasing Gender, Racial and Ethnic Diversity."



The racial makeup of the U.S.'s life and physical science workforce is skewed, with white and Asian scientists overrepresented. Source: Pew Research Center, April, 2021, "STEM Jobs See Uneven Progress in Increasing Gender, Racial and Ethnic Diversity."

Of course, "diversity" includes much more than just racial and gender identity – and the scientific enterprise benefits from participants with different cultures, religions, ages, sexual orientations, gender identities, disabilities, incarceration histories, classes, and so much more. Here are just a few of the ways that science benefits from diverse participants:

Diverse scientists ask diverse questions

While science can investigate any part of the natural world, progress is only made on those questions that scientists think to ask. Our backgrounds and identities shape the questions we ask about the world. For example, Black scientists are more likely to study health disparities than are white scientists, and female scientists are more likely to study pregnancy and education than are male scientists.[3] If we want science to address the whole natural world and problems that affect *all* sorts of people, then we need *all* sorts of people to be able to participate in science.

Diversity facilitates specialization

Scientists have different strengths and different interests. People from different backgrounds may approach the same question in different ways. So, the biologist with a penchant for math, the biologist with an interest in human behavior, and the biologist who can't get enough of microscopes and lab work can all focus on their strengths. While each might choose to tackle the same topic (say, human cognition), they will do so from different angles, contributing to a more complete understanding of the topic.

Diversity invigorates problem solving

Science benefits greatly from a community that approaches problems in a variety of creative ways. A diverse community is better able to generate new research methods, explanations, and ideas, which can help science over challenging hurdles and shed new light on problems. For example, scientists who study how science works (yes, that's a thing!) have found that scholars from historically excluded backgrounds (e.g., African-American PhD students) produce more innovative research than their counterparts from overrepresented backgrounds.[4] Similarly, because of their identities and backgrounds, Indigenous scientists often see ecological challenges in different terms than scientists from dominant backgrounds; in particular, they may be more likely to take a holistic approach, integrating many subdisciplines of biology and recognizing the interconnected nature of an environmental problem.[5] Indigenous scientists also have access to valuable traditional knowledge built from generations of experience with and connections to a particular place, such as recognizing differences in subspecies that non-indigenous scientists might not.[6] Diverse perspectives simply lead to richer and more exciting scientific discoveries.

NEURODIVERSE IDEAS

Temple Grandin. Photo credit: Flickr user ALA The American Library Association.

Scientist Temple Grandin studies animal behavior. She is well known for investigating how animals raised as livestock react to their surroundings and for developing ways to make our treatment of livestock more humane. Grandin is autistic and has explained in interviews and talks how this has deeply shaped her science. For example, she describes her own thinking as based in pictures, not words, and credits that aspect of her autism with helping her relate to livestock animals and focus on their visual perception.[7] This was an important part of her early research, which showed how small visual elements in a slaughterhouse, like shadows, can cause stress for livestock. Grandin's autism led to research and compassionate innovations in the livestock industry that might not have come about otherwise.

Diversity balances biases

Science benefits from practitioners with diverse beliefs, backgrounds, and values to balance out the biases that would occur if science were practiced by a narrow subset of humanity. As an example, consider the ongoing scientific investigation of climate change. With such a hot-button issue, personal beliefs about the environment, the economy, business, and politics could unwittingly bias one's search for or assessment of the evidence. But science relies on a diverse community, whose personal views run the gamut: liberal to conservative, tree-hugging to business-friendly, and all sorts of combinations thereof. Scientists strive to be impartial and objective in their assessments of scientific issues, but when personal biases sneak in (and they are bound to – scientists are, after all, human!), a diverse scientific community can help keep them in check.

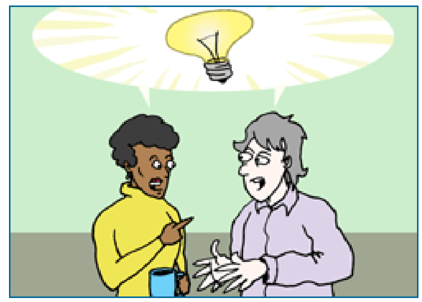
We should do all we can to support more different sorts of people becoming scientists, not only because everyone deserves to be able to pursue their curiosity and experience the joy of science, but also because we *all* stand to benefit from science informed and pushed forward by diverse perspectives. If scientists were all the same, scientific controversy might be rare, but we would learn less about a much smaller portion of the natural world. Science depends on diversity – and yet, science has been, and very often still is, exclusionary. Many people are beginning to recognize this and are taking steps on a variety of fronts to make science more inclusive – from training to hiring, from workplace culture to funding systems. There is a long road to travel before science will reflect the diverse societies in which it is embedded and serve the whole spectrum of the world's inhabitants.

