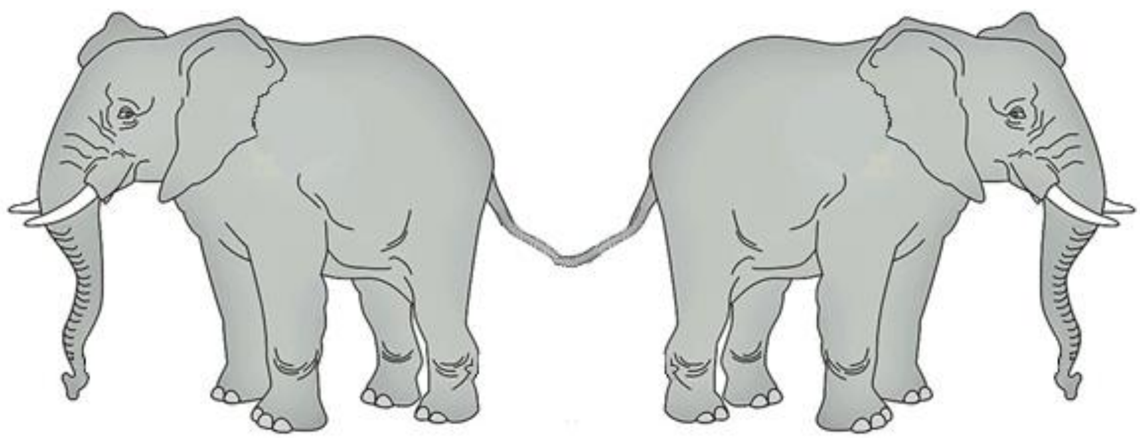
Everyone Does Science



A tale of two elephants

1. Rationale

Suppose that a weird arrangement of sunspots sends the mind of 27-year old Charles Darwin (fresh from his journey on *The Beagle*) into the head of a Virginia 9th grader. Before Darwin has a chance to voice his astonishment, he finds himself, pencil in hand, in front of an exam assessing his knowledge of the Biology Standards of Learning. He decides that his first task is to do what is expected of him and complete the exam.

Although his head is stuffed with the biological and geological experiences from his 5-year voyage, plus the lessons learned from his medical school training and field experiments while in the university, he finds himself mystified by most of the questions. "*What did Rosalind Franklin contribute to the understanding of DNA molecules?"* Who is Rosalind Franklin? What is DNA? And other questions -- the germ theory of disease? The energy of activation in enzymatic reactions? How viruses differ from animal cells? His confidence is shaken, but he does his best. In the end, he scores 10 out of 46 questions.[1] Darwin failed.

Of course, it really doesn't matter whether Darwin knows about Rosalind Franklin's contributions. In a few minutes, he could find out. It would take longer to figure out what DNA is about, but with the proper cast of mind, he could do it… and Darwin had the proper cast of mind. That's why he was so successful. If everyone left K-12 with the kind of inquiring mind Darwin had, we should be crying with joy. Instead, students leave with factlets that dribble away, leaving them little improved by the experience.

It is far more important to know how to peer into a phenomenon, see what are the critical questions to ask, and imagine how to answer them. We amplify ourselves by the work of others, but only if we know how to distinguish what they have observed from what they merely assert. The Virginia Standards of Learning recognize the importance of these more basic abilities – many of the objectives stated in the Biology SOLs are of this type (e.g. #7: "Develop scientific dispositions and habits of mind…").

But it doesn't work. For the past 24 years, I've directed science courses in Virginia universities. In general, the students come in ready for me to tell them what to do, what to think, what to write on the next exam. I've needed to expend extraordinary time and effort breaking them of the habit, so that they will ask their own questions and rely on themselves to carve up a phenomenon into pieces they can address. Those who have been the most successful in academics – those who get the highest grades -- are often the most resistant to change.

Almost to a person, they have no idea how to distinguish an observation from an assertion. They rely on authority rather than evidence. They are intellectually passive. Most important (and the basis for all the other problems), they have not taken in the fundamental ethos of science, the usually unstated presumptions that guide scientific activity and discourse. Instead, they apply the

[1] I took the Biology end-of-course SOLs released Spring 2015 for Darwin, giving him every benefit of the doubt but taking into account what was known in 1836.

