The process of science

Astronomy 101
Syracuse University, Fall 2020
Walter Freeman

October 13, 2020

Announcements

All labs will be held online only for now.

(My first priority as always is people's safety and wellbeing)

Project 3 is posted. It is due next Wednesday. We aren't going to do peer reviews for it – just submit it to `suast101projects@gmail.com` directly.

Help hours will be held today as always from 4-5:30. Sorry to anyone who tried to find me on Zoom last week!

Exception: I may need to leave to help out with a medical issue in the family. If I do I'll send out a message.

Announcements

We posted a lot of grades.

Some people got 0's for things that they completed, but that we couldn't find because they didn't follow the submission instructions. (We can't grade it if we can't find it, and those instructions aren't there because we are grouchy and mean – they're there to help us help you!)

If you got a zero for something you did and submitted on time:

- Don't panic
- Find the email where your group submitted it
- Forward it to your lab TA cc: the correct submission address, with the correct subject line
- We'll fix it. (We can't fix it unless you do this.)

If you got a zero for something you did and submitted late:

- Do the above
- Also include a note explaining why your work is late

Astronomy from Mauna Kea

A student posted a great article on Piazza about astronomy from the summit of Mauna Kea, the tallest mountain (4200m) in Hawai'i.

The summit of Mauna Kea is a great place for astronomy:

- The air is very stable (less "shimmer")
- The air is very dry (less haze)
- There isn't as much of it (better infrared observations, etc.)
- The Keck Telescope (used by Andrea Ghez in her Nobel Prize work) and other observatories are there
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- It is the traditional home of the gods
- There is a a traditional *kapu* (cognate to *taboo*) against visiting the summit for most people
- Some Native Hawai'ians oppose development on the summit

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It is also ecologically sensitive.

How do we resolve these conflicts? What are your ideas?

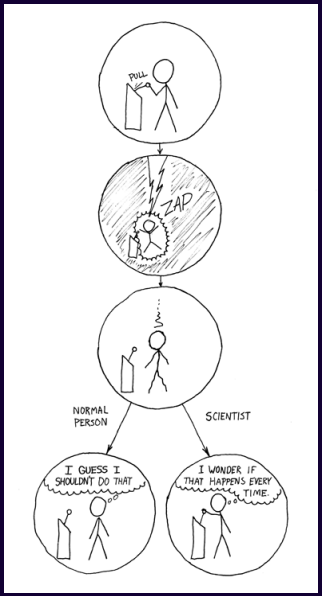
Astronomy from Mauna Kea

This is a complex issue. There are a lot of astronomers that oppose constructing the TMT on Mauna Kea because of Native Hawai'ian opposition; there are Native Hawai'ians who support it. I am not an expert on the TMT, Native Hawai'ian culture, or Indigenous rights generally.

But the questioner on Piazza asked for my thoughts, so here they are, from one guy's humble perspective:

- Science is just *one part* of the great project of humanity: to build a society that is continually improving in knowledge, prosperity, justice, capability, and beauty for everyone
- Everyone means *everyone*, and that if a group feels left out of the direction of this project or its benefits, that is a problem that needs fixing
- This is an issue that is bigger than a few telescopes on a mountain – it will require a lot of self-reflection by a society that has a lot of unfairness in its history

The process of science

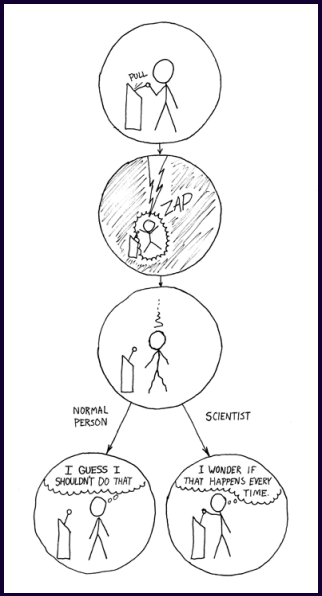


We've now told the story of how looking in detail at the motion of the Solar System led to the development of classical mechanics – the beginning of physics. (Want to know more? Take PHY211 in the spring!)

But let's step back for a bit. The development of mechanics was part of the *scientific revolution* – the development of a new way to understand our world.