[1]Pew Research Center, April, 2021, "STEM Jobs See Uneven Progress in Increasing Gender, Racial and Ethnic Diversity."
[2] Tilghman, S., Alberts, B., Colón-Ramos, D., Dzirasa, K., Kimble, J., and Varmus, H. (2021). Concrete steps to diversity the scientific workforce. *Science*. 372: 133-135.
[3] Hoppe, T. A., Litovitz, A., Willis, K. A., Meseroll, R. A., Perkins, M. J., Hutchings, B. I.,… and Santangelo, G. M. (2019). Topic choice contributes to the lower rate of NIH awards to African-American/black scientists. *Science Advances.* DOI 10.2226/sciadv.aaw7238
Kozlowski, D., Larivière, V., Sugimoto, C. R., and Monroe-White, T. (2022). Intersectional inequalities in science. *Proceedings of the National Academy of Sciences* USA. 119: e2113067119.
[4] Hofstra, B., Kulkarni, V. V., Munoz-Najar Galvez, S., and McFarland, D. A. The diversity-innovation paradox in Science. (2020). Proceedings of the National Academy of Sciences USA. 117: 9284-9291.
[5] Hernandez, J. (2022). Fresh Banana Leaves: Healing Indigenous Landscapes Through Indigenous Science. North Atlantic Books.
[6] For example, see Stronen, A. V., Navid, E. L., Quinn, M. S., Paquet, P. C., Bryan, H. M., and Darimont, C. T. (2014). Population genetic structure of gray wolves (*Canis lupus*) in a marine archipelago suggests island-mainland differentiation consistent with dietary niche. BMC Ecology. 14: 1-9. For more on the potential future relationship between traditional and western scientific knowledge, see Reid, A. J., Eckert, L. E., Lane, J., Young, N., Hinch, S. G., Darimont, S. J. C., … and Marshall, A. (2020). "Two-eyed seeing": an indigenous framework to transform fisheries research and management. *Fish and Fisheries*. https://doi.org/10.1111/faf.12516
[7] Richter, R. (2014). 5 Question: Temple Grandin discusses autism, animal communication. Stanford Medicine News Center. https://med.stanford.edu/news/all-news/2014/11/5-questions--temple-grandin-discusses-autism--animal-communicati.html

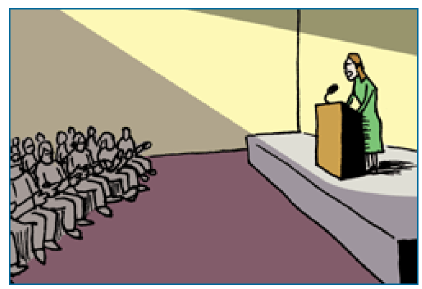
Science: A community enterprise

Most large-scale human endeavors involve a supporting community. From high schools to dairy farms, political parties to professional snowboarding competitions — they all rely on diverse communities with different members fulfilling different roles. And science is no exception. The scientific community is made up of researchers, students, lab technicians, the people who work at scientific journals, employees at funding agencies — in short, anyone who helps science govern itself and move forward.

In *How science works*, we briefly summarized some of the nitty-gritty, day-to-day functions served by the scientific community. Here, we elaborate on those and discuss broader functions served by the community:



Inspiration. Community-level interactions encourage innovation and spark ideas about new lines of evidence, new applications, new questions, and alternate explanations. For example, James Watson and Francis Crick came up with a new and brilliant idea for the structure of DNA, but that idea did not come out of the blue. The idea was sparked by evidence that many other scientists (including Linus Pauling, Erwin Chargaff, Maurice Wilkins, and especially Rosalind Franklin) discovered and made available to the scientific community prior to the Watson/Crick model.



Motivation. Some people are driven by the thrill of competition — swimmers swim faster, politicians campaign harder, and students study more for college entrance exams when they know that they are competing against others. Scientists are no exception. Some scientists are motivated by the sense of competition offered by the community (e.g., rival teams racing to unlock the sequence of the human genome). Similarly, the community offers scientists the prospect of recognition from their peers. In science, achievement is usually measured, not in terms of money or titles, but in terms of respect and esteem from colleagues. The idea of uncovering a new line of evidence relating to the Big Bang is motivating in and of itself, but many scientists also appreciate the respect from other scientists that making such a discovery would engender. In science, both competition and recognition from the community encourage going out on a limb, testing a new idea, creative thinking, and plain old hard work.

RACING FOR THE HUMAN GENOME

In the 1980s, scientists set their sights on what seemed to be a lofty, but for the first time, achievable goal: to record the DNA sequence of the three billion or so base pairs that make up the human genome. In 1990, the publicly funded Human Genome Project (HGP) began its work in earnest, using a tried and true sequencing technique that begins with a map of genetic landmarks on each chromosome. However, in 1998, that effort was challenged by a private company, Celera. Celera proposed to decode the genome using a new so-called shotgun technique that didn't require an initial landmark map — and to complete its work in just three years, four years before the HGP would complete their sequence! This competition inspired the HGP to accelerate their work and move their target completion date up to rival Celera's.
In the end, this rivalry propelled both efforts forward. Both teams published their working drafts of the genome ahead of schedule in February of 2001 — and when they did, the private team's paper had more than 100 authors and the HGP's had more than 1000. Talk about teamwork!

You can check out the long list of authors for one of these seminal papers on the Science website.

Division of labor. Science is simply too broad for an individual on his or her own to handle! Even research within a single narrow field (e.g., cellular biology) may cover an immense array of specialized topics, from the chemical details of decoding DNA to cellular communication. That specialized knowledge is divided up among different researchers, who may then share their expertise by working together. Collaborations and division of labor are increasingly important today, as our scientific understanding, techniques, and technologies expand. There's simply more to know than ever before! And as we learn more about the world, more research is performed at the intersections of different fields: chemical reactions within cellular organelles, the mathematics of protein folding, the interplay between Earth's geologic history and biological evolution, or the physics of snail locomotion. Such cross-disciplinary studies are better approached by a team of experts from different fields than by a single individual struggling to keep up-to-date with too many topics.