Figure 1.1: Common discourse. Left: groups supporting protesters in Hong Kong or supporting the Chinese government. Right: Representatives of groups present in Charlottesville, Virginia, with different narratives concerning the American experience. (Photos: Don McKinnon, AFP, Chip Somodevilla)

ethos of our society: truth is fungible. Truth is in the service of ultimate ends. First decide on the story you want to tell, the claim you want to make. Only then find the evidence to support it (or don't bother).

We are living in a world that is a result of this ethos that puts ends first, one that is driven by ideology and riven by passionate identification with ideological groups (for example, see **Fig. 1.1**). It isn't disagreement that prevents discussion. Disagreements are routine in science, the necessary friction that rubs away what is unnecessary to produce a better consensus. What's absent is a common framework to which all adhere Without that framework, we have not mere disagreements between groups with different identities but destructive warfare.

To leave school with the mind of Darwin does not mean that the student will have gained the genius required to formulate a profound organizing principle like natural selection. It means developing a searing devotion to truth rooted in common reality that lies at the heart of a shared scientific ethos. Just as reading, writing, and arithmetic are birthrights for all those who pass through our educational system – not just for those who will be scholars, poets, or mathematicians – the mindset of science should be absorbed by all as well. All of us live in a world where arguments are based on repetition and appeals to identity. We all need a defense. I can tell you, the road to this transformation is very tough going, but it should be easier in middle school than in the university, where students are invested in the artificial practices that have given them success.

The purpose of this book is to outline a path to the mind of science and propose how students might learn to engage in productive discussions. I didn't make it up. I'm following a well known view of science popularized by Robert Merton 80 years ago[2] and made more generally intelligible by John Zimon.[3] These ideas will be discussed later (Chapter 15), but they lurk in the background from beginning to end. Like all major changes in the habits of mind, this path relies less on the roles of a teacher presenting and a student absorbing a body of knowledge and more on the roles of a mentor demonstrating and apprentices trying out the mental tools of their trade. It is the teacher as prospective mentor that I am addressing in this book.

[2] Merton, RK (1973). The Sociology of Science: Theoretical and Empirical Investigations.
[3] Zimon, J (2000). Real Science: What It Is, and What It Means.

I start off by taking you through what I think are the primary obstacles separating people from the mind of science and several chapters later present dialogues that show students struggling to get there. In between, I present three Questions and three Axioms that can be wielded as bludgeons students can use to break down the obstacles. Although they are slogans, with all the dangers and limitations attached to such things, they are easy to hang on to and may continue to spur action when examples and subtle arguments have faded way. By the end, I hope that you will consider the notion that middle school is closer to too late than too early for students to regain the mind of science, the mind everyone starts out with. You might also imagine how students leaving school having experienced that mind might participate in their society and how they might address differently the arguments that bitterly divide their elders.

2. We live in the same universe

Imagine that your aging great-aunt recently suffered a fall. She's OK, but your family is understandably worried. She's reached the age where such events can have serious consequences. You come together to brainstorm about possible actions you might take to tilt the odds towards a better future for her.

Your brother starts off the discussion. "Look at this![4] I saw it in the news. We should be making sure she takes Vitamin D".

Chicago Tribune: Vitamin D Deficiency Figures in Hip Fractures

"Nonsense!" says your sister. "Here's what I found.[5] She should save her money for something worthwhile."

The Telegraph: Extra vitamin D and calcium 'a waste of time'

"No, no, no!" says your cousin. "It says right here[6] in plain English that Vitamin D has been proven to work. We gotta go with it."

The Times: Vitamin D can reduce number of falls and fractures in elderly

"Bogus!" cries your other cousin. "I don't know where that comes from. I read just the opposite.[7]"

Daily Mail: Vitamin D pills for elderly 'increase their risk of falls'

Well there you are. You've got to do something -- or nothing (which is something) – but how to decide? How can you reconcile these contradictory claims? It's easy to dismiss news you don't like as fake news, but before taking that step, consider: Is it possible that the seemingly contradictory claims can co-exist?