But what is science?

The process of science



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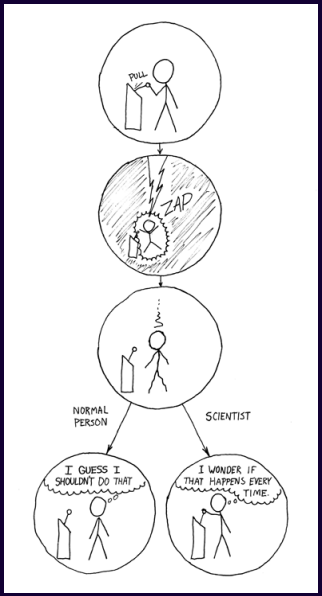

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What does science look like when it is being done well?

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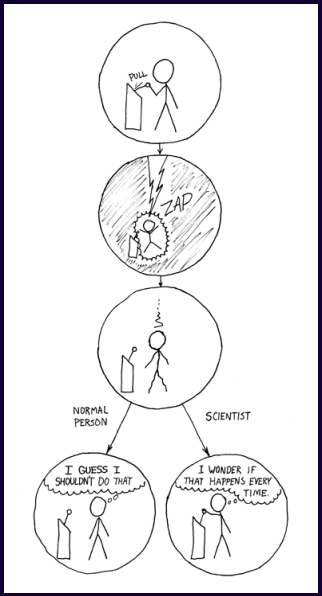

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But what is science?

How is science different from other ways of examining our world?

What does science look like when it is being done well?

How can the scientific process be derailed – on purpose or by accident?

Properties of science

Broad properties of science:

- **Empiricism:** the ultimate authority is what we measure about the world around us, not what we think.
- It is vitally important that the conclusions we *claim* come from our data actually do
- There's a whole field of math dedicated to data analysis: *statistics*. It has to be done honestly and well!

- **Self-skepticism:** someone making a scientific claim should actively search for things that might prove themselves wrong
- Potentially refuting arguments/evidence are a *good* thing

- **Universality:** the laws of nature apply in all places and times, and to all things (including humans)
- Since the laws of nature are universal, they form a coherent whole
- Any new finding must find its place within the framework of preexisting measurements and principles
- Very rarely previously-accepted things get overturned; more often they are *extended*

- **Objectivity:** scientific ideas, or the evaluation of them, should be independent of any particular human perspective
- Science is not about *you* (whoever you are)
- Criticism of other people's ideas isn't about them, either

Properties of science, in our story

Science – as a means of seeking truth – has a few fundamental properties:

- **Empiricism:** the ultimate authority is what we measure about the world around us, not what we think.
- The new scientific approach to mechanics started with the observations of the planets from Uraniborg, observations made by Galileo and Newton, and then built from there
- This is different from the old Greek natural philosophy, that valued *pure thought* over the dirty work of *measuring things*

- **Self-skepticism:** someone making a scientific claim should actively search for things that might prove themselves wrong
- Kepler was convinced planetary orbits were circles and tried *very hard* to make circular orbits work... until the data convinced him otherwise
- Tycho did *not* do this: when he observed a lack of stellar parallax, he didn't consider the possibility that the stars might just be very far (250,000 AU) away

Principles that come from these:

Empiricism: A model is only valid within the realm of data against which it has been checked.

- Precision: is the law of gravity valid to one part in a billion? One part in a trillion?
  - "Equivalence" (all objects fall at the same rate in a vacuum): holds to one part in 10^{17}
  - Universal gravitation: **Not quite true in regions of strong gravity!**
  - Conservation of energy: seems absolutely solid, from fragments of an atom to black holes
- Scope and scale: Is Newtonian mechanics valid for very fast things? Things as large as a galaxy? Things as small as an atom?
  - Very fast things: **not quite**, since close to the speed of light space and time get mixed up
  - Very large things: Yes, things as large as galaxies and beyond (but this requires dark matter)
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- Universality helps with this, but we have to be careful
  - We don't need to drop every rock off a cliff to understand projectile motion...
  - ... but it's hard to know exactly what limits we have to probe

Principles that come from these:

Self-skepticism: It's the duty of the claimer to search for experiments that they can do to possibly prove themselves wrong.

