



A CITIZEN'S GUIDE TO SCIENCE

WHAT SCIENCE IS,
HOW IT WORKS,
WHERE IT'S POORLY TREATED,
AND WHY SCIENTISTS HAVE
THE RIGHT TO FEEL UPSET

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FIRE YOUR DOCTOR

You're sitting in an upholstered chair, there is a duck painting on the wall and a paper weight on the desk. Your doctor comes in, opens a manila folder, and looks at the papers inside. She sets her face and with calm and compassion tells you that the tests indicate cancer. What do you do?

Quietly take the papers she's holding, alter the test results with a pen (so they can't be erased) and go home and celebrate. You beat cancer!

Right?

PRIMER ON SCIENCE

What Science Is: The dangerous idea behind science is that it's a way of trying to understand how the universe (nature) works *by actually studying the universe*. Science can be used to answer big questions like the age of the universe, the origin and evolution of life, and smaller questions like Bilbo Baggins' "What have I got in my pocket?" Because Science is based on looking at nature, it's open to everyone: every gender, race, nationality, sexual orientation, religious (or non-religious) background, even bald people. We are all scientists. As we move through the day we are constantly erecting hypotheses, conducting tests, evaluating results. I grasp my coffee cup and use the external temperature of the cup to judge how hot the coffee is and how big a sip I can take. Science ten-thousand times a day.

However, at birth we humans are ill equipped to understand the universe, we are rife with biases and handicaps. It really seems like the Earth is sitting still while the sun moves across the sky. Calculus (calculus!) is required to understand that gravity is more than a series of random events. We wash hands and fruit to remove invisible bacteria. We lose at the casino, but remember winning. We hear something that confirms a strongly held belief and remember it, while we forget or deny those things that refute the same idea. (This last, known as "Confirmation-" or "Myside-Bias," is the greatest demon of all scientists, professional and amateur alike. Certain recent geo-political events are almost certainly the result of this human defect.)

How Science Works: Coupling the two ideas—to understand the universe, study the universe; and that humans are prone to mistakes—results in the process we call Science. Every time we discover a new human failing,

scientists incorporate that into the next round of tests to make sure results are less tainted by bias. The double-blind test, where neither doctors nor patients know who is getting the active medicine and who the placebo, is an important result of this rule. **The very design of Science—rejection of arguments from authority, peer-review, public publications, reproducibility, falsifiability, and findings that are constantly subject to testing and skepticism—creates a system designed to remove human failings and provide accurate descriptions of nature.** Whenever this process isn't used, there is an enormous chance conclusions will not accurately reflect reality.

When a scientist tests an idea about how nature works they do not simply gather evidence for that idea. Rather they work as hard as they can to show that the idea isn't an accurate description of nature. Only if they fail to show it doesn't work (note double negative) do they reluctantly accept that it might be acceptable. It sounds counter intuitive until you put it to a test.

In *The Hitchhikers Guide to the Galaxy*, we learn that the answer to "life, the universe, and everything" is 42, an answer arbitrarily picked by the book's author, Douglas Adams.

Recently a fan compiled an entire book listing hundreds of instances where 42 is an

"important" number. As a fan myself it pains me to say 42 isn't any more magical than, say, 37. Imagine the Cult of 37 compiling their own list. Has the group with the longest list really found the ultimate answer? Conspiracy theories are created in this way, too, by only seeking explanations that affirm a preconceived notion, never being skeptical of them. An idea/ explanation/ description of nature only has merit if it can stand up to scrutiny, tests, and skepticism. **Confirmation bias is simply the failure to be skeptical of your own beliefs. Many of the most spectacular failures in Science and Politics are the result of confirmation bias. We are very good at fooling ourselves.**



What Science Isn't: If you don't do Science right—include ALL of the steps—then it's not Science. Pseudo-science, non-science, and just plain lies presented as Science are not Science. Making random noises is not the same as speaking Mandarin Chinese. ***Science is not political.*** Tree growth, earthquakes, the energy required to boil water, in fact, all the known "rules" of the universe, are indifferent to, and unalterable by, human endeavors including politics,

religion, charming ad jingles, hacktivism, etc. If a group holds that the moon is made of green cheese, it is not the moon's responsibly to change. **Science does not prove anything** (talk to a philosopher about why not). **Science is not perfect.** Scientists are humans with all the usual human failings of lust, pride, greed, bad breath, etc. We realize this, and a major part of the scientific process is designed to remove those failings from research. (Science does seem to produce fewer felons than Politics, though.) **Science doesn't know everything.** There is still a lot to learn, give us time or feel free to join in.