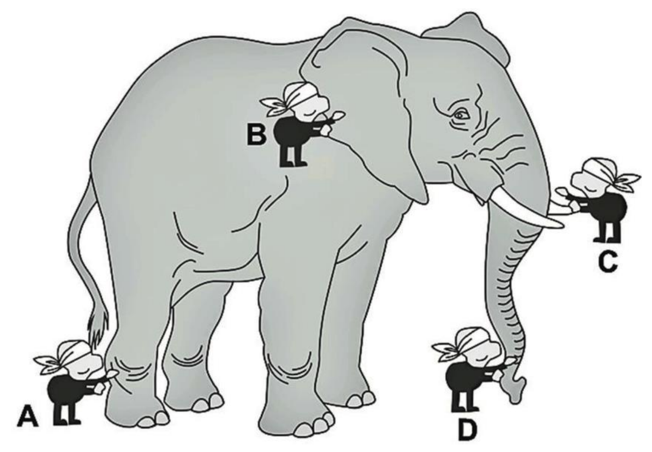


Figure 2.1: Four blind people trying to understand an elephant.
(From John N Maina http://dx.doi.org/10.5772/intechopen.69062)

In **Fig. 2.1**, there are four people doing their best to figure out what they're sensing. Person A might claim zhe's touching a tree trunk, Person B a large leaf, Person C, a spear, and Person D, a snake. No fakery here. Their assertions make sense (even if they're wrong) in a universe where elephants exist.

This is the human condition. We all can feel only a tiny slice of the elephant, but because of the way our brains are built, we insist on making sense out of it, and we can't help but believe the stories we tell ourselves.

[4] Cassandra West (1999). Chicago Tribune, 2 June 1999.
[5] Nick Fleming (2005). The Telegraph, 28 April 2005.
[6] Melanie Reid (2009). The Times, 28 December 2009.
[7] Sophie Borland (2016). Daily Mail, 4 January 2016.

We all live in the same universe, so there must be some elephant that explains our different assertions. However, the thing we are feeling could not possibly be both a spear and a tree trunk. The assertions are incompatible. But what IS compatible is the underlying reality that led to those assertions. Suppose Person A said, "I feel something cylindrical", Person B said, "I feel something thin and leathery", Person C said, "I fell something with a point", and Person D said "I feel something long and flexible that I can wrap my hand around." These observations ARE compatible. They're compatible with the elephant we can't see. After trading observations, some blind genius might come up with a way to connect the different parts into a coherent whole.

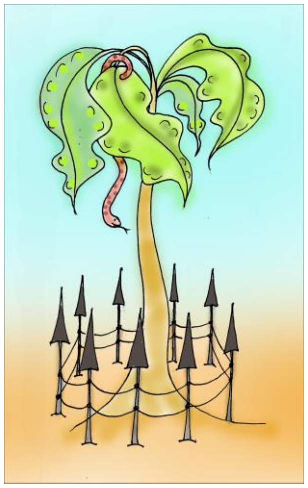


Figure 2.2: Possible object that has something cylindrical, thin and leathery, pointy, and long and flexible. (graphic courtesy of Joline El-Hai)

Of course genius is not the same thing as clairvoyance, and it's likely that the coherent whole zhe comes up with is not very close to an elephant (**Fig. 2.2**). That's the way it is. But with more blind people making more observations, the community stands a chance of getting closer to a vision of an elephant.

If they're stuck on their fanciful assertions – tree trunks and snakes – they'll go nowhere except fruitless arguments. If they put aside the assertions and focus instead on the underlying observations, then they are rooted in reality and can make progress.

But humans almost always operate at the level of assertions. How can we guide the discussion to observations?

Practical strategies

Students can hone their skills by playing the Elephant game. Prepare a few boxes, each with something complicated inside. Make four holes in each box and attach to each hole a long glove. A chemical glove or evening gown glove will do, but so will a simple plastic bag if gloves are scarce. Label the gloved holes A, B, C, and D. Break the students into four groups – A, B, C, and D – and invite each group to investigate the contents of one box through their specific portal. After writing down their thoughts, pass the box to the next group. When every group has had a crack at every box, the thoughts are collected, aggregated, and discussed.

3. *How do you know?*

In the last chapter, I introduced the first of three axioms that I claim underlie scientific discussion: *We live in the same universe.* We lose sight of that when we operate in the world of assertions (as we usually do in casual speech). Conversely, we can see the connection between seemingly contradictory phenomenon only when we operate in the world of observations. It is therefore critical to distinguish between assertions and observations. In this chapter, I'll introduce the first of three questions, one that will help you make this critical distinction.

