Science and pseudoscience

Physics 211
Syracuse University, Physics 211 Spring 2021
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May 4, 2021

Announcements

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What is science?

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And how is it different from other ways of gaining knowledge?

Tell us in Zoom or Twitch chat!

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Long ago, we thought:

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- The stars look like they are moving so they must be
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- The stars don't fall because they are heavenly
- Moving things come to rest on their own

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But people also figured things out:

- The Greek/Egyptian astronomers figured out a geometric way to predict the motions of the planets
- The Muslim mathematicians that followed them fixed their math
- These calculations were very accurate
- ... but they were not related back to natural philosophy (the truth of nature) as a whole

In the scientific revolution:

- People made detailed **observations** of the planets and did careful **experiments** on moving objects
- People proposed **models** to explain these observations
- They judged the validity of these models by their ability to match the data
- They discarded the ones that didn't work and refined ones that sort-of worked
- Example:
  - "Maybe the planets, including Earth, go in circles around the Sun?" – explained retrograde motion
  - Telescopic observations of Venus – this *requires* a Sun-centered solar system

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    - "Maybe the planets, including Earth, go in circles around the Sun?" – explained retrograde motion
    - Telescopic observations of Venus – this *requires* a Sun-centered solar system
    - Didn't fit detailed data – model had to be modified
    - Circles are perfect – but ellipses fit the data
- Newton realized that the **same set of laws** ($\vec{F} = m\vec{a}$, $F_g = \frac{GMm}{r^2}$) governed both the planets and things on Earth

Science – as a means of seeking truth about nature – 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 observations: planet motion, Newton's pendulums, falling objects...

- **Self-skepticism:** someone making a scientific claim should actively search for things that might prove themselves wrong
- Kepler was convinced planetary orbits were circles... until the data convinced him otherwise

- **Universality:** the laws of nature apply in all places and times, and to all things (including humans)
- Newton was able to explain *all* motion with one set of principles, in space and on Earth

- **Objectivity:** scientific ideas, or the evaluation of them, should be independent of any particular human perspective
- Earth was no longer given a privileged place or special rules

Two notes

1. “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. (Examples?)

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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2. There is a difference between a flawed process of science and simply being wrong. We aren’t talking about math errors or physics mistakes here; we’re talking about *bypassing the safeguards in the scientific process*, either by accident or deliberately.

Properties of science

Broad properties of science as a means of seeking truth:

- **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

First, some definitions

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  - Examples: The US Army survey of aircraft damage

The lines between these can get kind of fuzzy...

Common fallacies

Let's explore some common ways that these principles get violated. This isn't an exhaustive list!

Please feel free to comment in chat with your own examples.

I'd like to spend much of the time today "off script" – discussing your examples, not 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: the previous administration's response to COVID-19, climate change, creationism, vaccination, drug laws...

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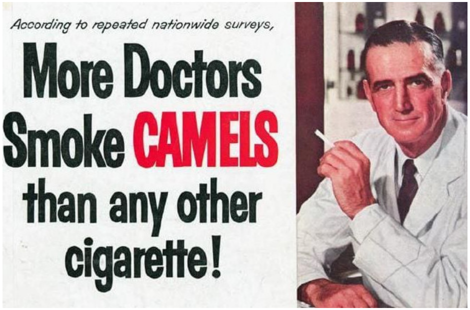
... and using "argument from authority" is the reverse: well, if these doctors say that they smoke Camels, they must be safe... right?

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



Ad hominem arguments

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

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"[A]fter the rocket quits our air and really starts on its longer journey, its flight would be neither accelerated nor maintained by the explosion of the charges it then might have left. To claim that it would be is to deny a fundamental law of dynamics, and only Dr. Einstein and his chosen dozen, so few and fit, are licensed to do that.... That Professor Goddard, with his "chair" in Clark College and the countenancing of the Smithsonian Institution, does not know the relation of action and reaction [Newton's third law], and of the need to have something better than a vacuum against which to [push] – to say that would be absurd. Of course he only seems to lack the knowledge ladled out daily in high schools."