"Truth", "correct", "incorrect", "right", "wrong", "real", "fake", "good" and "bad" are all words that work well in many everyday situations but don't work well in Science. Those words are too generalized and can carry (often moral) connotations. (It might be *right* that you backed over the cat, but it's not *right* that you backed over the cat.) **The appropriate way to consider Scientific findings is to refer to accuracy and precision.** As we develop better tools, technology, and techniques we can make finer measurements and more accurate models (think climate change). More accurate descriptions/measurements do not invalidate past findings, they enhance them.

The terms "accuracy" and "precision" also highlight uncertainty which is a real part of the real universe we live in. Scientists cannot say "absolute", "100%", "never", etc. because all things carry uncertainty. We humans are very poor at dealing with uncertainty and probability. One way to think about it is to consider warranties. If a product has a warranty, the manufacture feels the probability of failure within that time is low. A lengthy (strong) warranty implies confidence that the product will be defect-free for a long time. A short (weak) warranty implies the product may break quickly. For example, scientists can offer a very strong "warranty" concerning the notion that human-caused global climate change is an accurate explanation of current climate events.



Abuses of Science: Current abuses of Science come in many forms, but two are the most pervasive. The first (and oldest) rejects the idea that the best way to understand how the universe works is to look at the universe (Science), and embraces the idea that the universe is best understood through interpretations of sacred literature. Creationism is a specific example of this larger issue (age of the earth, origin of languages, and rights for homosexuals are

a few other examples). **Creationism is based on the idea that *interpretations of sacred literature* are a better way to understand life than *actually studying nature*.** That's why groups with different sacred literature celebrate different creation stories (Genesis, Spiderwoman, Brahma) and why individuals that share sacred literature disagree over what it says (the vast majority of Christians see no conflict between evolution and their interpretation of the Bible, others interpret an old Earth, others a young Earth, etc.). **Interpretations of sacred literature do not help us understand how nature works with any accuracy or precision and are often incredibly misleading if taken literally. If you disagree, complain to the universe, it's the one that "made" the rules.**

A related situation is not the rejection of Science itself, but the rejection of using Science. Kurt Vonnegut articulated this well in his essay, "Your Guess is as Good as Mine". He pointed out that many decisions made in the past were guesses, simply because information and ability to know was lacking. "Our most enthralling and sometimes terrifying guessers are the leading characters in our history books. I will name two of them: Aristotle and Hitler. One good guesser and one bad one." Today we have information. Today we have models. Today we don't need to guess. Listen to representatives and pundits, when are they speaking from knowledge and when are they guessing? Don't turn this into a drinking game.

Maligning Science for financial reasons is the second major abuse. "Skepticism" over global climate change is not based on lack of scientific rigor or clarity, it is simply a technique to reduce competition. Rejection of scientific findings in order to denigrate the EPA, OSHA, NOAA, NIH, and other organizations that rely heavily on science to set policy and make decisions to improve environmental and human health and safety is another red-herring argument. In both cases scientists should continue to refute these red-herrings with evidence and rational discourse. However, much more time needs to be devoted to specifically pointing out that "uncertainty" in Science is used as an excuse to institute policies that specifically profit a small number of people while reducing the health and wellbeing of a much larger group. We could have cheaper food if companies weren't forced to buy rat traps.

These and other abuses of Science and scientists are offensive. Scientists are professionals. The very nature of Science requires that it's always open to review and scrutiny. No other institution and no participants in any other institution, political, religious, legal, artistic, etc., are subject to such public examination. While scientific fraud can and does happen, in the long run scientific fraud will always be discovered. As Richard Feynman put it, "We've

learned from experience that the truth will out. Other experimenters will repeat your experiment and find out whether you were wrong or right. Nature's phenomena will agree or they'll disagree with your theory." Scientists are held accountable for their work and called upon to check the work of others. When levies fail, no one interrogates a religious leader, when health supplements are associated with heart attacks, scientists are called in to investigate. **Scientists are working to describe the universe, a fixed element, and report what they find. Sometimes the answer is not what a particular person, group, industry, etc. wants to hear. Jon Stewart put it simply, "Reality has a liberal bias."**