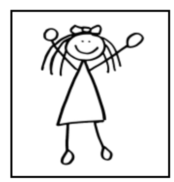
It may seem silly to stress something that seems obvious: assertions are assertions and observations are observations. Actually, most people have a difficult time making the distinction, because English is treacherous. You probably wouldn't think twice to tell someone something like "*I observe that you're angry*". No you don't! You may observe that the person's face is red or that there's foam dripping from zher mouth. But you can't observe an internal state of anger.

Even so, you still might consider the distinction to be no problem. Yes? Let's try it out. Consider the excerpt below from a well known work:

1. *Mary had a little lamb,*
2. *Whose fleece was white as snow*.
3. *And everywhere that Mary went, the lamb was sure to go.*
4. *It followed her to school one day,*
5. *Which was against the rules*.
6. *It made the children laugh and play to see a lamb at school.*

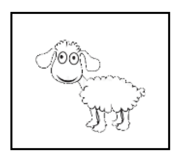
Now consider each line and decide whether it is an assertion or an observation. I'll wait.

If this isn't going to devolve into a mindless shouting match, we need some criterion to decide the matter, and I'll propose this. When you have a candidate observation, ask the purported observer, "*How do you know?"* If the answer is justifiably "*Because I saw it!*", then we'll call it an observation. But if the observer needs to resort to some theory, then not.



Start with line #1. "*Mary had a…*" Wait a second! How do you know that's 'Mary'? Did you observe her being 'Mary'?

I'm going to brush this one aside. 'Mary" is neither an observation nor an assertion. It's just a definition. Whoever that entity is, I'm going to label her 'Mary', just to have something to refer to. Maybe she calls herself that too, or maybe Cuspadilla. For these purposes, I don't care.



What about 'lamb'? How do you know that the entity is a lamb? Is that just a definition? I'm not so sure. [Entity code-named Mary] had a little [entity code-named lamb]? No, I think it's important to the story that the second entity has the characteristics we associate with the animal 'lamb'. Does it? The narrator (whoever wrote the poem) might respond, "*I saw it! It's a lamb!*" This might be good enough. We routinely name things using standard characteristics ("*Four legs… check. Tail… check. Fleece…check*" and so forth). I'll grant for the moment that the narrator did this the same way I would.

But 'little' lamb? How do you know it's little? "*I saw it!*" says the narrator. Saw 'little'? By what standard? Newborn lambs are really tiny. That small? You might say "*Lambs have a standard size, and this lamb was smaller than that.*" Really? How do you know the standard size of a lamb? Well, I can imagine a response like "*I measured the distance from the lamb's pelvis to neck to be 18.7 cm, which is smaller than all but 5% of lambs 12 to 20 months old, according to the 2010 U.S. lamb census.*" OK… how do you know the age of the lamb? Never mind. Let's go on to the main event.

"*Mary HAD a little lamb*". How do you know?

[had]

> "*I saw it!*" says the narrator.
> Saw WHAT? How do you see a 'had'?
> "*I saw Mary and the lamb walking together.*"
> Maybe a wild lamb, an evil lamb, stalking Mary.
> "*I even saw her carrying the lamb.*"
> Maybe she found him injured in the woods and was bringing him to a veterinarian.
> "*Look. She showed me a contract with her name on it, a bill of sale from a farmer!*"
> OK. That's an observation. You saw a contract. But not '*Mary had a little lamb*'.

"*How do you know?*" is a very powerful tool! Make sure, however, you read it correctly. It isn't "*How do **you** know?*", which sounds like a schoolyard taunt. The 'you' doesn't matter. The question is how does anyone know? You just happen to be the person who made the claim and who presumably knows the answer.

So you can trot out the question "*How do you know*" to help you make the distinction between assertion and observation. And that distinction is critical in… …in analyzing popular poems. OK, I'm not so sure that whatever inroads we've made in literary analysis are where we want to go. In the next chapter, we get back to scientific claims that seem to live in separate universes.