A cumulative knowledge base. Science builds on itself. We wouldn't have general relativity if we didn't have classical mechanics. And we wouldn't have classical mechanics if we didn't have Galileo's studies of motion and revolutionary ideas about astronomy. A similar deep history spanning hundreds of years could be given for almost any scientific idea. The scientific community provides the cumulative knowledge base on which science is built.

Scrutiny. Participating in the scientific community involves scrutinizing the work of others and allowing your own work to be similarly evaluated by your peers. This system of checks and balances verifies the quality of scientific research and assures that evidence is evaluated fairly.

Scientific scrutiny

The scientific community provides a system of checks and balances that ensures the quality of scientific work, double-checks arguments, and makes sure that ideas are evaluated fairly. This scrutiny can serve a few different functions — from fact-checking to whistleblowing:

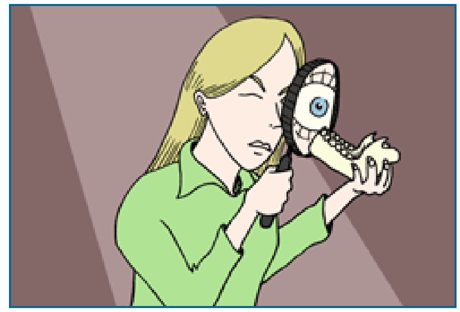
The community evaluates evidence and ideas. Scientists describe their work at conferences, in journal articles, and in books. By disseminating their ideas, study methods, and test results in these ways, scientists allow other community members to check their work, both by reviewing what has been done and trying to replicate all or part of it. This helps to ensure that evidence meets high standards, that all relevant lines of evidence are explored, that judgments are not based on flawed reasoning, and hence, that science moves in the direction of more and more accurate explanations. For example, in 1989, when two scientists claimed to have produced nuclear fusion at temperatures lower than was thought possible, the scientific community took a close look at their methods and results. Community members found several ways to improve the experiments and several tests that the original researchers had failed to perform. Meanwhile, other scientists got started on trying to replicate the experimental results and discovered that they could not be consistently reproduced. The scientific community ultimately found that the evidence was not compelling enough to warrant accepting the researchers' claims.

The community balances biases. Scientists are people too. They come from different backgrounds, have different personal beliefs, and favor different hypotheses and theories — and all of that can result in unintentional biases — even when scientists strive to remain objective. Luckily, the scientific community is diverse, and for every scientist who looks at a result through rose-tinted glasses, there is another who peers at it through her own blue-tinted ones. Because of the community's diversity, individual biases are balanced out and the community as a whole can evaluate scientific ideas fairly.

CHECKS AND BALANCES

Before the 1970s, the field of primatology was dominated by men. Male scientists observed and recorded primate behavior in the wild, male scientists developed explanations to understand those behaviors, and male scientists read and evaluated each others' work. And at that time, observations suggested that primate social life was largely controlled by males, with females playing a more passive role. But that changed when women scientists began to work in the field in the 1970s. Because of their own gender experiences, these women paid more attention to subtleties in the female primates' behavior, and revealed that female primates actually have elaborate sex lives and manipulate male behavior in many ways. So in this case, a diverse assemblage of scientists counterbalanced each others' biases, leading to a more complete and accurate understanding of primate societies.

Black and white portrait of Jeanne Altmann. Jeanne Altmann has studied the behaviors and social interactions of primates, primarily baboons, for more than 35 years. Photo credit: Jeanne Altmann.

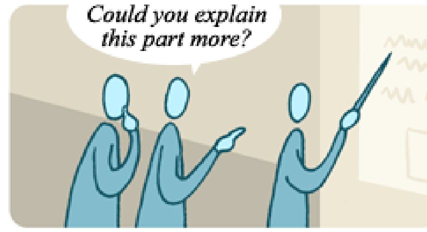


The community helps identify and eliminate fraud. Though fraud is rare in science, it sometimes happens. These occasional cases of fraud are identified through the scrutiny of the scientific community. For example, a recent case in which medical researcher Jon Sudbø faked data on 900 Norwegian patients was discovered by another scientist familiar with the group of patients with whom he claimed to be working. Because they build upon the work of others, scientists take fraud very seriously. No one wants to build their own work on a shaky foundation supplied by fraudulent ideas. To learn more, skip ahead to *The scientific community and misconduct*.