- "Neutrinos faster than light"
- The caution of LIGO after their Nobel Prize-winning discovery

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- The most powerful evidence for an idea is an experiment that will produce something unexpected if you're right, but can conclusively disprove your idea if you're wrong
- In 1917 Einstein proposed a radical new way of thinking about gravity
- ... and calculated from it two things, one of which could be tested the next time there was an eclipse
- If Einstein was wrong, we'd know it immediately.

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- These experiments need to be as diverse as possible: this is hard, since you have to check things you're not familiar with

Principles that come from these: objectivity

Maintaining **diversity** in the scientific community is important to ensure valid conclusions.

Since results shouldn't depend on the particular perspective of the scientists working on them, science benefits from having people with different experiences and backgrounds work on a problem.

That way, any "blind spot" that people with a particular background tend to have will be caught by people from a different background.

Science: a powerful, corruptible tool

This synergistic enterprise has been behind a vast amount of progress for humanity in the last 350 years.

As with anything powerful, this process can be corrupted.

Your second paper will involve analyzing an incident where it has been.

Let's look at how that can happen.

Common fallacies

During this process, please freely discuss your own examples.

I'd like to spend much of the time today "off script" – talking about your examples, rather than my slides.

I'll also be steering clear of any topics that are "hot-button". Feel free to write about these in your papers! But I won't be using them as examples here: climate change, creationism, vaccination, drug laws...

Two notes

"Scientific integrity" is not a reference to the usual sort of integrity – to being a good, honest person.

It is possible to do horrible things in the process of research, but do research that is well-grounded and draws correct conclusions.

It is also possible to be an honest, diligent scientist and make mistakes, and come to incorrect conclusions because of flaws in the application of the scientific process. (I have done this myself.)

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There is a difference between a flawed process of science and simply being wrong. Everyone makes errors.

The scientific process has safeguards in place to avoid those errors from spreading too far, and we bypass those safeguards at our peril.

There is a difference between a flawed process of science and being a terrible person, too. We aren't talking about experiments that hurt their subjects, either.

Measurement bias

One example of how this goes wrong: **measurement bias.**

Using limited, biased data will give you a biased result – whether accidentally or intentionally

Example: the "fifth force", a proposed modification to gravity

- People in the 1980's uncovered evidence that gravity might depend on the type of matter
- They made careful measurements from the top of a tower that seemed to confirm this
- ... but they required precise measurements of the gravitational force nearby to analyze them

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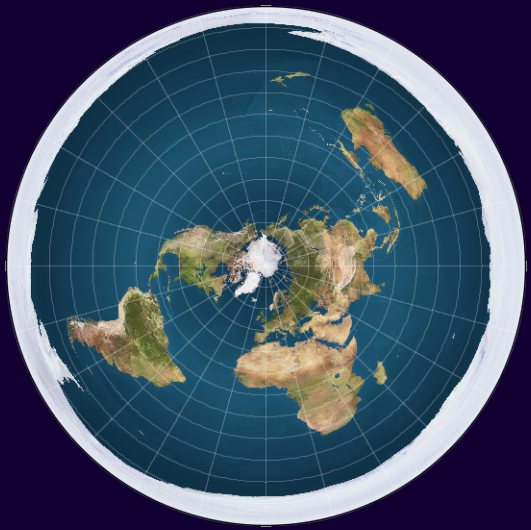
- Once this was realized and corrected, the signal went away
- Nobody meant to deceive anyone here

Examples



PeteSvarrior, for the Flat Earth Wiki; cc-by-sa.

Here's a map of a flat earth from the Flat Earth Wiki (ugh).

The distances are more or less right for the Northern Hemisphere...