–*The New York Times*, 1920

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–*The New York Times*, 1920

"*Further investigation and experimentation have confirmed the findings of Isaac Newton in the 17th Century and it is now definitely established that a rocket can function in a vacuum as well as in an atmosphere. The* Times *regrets the error."*

–*The New York Times*, 1969

Statistical dishonesty

Statistics is the mathematical discipline that lets us turn empirical data into conclusions.

It lets us turn a collection of "maybes" and "probablys" and "unlikelys" into "almost certainlys".

Statistics is immensely powerful. But:

- It is a subtle, complex field of math (you can get PhD's in it)
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- It is a subtle, complex field of math (you can get PhD's in it)
- It is a lot of work and only someone intimately familiar with data is really equipped to analyze it
- It is absolutely essential if science is going to look to empirical data as the highest authority

A great many flawed scientific processes come down to flawed statistics. Some common statistical fallacies:

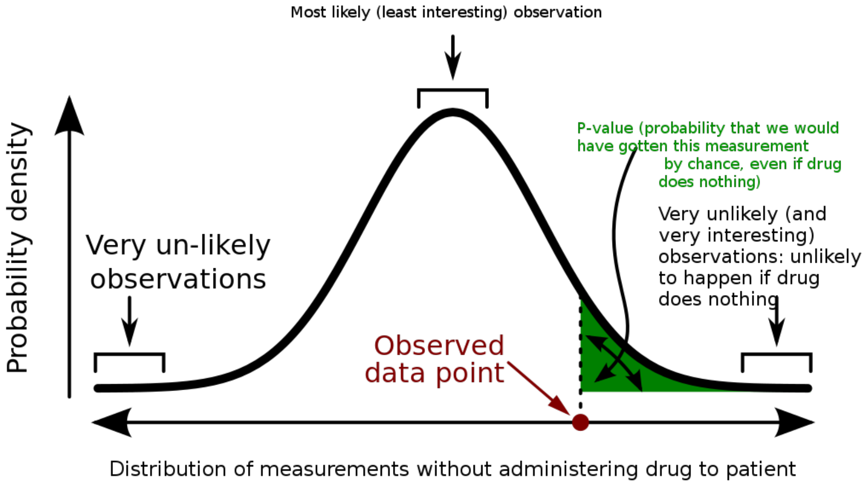
- "Garbage in, garbage out": flawed, stinky data $\rightarrow$ statistical analysis $\rightarrow$ incorrect but nonstinky conclusions!
- Correlation implies causation: does the decline in pirates cause climate change?
- Incorrect use of statistical inference (statistics is hard)
- Some types of statistical shenanigans (often related to sampling bias):
  - "P-hacking"
  - Publication bias

Statistical inference done honestly

Suppose we want to test if a new drug (or a chemical in food) has any effect.

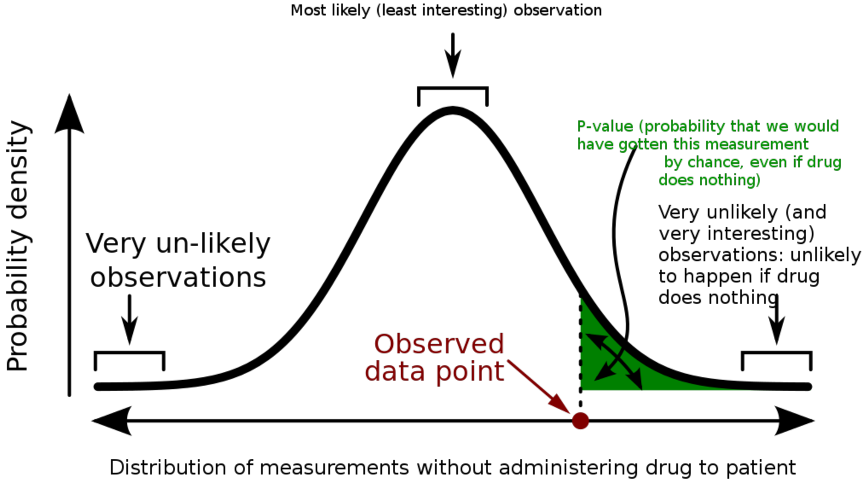
Correct thing to do:

- Make lots of measurements of how people react to the drug
- Compare their distribution to the black curve (what you'd expect if the drug does nothing)
- Get excited if their average is very different from the center of the curve (maybe drug made that happen?)
  - (Statistics gives us tools to quantify "very different")



Classic cherry-picking:

- Make lots of measurements of how people react to the drug
- Forget about the ones close to the center (they are boring!)
- Compare their distribution to the black curve (what you'd expect if the drug does nothing)
- Even if the drug does nothing, you'll get a distribution looking like the green portion
- Notice that their average is very different, get excited!



Statistical inference gone wrong, II: biased data

One example of biased data is *survivorship bias:*

- Make lots of measurements of how people react to the drug
- Fail to measure the ones on the left-hand side (they're dead)
- Compare their distribution to the black curve (what you'd expect if the drug does nothing)
- We removed the left-hand side, so the average shifts right
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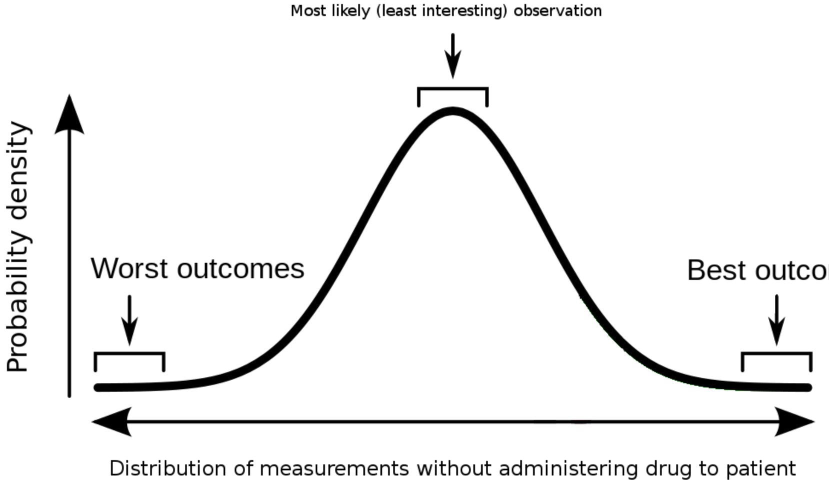

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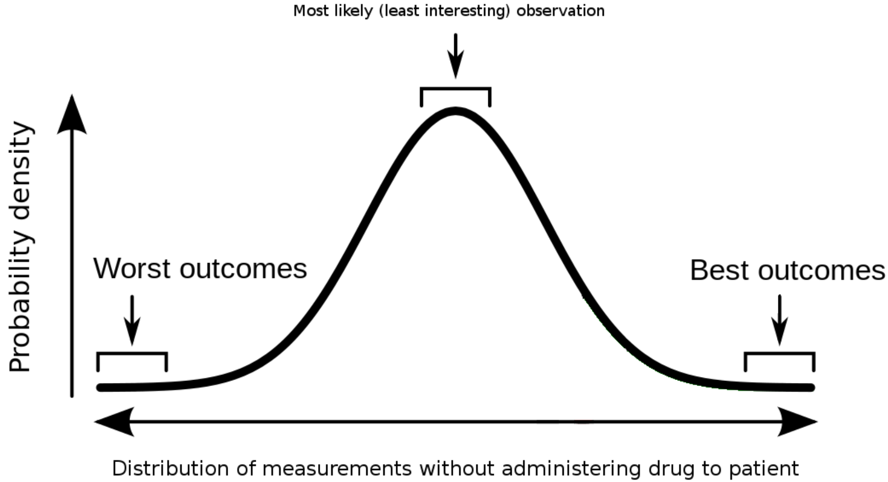

This sort of thing happened in a hydroxychloroquine study in 2020!