Science depends on its community in many ways: from the specific (e.g., catching a mistake in an article) to the general (e.g., dividing up the enormous amount of work that keeps science moving forward). Being part of that community means meeting some expectations…

Scientific culture: Great expectations

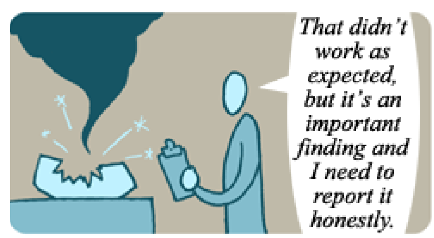
While we typically think of culture as defined by geography or ethnicity (e.g., American culture, Chinese culture), the term also applies to the practices, behaviors, and expectations of smaller groups of people — whether they're a gang of skateboarding youth or the employees of a high-powered consulting firm. Though embedded in the larger culture surrounding them, such subcultures have their own sets of unwritten rules for interacting with one another, and scientists are no exception. In science, these rules of good behavior are fairly general but are essential to maintaining the quality of scientific evidence and ideas. The scientific community expects:



Rigorous scrutiny. Imagine that you walk into a room where someone is speaking to a crowd of people. Audience members are questioning the speaker intently: "Did you consider …? But what about …? Why do you think that …?" In many communities, such intense scrutiny would signal distrust of the speaker, but in science, such scrutiny is business-as-usual. In fact, it often means that the speaker has made an important point that everyone cares enough about to question and investigate further. In science, all ideas (especially the important ones!) must stand up to rigorous scrutiny. The culture of science does not value dogma. Scrutinizing, questioning, and investigating important ideas helps ensure that only ideas supported by evidence and based on sound reasoning are accepted by the community.

IS IT REALLY ALL RELATIVE?

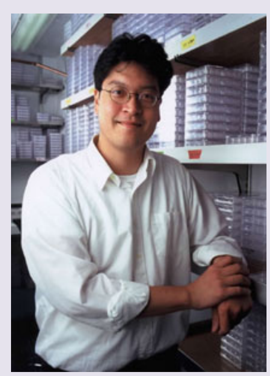
Albert Einstein's writings on special and general relativity presented a novel picture of the universe: time could expand and contract, space was integrated with time into the new entity space-time, and matter could theoretically be reconstituted in the form of energy. When general relativity was proposed in 1916, the ideas were strange to many and confusing to others, but definitely intriguing — especially since the theory helped make sense of previously inexplicable anomalies, like aberrations in the orbit of Mercury. Immediately afterwards and right up to today, scientists continue to scrutinize and test Einstein's ideas, not because they think that general relativity must be wrong — but because so many aspects of those ideas seem to be right!



Honesty, integrity, and objectivity. The aim of science is to uncover the real workings of the natural world, and that requires honesty. You can't get to the truth by exaggerating results, fudging numbers, selectively reporting data, or interpreting evidence in a biased way. Hence, scientists expect other scientists to act with honesty and integrity, and treat any violation of this expectation quite seriously.

THE BEST POLICY

In science, honesty really is the best policy — even if that means publicizing a slip-up. Geoffrey Chang, a professor at the Scripps Research Institute, has made a successful career working out the physical structures of proteins used in cell membranes. His work was published in top journals and cited by other scientists many times. Then, in 2006, he found a mistake. Prompted by conflicting results from other researchers, Chang discovered that, for the past five years, he had been analyzing his data with a flawed computer program, leading to incorrect results. So what did he do? Exactly what the culture of science expected of him: he published letters retracting his previous work, offered an apology, and then started the work of reanalyzing his data in order to correct his results.

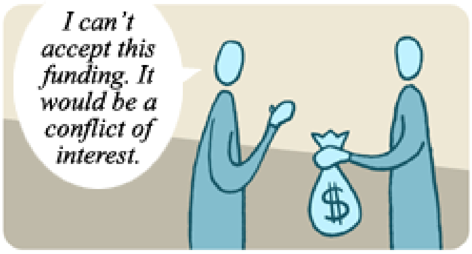


Geoffrey Chang. Photo credit: Scripps Research Institute.

Credit where credit is due. In science, credit matters. A magazine or newspaper article rarely acknowledges the sources of its arguments, the books the author read, or the interviews conducted. Science, on the other hand, is scrupulous about giving credit where credit is due. Scientific research articles always provide a list of citations, crediting other scientists for ideas, techniques, and studies that were built upon by the current research. This reference system gives credit to those who deserve it, but it also creates a sort of paper trail that helps other scientists better evaluate the new study and see how it fits with previous research. By providing a list of references, an author invites other scientists to see for themselves if the ideas the author cites are supported by evidence, if the assumptions he or she makes are justified, and if the techniques described by others have been properly implemented.

SETTING YOUR CITES

The number of citations a paper receives can help indicate how influential it was, since important research influences how other scientists think about a topic and will be cited many times in other papers. For example, the 1974 paper that originally hypothesized that chlorofluorocarbons would deplete the ozone layer has been cited more than 1700 times! Compared to many other papers published the same year (e.g., a paper on the nutritive value of coconut protein extract, which has received five citations), that's a pretty impressive statistic!



Adherence to ethical guidelines. Science is flexible and open to new ideas, but it is not an anarchic free-for-all. Many laws apply to science, and in many cases, scientists have constructed their own even more stringent guidelines in order to ensure that scientific work is of high quality, is performed in ethical ways, and benefits society. For example, scientific journals maintain an elaborate set of policies covering everything from scientists with a financial stake in their own studies, to biosecurity threats that might result from publishing an article, to the care and use of research animals, to how human participants in a study must be treated. Not abiding by these policies makes it difficult (or impossible) to get one's research published. Funding agencies maintain a similar set of guidelines that must be followed if a scientist hopes to get research funds from that agency. And of course, scientific organizations get in on the act too. For example, the National Academies (a group of premier scientific organizations in the U.S.) assembled more than 40 scientists to draw up a set of guidelines that balance ethical concerns about embryonic stem cell research with its potential rewards. Members of the scientific community are expected to abide by such guidelines.