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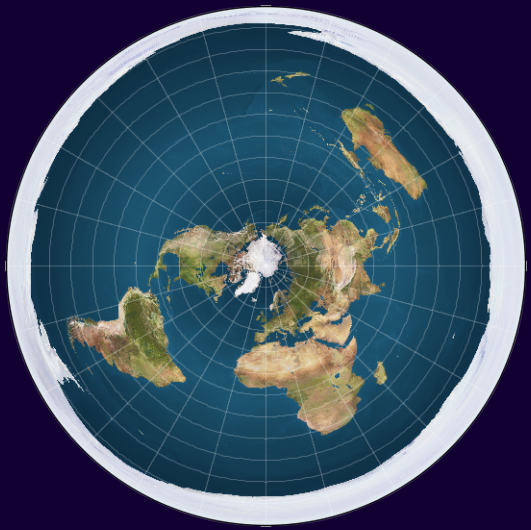

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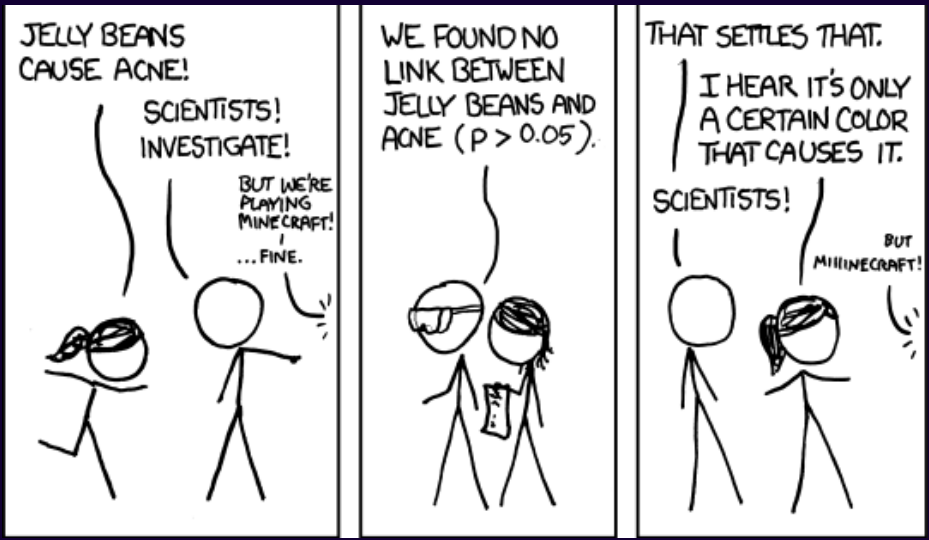
The distances are more or less right for the Northern Hemisphere...

They're completely absurd for the Southern Hemisphere!

Clearly no Flat Earthers asked any Argentinians how far it was to New Zealand...

Examples: reporting bias



$p > 0.05$: "whatever we found, there's more than a 5% chance that it is just a coincidence"

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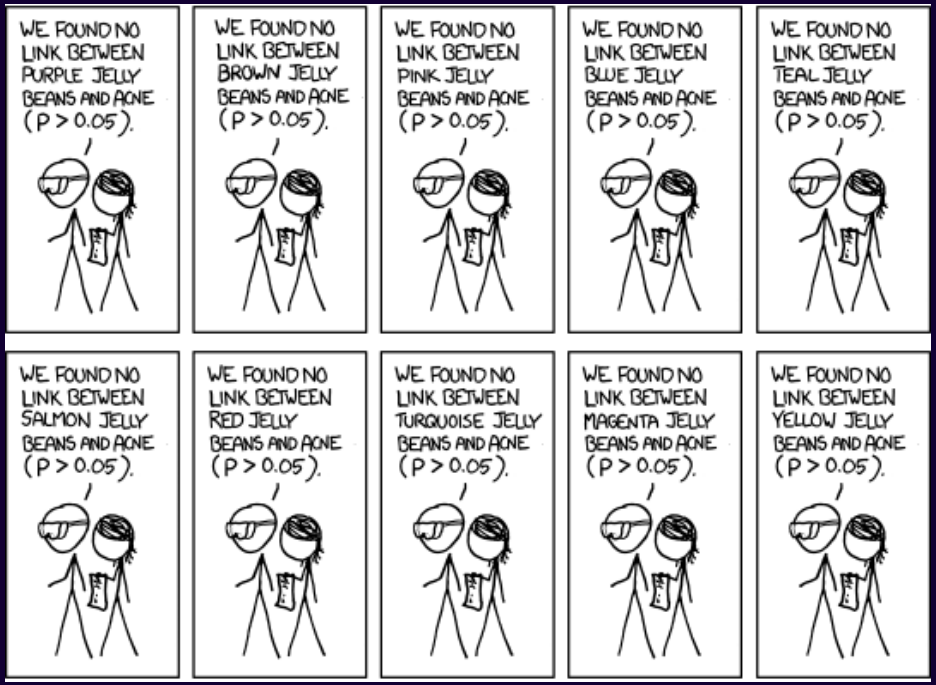