A SCIENTISTS' LAMENT

Science works: We went from walking behind a plow mule to walking on the moon, we eradicated small pox and have revolutionized medicine, we can look into the heart of stars, we can edit genomes, we have the internet and Angry Birds. **By applying scientific principles to industry we've been able to take things that even gods and kings couldn't imagine and make them available to virtually anyone: flying through the air, instant communication, air-conditioning.**

It's no easy feat. Making a lightbulb—tungsten, florescent, LED— requires that we work with what exists in the universe, the raw elements, and combine them in a fashion agreeable to the rules of the universe. Efficiently mass-producing lightbulbs requires that we develop techniques to work with materials, energy, and processes on a large scale. Both science and industry experience real constraints placed on them by the rules of the universe and reality of the available resources here on Earth.

Science and industry have developed technological solutions to most of the problems associated with humans' basic needs. The technological impediment to providing adequate food, water, shelter, healthcare, housing, transportation, and communication is gone. We know how to grow LOTS of food. We can purify and deliver LOTS of water. We figured most of this stuff out in the 1970s and have improved on it since then. Absolutely, Science has provided us with bulldozers, diesel fuel, pesticides, and loud speakers. **Inappropriate and over judicious uses of technology have caused enormous environmental damage and human suffering. But here again, Science not only anticipates, detects, and measures damage, but provides technological solutions to these problems.** For example, Science has been telling us for decades that the one and only lifeboat we have in the enormity of the universe is currently being radically altered by (among other things) over use of fossil fuels.

Natural Experiments: There are nearly 200 countries on Earth. Each one has a health care plan for its citizens ranging from full coverage to no coverage. Each one has air and water quality regulations, drug laws, and gun control laws that range from strict to nonexistent. **Each action or inaction taken by each country represents an experiment, one that is freely observable, one we can learn from.** Watching the United States flail about trying to enact adequate health care is both one of the greatest comedic farces, and one of the greatest tragedies, the world has ever seen. When others have gone out of their way to reap the rewards or suffer the consequences of their own experiments, why would we not want to learn from their experiences?

"Everything that is broken in our country can be fixed.": If Science and industry solved so many of the problems of human basic needs, then why do hunger, slums, and cholera still exist? Why doesn't everyone have access to clean water? If Science anticipated and measured (and is measuring!) the maladaptive changes to the Earth due to fossil fuel use, then why are we still using so much fossil fuel when reasonable alternatives of solar, wind, waves, and biofuel are available?

There is no evidence that human endeavors are held back by lack of energy or materials. No evidence that lack of human imagination or ingenuity is keeping us from solving basic problems like adequate food, shelter, healthcare, and education for all humans on Earth. Nothing in the laws of physics says we can't visit Europa, double our lifetimes, or even jury-rig a reasonable facsimile of a Woolly Mammoth or Dodo. **And there is no reason to believe we have to poison streams or factory workers to achieve those goals.**



So many times when we ask our political leaders to explain why they can't solve these problems, their answer invariably is: "We can't afford it." But we can. Economy is a human creation, partially dependent on nature (there is only so much fresh water), but mostly one of our own making. What we can't afford any more is *guessing* about how economies work. **Science and Industry stepped up to the challenge and delivered, but Economy has failed.** Economy has failed

because those that institute it are not interested in discarding ideas that don't work, but have become entrenched in dogma and ideology. It's time we began treating Economy as what it really is, hypotheses and experimental statements, rather than an immutable ideals. It's time economic practices had to withstand the scrutiny of Science.

The only way to truly solve the problems we face today is through economic and social change. For example, we need politicians brave enough to admit that a capitalist model that relies on profit will not work for a government service that should be available to everyone. We need to change the "moral" attitude we take when providing basic needs. For example, we live in communities where people are guaranteed a sidewalk but not food. No moral judgement is assigned to use of government-mandated and taxpayer-financed sidewalks, but a government-mandated and taxpayer-financed food assistance program comes with moral indignation, "my tax dollars," "warm food not allowed," etc. **Science and Industry have given us plenty, we should not waste, but we are not without resources. We should be indignant when others lack basic needs, not when they receive them.**

Economic and social policies are created by humans, for humans. We are in control, and those can easily be changed. What can't be changed is the fact that one group of humans isn't better than another, that pollutants cause damage, that climate change is happening, and that reality can't be altered with paperwork, even if you use a pen.