KEEPING TABS ON TESTING

A cancer researcher discovers a chemical that she thinks might help treat leukemia. What should her next steps be? You might imagine that recruiting leukemia patients to begin testing would be next up — but in fact, jumping into human trials at this point would violate many federal regulations and international codes. In order to protect participants, scientists have drawn up a strict set of guidelines outlining when humans can participate in experiments and how they must be treated. These guidelines, known as human subjects protocols or policies for the protection of human subjects, cover everything from how much testing a drug must undergo before it reaches human patients, to what information participants must have before entering into a test, to what sort of paperwork study participants must sign. And these regulations apply to any sort of scientific research involving human participants — whether it's testing a new drug, monitoring the effect of exercise on cholesterol levels, or just studying factors affecting the reading ability of fourth graders. Such guidelines (which vary slightly from country to country) are designed to ensure that scientific interest in the outcome of a test never outweighs risks to the well-being of human participants. So before a potential leukemia drug is ever tested on human patients, it must first be tested in both Petri dishes and animals (adhering to another set of ethical guidelines in the case of animal research) to show that the drug is safe and holds promise above and beyond other treatments currently available. To learn more, branch out and visit: The National Institutes of Health's resource on protections for human subjects/

Here we've seen that the culture of science expects certain sorts of conduct from its community members. To find out what happens when a scientist doesn't meet those expectations, read on…

The scientific community and misconduct

Some types of scientific misconduct:

- Failing to fairly scrutinize research
- Failing to be honest
- Failing to assign credit fairly
- Failing to work within ethical guidelines

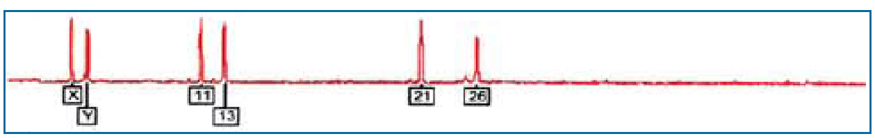
Types of scientific misconductOn the preceding page, we saw that scientific culture entails a set of norms and practices: scrutinize ideas, be honest, give credit where credit is due, and work within the ethical guidelines of the community. So what happens when someone within the community doesn't meet those expectations? In science, not playing by the rules amounts to scientific misconduct, or at least scientific misbehavior. Serious misconduct is rare, but nevertheless, since scientists are people and have human frailties, it does happen. Perhaps a chemist is asked to review the paper of a personal friend and chooses to overlook a flaw in the research — thus, failing to fairly scrutinize the work. Perhaps a physicist performs an experiment and chooses only to report results that fit with his or her favorite hypothesis — thus, failing to be fully honest. Perhaps a biologist writes a research article but doesn't cite a previous study that inspired the work — thus, failing to assign credit fairly. Or perhaps a psychologist studies a group of students' problem-solving skills but circumvents a few guidelines about how the participants should be recruited — thus, failing to work within the ethical guidelines established by the scientific community. Such behavior works against one of science's main goals — to build accurate knowledge about how the world works in ways that are ethical and humane.

Because it undermines science, scientists take misconduct very seriously. In response to misconduct, the scientific community may withhold esteem, job offers, and funding, effectively preventing the offender from participating in science. For example, a scientist found to have plagiarized parts of a grant application to the National Institutes of Health will likely be prevented from participating in federally funded grants for a period of time, a tough punishment for someone whose salary may be partly dependent on such grants. Some types of misconduct are even punishable by law. For example, because he faked data in funding applications and journal articles, medical researcher Eric Poehlman received a $180,000 fine, a year in prison, and a lifetime ban on receiving federal research funds!

Not getting away with it

Serious and damaging cases of scientific misconduct are almost invariably found out. That's because science is designed to get at how the world really works. Any fraudulent results that paint a false picture of the world will be uncovered as science proceeds and zooms in on the true picture. For example, in the early 1900s, the influential physiologist Emil Abderhalden claimed to have shown that humans produced protective enzymes that could be used in many practical ways — foremost among them, detecting pregnancy. The only problem? Such enzymes don't actually exist — so of course, Abderhalden's fraud was eventually found out by other scientists who could not reproduce his test results and found that his pregnancy test simply didn't work.

Science's system of scrutiny, peer review, and checks and balances help accelerate the process of discovering and weeding out occasional cases of fraud. For example, the world was first clued in to Woo Suk Hwang's fraudulent claims regarding stem cells when other scientists scrutinizing his work drew attention to an anomaly: some of his data looked too good to be true. DNA fingerprint graphs purportedly representing DNA from different samples showed peaks that seemed to be exact duplicates of one another — more likely the result of image manipulation than actual DNA fingerprinting analysis. The ensuing investigation revealed that the copycat graph peaks were only the tip of the iceberg. In fact, Hwang's basic claim, that his lab had cloned human embryos and collected stem cells from them, turned out to be entirely fabricated!



A DNA fingerprinting graph from one of Woo Suk Hwang's retracted papers. Careful scrutiny of the peaks in such graphs helped identify his fraud.