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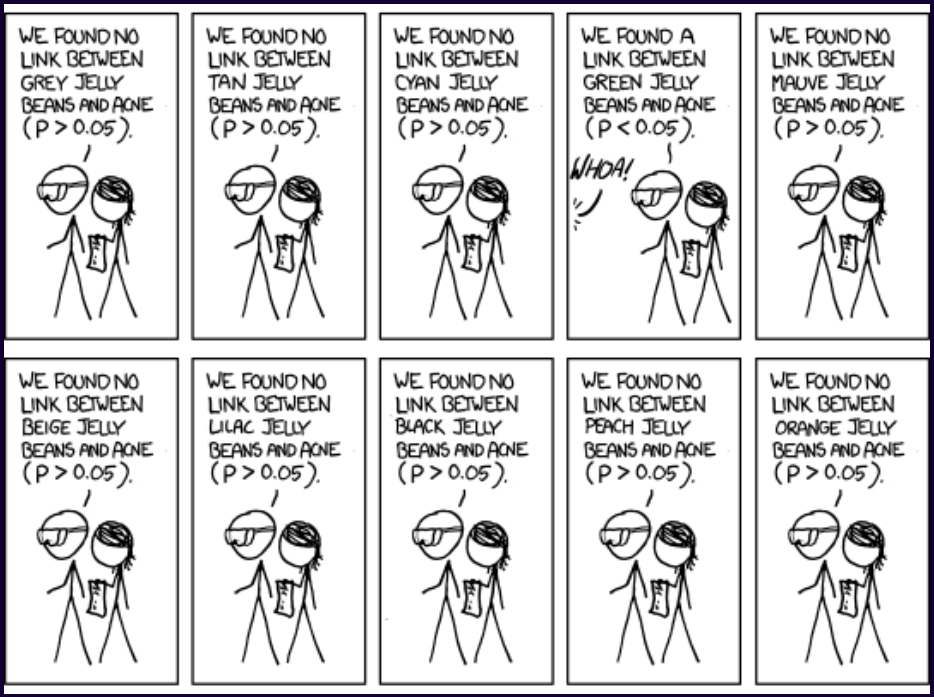

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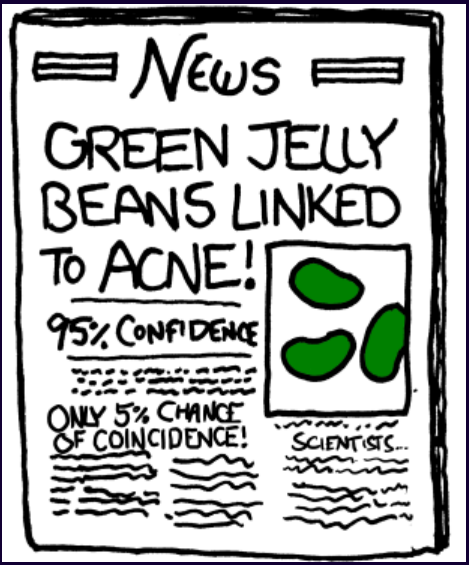

xkcd #882, by Randall Munroe: cc-by-nc.

Laundering data through statistics: dangerous!

Reporting only an interesting/profitable/exciting piece of data, and ignoring the rest, leads to flawed conclusions!

This is particularly worrying in medical research.

Examples: some airplanes

In World War II, the US sent large airplanes to bomb Nazi Germany. The Nazis shot at them.

Many of them returned to airbases in England with battle damage.

The Army Air Corps got an idea: let's use science and statistics to keep our airplanes safer!