If the measurements are entire *studies*, we often unintentionally cherry-pick them in *meta-analyses* (studies averaging many studies together)

- Different scientists do experiments on how people react to the drug
- Nobody publishes the ones close to the center (they're boring, back to the drawing board!)
- Compare their distribution to the black curve (what you'd expect if the drug does nothing)
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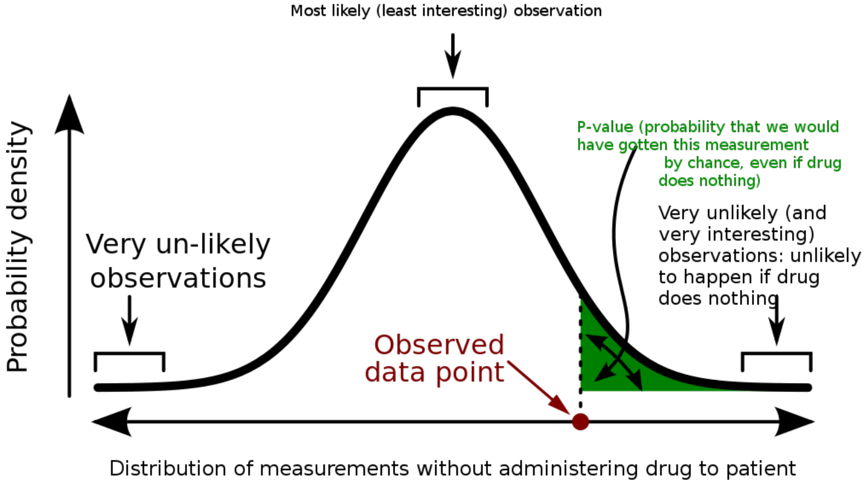

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(Discuss them in chat)

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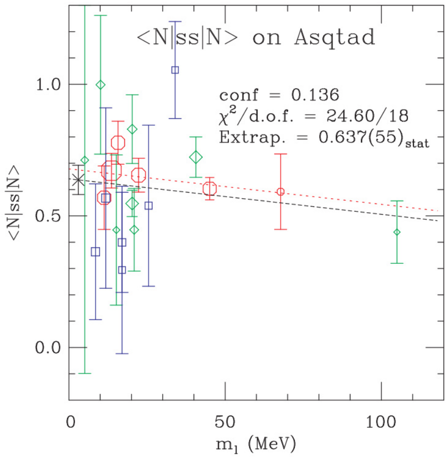
The above example about drug studies is real: publication bias is a serious problem in drug development! (See `https://www.nejm.org/doi/full/10.1056/NEJMsa065779`)

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



A figure from my PhD thesis. I spent probably five times as much effort on quantifying the uncertainty in my results than I did getting the result itself. All the complicated statistics above was in service of this!

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?

(Discuss them in chat!)

`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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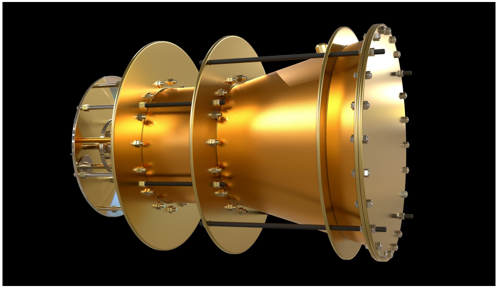
- We see nuclear reactions that don't seem to conserve momentum; what happened?
- ... there's another particle produced we can't detect (the neutrino)

- 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.)
- ... turns out space and time *aren't* independent – this sort of revolution is rare!

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)

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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 poor 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.

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, not just why they are exciting

Sensationalism

Do you have any favorite examples of over-sensationalized scientific claims?