Such flagrant examples of fraud can be disturbing and should lead to the indictment of offenders — but they should not lead to the indictment of science. Science has many safeguards in place to prevent fraud, and when fraud does happen, science has mechanisms for detecting it. Scientific misconduct may temporarily lead science towards incorrect conclusions, but the ongoing processes of science regularly correct such diversions.

Human endeavor, human biases

Because science is a human endeavor, it benefits from our best traits – our curiosity, creativity, and perseverance. Unfortunately, it can also be affected by some of our worst motivations and beliefs – like racism, sexism, ageism, ableism, homophobia, and other forms of prejudice. These prejudices have shaped and continue to shape the course of science in many ways.

Scientists and scientific institutions have:

Built or used scientific “knowledge” to falsely justify prejudice and prejudiced actions

Najeh Davenport in yellow in 2006. Davenport and Kevin Henry, another player, filed a lawsuit against the NFL over race norming. Photo credit: Wikimedia.

Scientists with racist, sexist, and otherwise biased agendas have pursued research in support of their ideas and actions, which include colonization, slavery, and genocide. For example, in the early 1950s, scientists that were part of the eugenics movement conducted what were often poorly conceived and biased studies, marshaling “evidence” aimed at ridding society of characteristics that they deemed undesirable. The traits targeted by the movement were based on wide-ranging prejudices, prominently towards those with physical and mental disabilities. Roughly 60,000 Americans were forcibly sterilized as a result of policies that grew out of eugenics research.[1] Because science involves testing and retesting ideas in many ways, false ideas (e.g., that so-called “feeblemindedness” is a discrete and neatly heritable trait, that one race is more intelligent than another, that men have more logical minds than women do, or that being raised by a same-sex couple harms children) are ultimately shown to be just that – false. But when societal prejudices align with these false ideas, they can take longer to overcome and do more damage as they are used to justify cruel and unethical practices. Sadly, we *still* see these refuted ideas used to support racist and biased policies today – for example, when the NFL made it easier for white players to claim compensation for brain trauma than Black players, arguing that the two races should be judged on separate scales of brain function.[2]

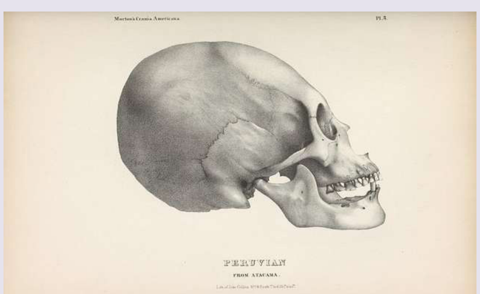


Illustration from Samuel Morton’s book Crania Americana titled “Peruvian, from Atacama.” Photo credit: New York Public Library.

SAMUEL MORTON'S SKULL STUDIES

In the 1800s, researchers like American doctor Samuel Morton[3] studied the skulls of people of different perceived races. He and many others wanted to make the case that white people had the largest brains and highest intelligence, and so were fundamentally better than people with other skin colors. Racist ideas like this had been around for a long time, but Morton and others tried to use science to prop them up. Morton’s investigations were based on the faulty assumption that brain size is an indication of brainpower and used techniques that scientists have since argued were biased.[4] Morton’s personal racism shaped the questions he asked, his assumptions, his choice of research methods, and his interpretation of his results in ways that allowed him to justify his own (and his society’s) racist beliefs. And ultimately, it seems to have been effective. Morton’s work was championed by Southerners who claimed it justified enslavement of Black people.

Used prejudiced research and data collection methods

Scientific research has been conducted in biased ways that value some groups above others. This includes well known (and horrific) examples, such as studies in gynecology that involved performing surgeries on enslaved Black women without anesthesia and a study of syphilis that withheld information and treatment from Black participants for decades.[5] Cases like these have motivated scientific institutions to put in place rules that protect people who participate in studies and ensure that research methods are fair. These important changes help, but biased research is an ongoing problem that needs to be continually guarded against.

Used scientific knowledge in biased ways

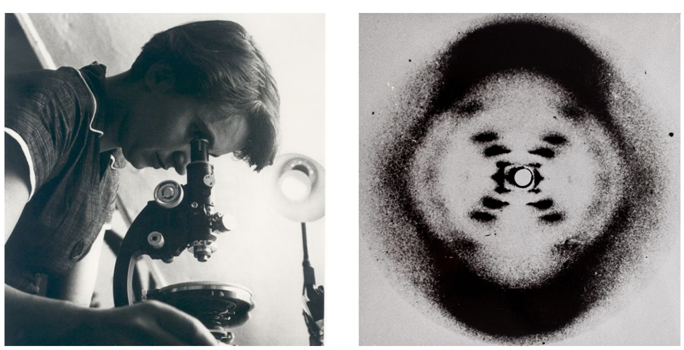
Scientists and others have used scientific knowledge in ways that are oppressive and that have unfair outcomes for members of some groups – and science is still used in these ways. Whether the unfair outcomes are intended or not, they are caused by the assumption that some groups are less worthy of care than others. Science, technology, and engineering are full of such examples – including the development of medical equipment that gives accurate readings for people with white skin but not for people with dark skin6 and facial recognition algorithms that consistently perform worse on young, Black women than on people from other groups.[7] Scientists can do much more to ensure that the innovations that come from scientific knowledge are developed with *all* people in mind.