- They wanted to add armor to the airplanes wherever they were being shot
- They looked at aircraft that returned from bombing missions and made maps of where they had been damaged by enemy fire
- They noticed that they had damage on the wings, on the fuselage, on the tail
- They did not see much battle damage near the cockpit or on the engines

Where would you add armor to these aircraft? (This is a matter of life and death, after all!)

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Where would you add armor to these aircraft? (This is a matter of life and death, after all!)

Thankfully, a statistician stopped them from making a mistake!

This is an example of *survivorship bias*. This happens in medical studies, too!

Do you have any favorite examples of biased data causing flawed conclusions?

Common fallacies: ad hominem arguments

An ad hominem argument is one that condemns someone else's argument because of *who* they are, not the content of their logic.

A few types (paraphrased):

Conspiracy-type reasoning (false allegations of ulterior motives):

- "NASA faked the moon landings because they wanted to cover up the fact that their rockets didn't work"
- "The anti-smoking campaign is there to make money, and also something something Nazis" (`http://www.smokingaloud.com`)
- "They just *say* that fluoride helps dental health but it's really a Communist plot"

Arguments based on status or identity:

- "That person is an esteemed expert; we must trust them without question!"
  - Four out of five dentists recommend such-and-such brand of toothpaste...
- "That person is a nobody; how could they have any good ideas?"
- "That person is a member of race/religion/gender/political party XYZ, how could they have anything right to say?"

Ad hominem arguments

Ad hominem (Latin: "against the person") arguments fail the scientific standard of *objectivity*: claims should be evaluated based on data and logic, not on who is making them.

False claims of ulterior motives are a common sort of *ad hominem* attack.

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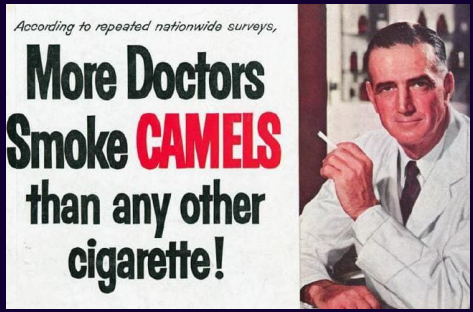
... and using "argument from authority" is the reverse: well, if these doctors say that they smoke Camels, they must be safe... right?

Sometimes deliberately deceptive people really *do* have ulterior motives. This can be a warning sign that someone is being deceptive...



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Do you have any favorite examples of *ad hominem* arguments being used to support flawed scientific claims?

(Comment in chat)

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–*The New York Times*, 1920

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We know how this one turned out...

Ignoring refuting evidence

Self-skepticism is a hallmark of sound science. Good scientists report:

- Any experimental evidence that might conflict with their proposal
- All of the possible flaws that *they* thought of in their claim
  - ... and how they considered them
- Any tests that anyone *else* could do to try to disprove them
- All the things that make them uncertain about their result
- The limits of their conclusions

Most good scientific writing spends much of its time doing the above. You should only try to convince other people you are right once you have tried very hard, yet failed, to prove yourself wrong.

Any claimant that spends most of their time talking *up* their conclusions is likely suspect.

Ignoring potentially refuting evidence

Ignoring or failing to search for refuting evidence is a common trait of faulty scientific process. This can either be:

- Ignoring refuting evidence altogether, even if it's widely known
- Dismissing refuting evidence out of hand, without considering it in any real way
- Failing to think of potentially refuting evidence and search for it

Do you have any favorite examples of flawed scientific claims that fail to address potentially refuting evidence?

`https://wiki.tfes.org/Flat_Earth_-_Frequently_Asked_Questions`

Ignoring the rest of science: "island claims"

Natural laws are universal: the laws of physics are the same everywhere and at all times.

This means that a new idea doesn't just have to fit together with the evidence used to support it, and a few bits of potentially refuting evidence.

It has to play nice with **all** other data, from centuries of experience.

If you're proposing a new fundamental law of physics, it has to be compatible with *everything* else.

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- We see nuclear reactions that don't seem to conserve momentum; what happened?

- The following things are mutually inconsistent; what do we do?

Ignoring the rest of science: "island claims"

Natural laws are universal: the laws of physics are the same everywhere and at all times.

This means that a new idea doesn't just have to fit together with the evidence used to support it, and a few bits of potentially refuting evidence.

It has to play nice with **all** other data, from centuries of experience.

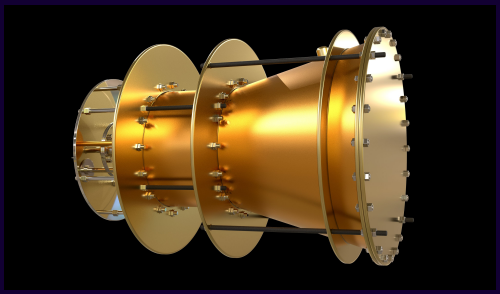
If you're proposing a new fundamental law of physics, it has to be compatible with *everything* else.

- We see nuclear reactions that don't seem to conserve momentum; what happened?

- The following things are mutually inconsistent; what do we do?
  - Electromagnetism (very well tested in the lab)
  - The independence of space and time (seems obvious to everyone, right?)
  - A universe that fundamentally makes sense (we all agree on how things will happen, etc.)

Ignoring the rest of science: “island claims”

If you’re proposing a new machine, then there needs to be a plausible explanation for how it works.



“The EM-Drive”, not actually a rocket engine

People claimed this is a rocket motor that uses no fuel (reaction mass), only an energy source.

They acknowledged that it seemed to violate Newton’s third law / the conservation of momentum, but had no explanation for how it actually *did* work. But they claimed it produced a tiny fraction of a newton of thrust.

(It didn’t. It was interference between the machine and the measuring equipment. It’s hard to measure a tiny force on a huge thing in the context of lots of microwaves.)

Manufacturing a controversy

We've discussed some of the common features of people *advancing scientific claims* incorrectly, negligently, or dishonestly.

Sometimes dishonest people aren't trying to *advance* something they know to be false, though.

They're more interested in convincing people to *reject* something that is true.

To do that, they only need to create doubt. This is commonly done by *manufacturing a controversy.*

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(This is a common tactic to erode trust in *anything*, not just science – common in politics and negative advertising)

Manufacturing a controversy

Do you have any favorite examples of manufactured controversies?

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Consider again the tobacco industry:

- "Secondhand smoke doesn't cause health problems; those studies are wrong"
- "Are you really sure that secondhand smoke causes health problems? Maybe it was building ventilation!"

One of these is a far easier sell than the other!

The industry's strategy does not require winning the debates it manufactures. It is enough to foster and perpetuate the illusion of controversy in order to muddy the waters around scientific findings that threaten the industry. Thus it offers reassurance to smokers, helping them to rationalize and repress their health concerns. Furthermore, claims of "not proven" resonate with friendly or naive journalists and governments, and provide an excuse for not taking strong governmental or societal action against tobacco.

–Yussuf Saloojee and Elif Dagli, "Tobacco industry tactics for resisting public policy on health" Bull. World Health Organ. 78(7): Genebra, July 2000.

Sensationalism

Two things are both true:

- Some scientific findings can dramatically change our lives and our perspective on the world, and are compelling and exciting
- Whether a scientific claim is true or not doesn't depend on whether it's exciting or not (objectivity)

Scientists thus have twin duties:

- They should engage with society in sharing the excitement and interest of their findings. Science communication is vital (and many of us are bad at it; the astronomers do better than the physicists!)
- They should separate this excitement from the task of evaluating the validity of claims

Sensationalism

Beware of any sort of scientific claim that conflates the evidence that it is true with why you should be excited by it, or that seems to be hyped by its claimant.

Good scientists do hold press conferences, because many discoveries are exciting!

But these happen only in the context of:

- a vast amount of self-skepticism applied to their results first
- objective, sober presentation of the *evidence* for their conclusions

Science vs. pseudoscience

Often people adopt the trappings of science to give nonscientific ideas a veneer of validity. This is called "pseudoscience" – fake science.

Science

- Universal models
- Natural principles
- Testable predictions
- Not anthropocentric
- Replicable results
- Self-skepticism

Pseudoscience

- Singular events
- Supernatural explanations
- Untestable predictions
- Different rules for people
- Results defy replication
- Self-promotion