Pulse oximeters, such as that shown here, were originally calibrated for white skin and can give inaccurate readings for darker skin. Evidence suggests that this delayed effective treatment of Black and Hispanic people during the COVID-19 pandemic.[8] Photo credit: Wikimedia.

Not valued or credited scientific contributions fairly

In science, it is important to provide credit when building on the work of others. This helps scientists check the work, and importantly, it also affects who gets to do what research. Career advancement, award, and funding decisions are partly based on whose work receives credit from other scientists. Not giving proper credit could rob someone of a promotion or grant money to further their research.

Unfortunately, because of individual and institutional biases, women, people from historically excluded groups, and others have not always received the credit they deserved in science. Infamously, James Watson and Francis Crick's hypothesis about the structure of DNA was based on key evidence collected by Rosalind Franklin. Franklin was not given credit for that evidence when Watson and Crick published their hypothesis. This is now considered a serious violation of scientific ethics – but we only know about it because the discovery was such a pivotal one in the history of science.



Rosalind Franklin and the photo from her lab that Watson and Crick used to help formulate their hypothesis about the structure of DNA. Photo credits: Franklin photo © Henry Grant Collection/Museum of London; X-ray diffraction pattern courtesy of Cold Spring Harbor Laboratory Library and Archive, James D. Watson Collection.

In many cases, such biased oversights and exclusions go unnoticed by the broader scientific community. These unrecognized exclusions are particularly egregious with scientific knowledge originally generated by Indigenous people. For example, white scientists have routinely "discovered" species that were already well known to Indigenous people through direct experience and traditional knowledge. Western scientists have simply ignored and discounted the scientific knowledge already existing about these species in Indigenous communities.

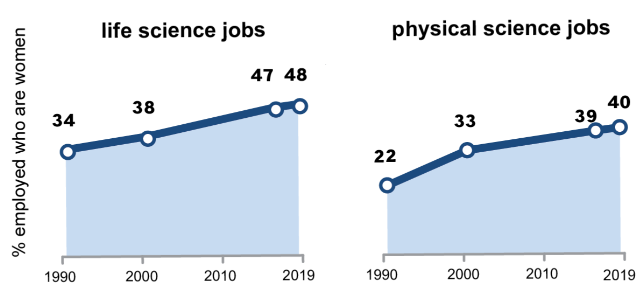
WHAT IS COLONIALISM?

Colonialism is the theft of Indigenous lands and resources by settlers, which is accompanied by exploitation and genocide. Colonialism is a horrific and recurring theme in world history. It has also shaped and continues to shape the course of science. Scientists from Western countries have collected and continue to collect fossils, artifacts, plants, animals, and minerals from around the world and use them for their own studies, often without consulting or crediting, let alone investing in, including, or deferring to the local community. Western scientists have conducted medical research in developing countries and with Indigenous people, collecting genetic and other data from them, again extracting information – information that has generated large profits for pharmaceutical companies – without providing recompense to or sharing control with the source of that data, the local population. In the last few years, many scientists and others have taken a stand against colonial science. This means making a range of changes – from returning specimens and artifacts to their rightful caretakers to investing in the capacity of local people to shape, participate in, and lead research efforts in their own countries and communities.

Prevented or discouraged many groups of people from participating in or achieving at science

Science *should* be open and welcoming to everyone but is still very far from that ideal. A 2021 survey of working scientists around the world found that 27% experienced and 32% observed discrimination (including gender identity, age, racial, sexual orientation, disability, and religious discrimination).[9] Because scientists are shaped by their societies and experiences, and because institutions perpetuate their own historical legacies, prejudice, discrimination, and exclusion can be embedded in scientific cultures.

As a result of barriers like this, the people who do science for a living often don't reflect the ethnic, racial, and gender makeup of the society around them. For example, in the U.S. in 2019, Hispanic people made up 17% of the workforce, but just 8% of life scientists. Similarly, women (almost half of the American workforce) held only 16% of jobs as astronomers and physicists.[10]



The percent of the life and physical science workforce who identify as women has increased over the last 30 years, but has not yet reached 50%. Source: Pew Research Center, April, 2021, "STEM Jobs See Uneven Progress in Increasing Gender, Racial and Ethnic Diversity."

Similarly, on a global scale, many barriers exist to full participation and achievement. For example, 98% of scientific publications today are English-language, and many scientific conferences require presentations to be made in English.[11] Yet, less than 8% of the world's population speaks English as a first language.[12] This makes it harder and costlier for most of the world to make scientific contributions and have those recognized. Another way that scientists create uneven barriers to achievement in science at a global level is through "parachute science" – when scientists from a higher income country "parachute into" a lower income country to do fieldwork, and then leave without communicating with or engaging local people.[13] This practice disconnects local people from scientific data they could use to answer research questions important to them and creates reliance on external experts, all of which discourages local research efforts and makes it harder for people from lower income nations to achieve in science.

The ultimate causes of such discrepancies in participation and achievement are individual, institutional, and societal biases and their ongoing legacies, including colonialism. For most of its history, people of color, women, and other groups had to fight to participate in science, overcoming barriers that others (mainly white men) did not – and that's still the case. Many scientists and non-scientists alike now recognize the lack of diversity in science as a problem and are working to change things. While more people from different backgrounds now participate in science than ever before, there is still a long way to go before science is truly inclusive.

SAME QUALIFICATIONS, DIFFERENT OUTCOMES

In a recent experiment, researchers sent out identical fake resumes to apply for research jobs in biology and physics. The only differences among the resumes were the names, which suggested that the applicant was female, male, Black, White, Asian, and/or Latinx (the categorizations used by the researchers in this investigation). This study uncovered many clear biases. For example, physicists evaluating the applications rated males, Whites, and Asians as more competent and hirable than females, Blacks, and Latinx people – despite the fact that their credentials were identical![14]

Photo credit: US Armies Combat Capabilities Development Command.

Towards an unprejudiced science

As described above, science has been (and continues to be) shaped by racism and other forms of prejudice. While abhorrent in its own right, this history has also had negative effects on science itself, curtailing the diversity of its workforce and leading to distrust of science among some communities at the receiving end of this prejudice. Acknowledging where science has not lived up to its ideal of being unbiased is the first step of many in removing racism, sexism, and other forms of bias from the scientific enterprise. It will take a sustained effort on the part of scientific institutions to regain the trust they have lost, attract and retain diverse participants, and fix biased research practices and workplace cultures. This work to eliminate prejudice is worthwhile, not only because it is the right thing to do, but because society stands to benefit. When scientists aren't trying to prop up false beliefs, when scientific knowledge is built, applied, and credited in fair ways, and when the scientific community is representative of the diverse societies in which it is embedded, science can build better explanations for more parts of the natural world, benefitting more people and communities.

[1]Norrgard, K. (2008) Human testing, the eugenics movement, and IRBs. *Nature Education* 1: 170.
[2]Leigh, S. (2020). 'Race norming' blamed for denying payouts to ex-NFL players with dementia. UCSF. Accessed July 31, 2022 at https://www.ucsf.edu/news/2020/12/419426/race-norming-blamed-denying-payouts-ex-nfl-players-dementia
[3]Morton, S. G. (1839). *Crania Americana*. Philadelphia: J. Dobson.
[4]Gould, S.J. (1981). *The Mismeasure of Man*. 1st ed. New York: W. W. Norton and Company.
Lewis, J.E., DeGusta, D., Meyer, M.R., Monge, J.M., Mann, A.E., and Holloway, R.L. (2011). The mismeasure of science: Stephen Jay Gould versus Samuel George Morton on skulls and bias. *PLoS Biology.* 9: e1001071.
Weisberg, M., and Paul, D. B. (2016). Morton, Gould, and bias: "a comment on the Mismeasure of Science." PLoS Biology. 14: e1002444.
[5]J. Marion Sims performed these gynecological experiments in the 1800s. The Tuskegee syphilis study was conducted between 1932 and 1972.
[6]Moran-Thomas, A. (2020). How a popular medical device encodes racial bias. Boston Review. Accessed July 31, 2022 at https://bostonreview.net/articles/amy-moran-thomas-pulse-oximeter/
[7]Klare, B. F., Burge, M. J., Klontz, J. C, Vorder Bruegge, R. W., and Jain, A. K. (2012). Face recognition performance: role of demographic information. IEEE Transactions on Information Forensics and Security. 7: 1789-1801.
[8]Fawzy, A., Wu, T. D., Wang, K., Robinson, M. L., Farha, J., Bradke, A., … and Garibaldi, B. T. (2022). Racial and ethnic discrepancy in pulse oximetry and delayed identification of treatment eligibility among patients with COVID-19. *JAMA Internal Medicine*. 182: 730-738.
[9]Woolston, C. (2021). Discrimination still plagues science. Nature. Accessed August 1, 20222 at https://www.nature.com/articles/d41586-021-03043-y
[10]Pew Research Center, April, 2021, "STEM Jobs See Uneven Progress in Increasing Gender, Racial and Ethnic Diversity."
[11]Gordin, M.D. (2015). *Scientific Babe*l. University of Chicago Press.
[12]Noack, R., and Gamio, L. (2015). The world's languages, in 7 maps and charts. *The Washington Post*. Accessed August 1, 2022 at https://www.washingtonpost.com/news/worldviews/wp/2015/04/23/the-worlds-languages-in-7-maps-and-charts/
[13]Stefanoudis, P. V., Licuanan, W. Y., Morrison, T. H., Talma, S., Veitayaki, J., and Wodall, L. C. (2021). Turning the tide of parachute science. *Current Biology.* 31: PR184-r185.
[14]Eaton, A. A., Saunders, J. F., Jacobson, R. K., and West, K. (2020). Advancement of scholars in STEM: professors' biased evaluations of physics and biology post-doctoral candidates. *Sex Roles*. 82: 127-141.

Summing up the social side of science

In this section, we've seen that science is a community endeavor. Contrary to the stereotype of solitary lab work, scientists frequently interact with colleagues to collaborate on projects, review each other's work, share information, and brainstorm new ideas. In these interactions, scientists work to maintain a set of cultural norms and expectations: scrutinize ideas, be honest, give credit where credit is due, and work within the ethical guidelines of the community. The scientific community contributes to the progress of science in many different ways, from providing checks and balances to facilitating specialization — and all of those functions are furthered by a diverse scientific community. Science simply works better when lots of different sorts of people participate in it!

To see the counterpart of all this and find out how the broader community influences science, read on…