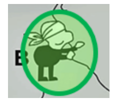
Practical strategies

Have students break into groups and come up with decisions regarding each line of the poem. Is it an assertion? An observation? Something else? Collect the decisions and discuss. This exercise is just to get into the habit of breaking down assertions until you reach observations. Every activity from this point on will incorporate "*How do you know?*", so much so that the question might become a sing-song mantra. There are worse mantras.

A second activity to help with separating assertions from observations is for each student to write down an answer to a straightforward question, e.g. "Did it rain yesterday?". Then break into groups to discuss the answers, attempting to tie each answer to actual observations, thereby limiting the answer. Some may think it clever to say "Yes it did rain yesterday,… somewhere in the world!" That too is an assertion that must be supported by an actual observation.

4. Drilling Down from Assertion to Observation

A few pages ago we were considering contradictory assertions concerning the benefit of vitamin D, and I made the claim that the contradictions arose because we were focused on assertions. Since all four asserters live in the same universe, that universe must accommodate what they actually observed. It's easy to dismiss the assertions, but how do we get to the observations, the truth?



Chicago Tribune: Vitamin D Deficiency Figures in Hip Fractures

Take one of the assertions. It came from an article in the Chicago Tribune. Many might say, "Chicago Tribune,… reputable… OK, good enough for me!". But that ***isn't*** good enough. You have to ask, "How do you know?". The article says:

> *"...according to an article in the Journal of the American Medical Association... Meryl S. LeBoff and colleagues at Boston's Brigham and Women's Hospital studied...*"

So the reporter knows because LeBoff and colleagues said so. From these clues, we can find the research article that provided the evidence for the assertion (we'll see how to do this in Chapter 14). The article is LeBoff et al (1999).[8] Their bottom line was this:

> **Conclusions** Postmenopausal community-living women who presented with hip fracture showed occult vitamin D deficiency. Repletion of vitamin D and suppression of parathyroid hormone at the time of fracture may reduce future fracture risk and facilitate hip fracture repair. Because vitamin D deficiency is preventable, heightened awareness is necessary to ensure adequate vitamin D nutrition, particularly in northern latitudes.

There's some difficult language here, but it isn't too difficult to get a general sense that the conclusion from the research article and the one from the newspaper article are in reasonable agreement. The reporter didn't make stuff up. But how do they know? The difference is, if you ask LeBoff et al *How do you know?*, **they have to answer**. If they don't, they can't publish their article. That's part of the rules of the game (for authors of research articles, not reporters). Their conclusion is, of course, an assertion, but somewhere in the article are the observations that brought them there. What were those observations?

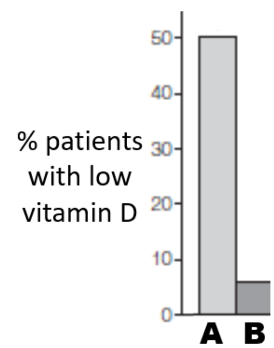


Figure 4.1. Comparison of vitamin D levels. In (A) 30 women with fractured hips, (B) 17 women with bone loss admitted for elective surgery (adapted from Ref. 8).

They observed vitamin D levels in the blood of certain patients. Can you really see vitamin D? No, but you ***can*** see the output of a procedure that measures vitamin D. Of course the nature of the procedure (a radioimmune assay) is important, but I won't go into it here. 'Certain patients' – not good enough. Who were they? LeBoff et al say they measured levels in 30 patients who came in because they had broken their hips. From the radioimmune assay, they determined how many of those 30 patients had vitamin D lower than a certain level. What they found is shown in **Fig. 4.1**. 50%

[8] LeBoff MS, Kohlmeier L, Hurwitz S, Franklin J, Wright J, Glowacki J (1999) Occult vitamin D deficiency in postmenopausal US women with acute hip fracture. Journal of the American Medical Association 281:1505-1511.

of patients presenting with broken hips had vitamin D at low levels (suitably defined), as compared to only 6% for patients in the hospital for some elective surgery (e.g. hip replacement).

That sounds like a big difference, but who are the people in these groups?

The authors have to tell you who they observed – not their names, of course, but their characteristics, to the extent they know them. **Table 4.1** shows some of the characteristics of the patients that they recorded.

Table 4.1: Characteristics of groups

	Group	
	A	**B**
Number	30 females	17 females
Avg age	78	70
Activity	1.5 hrs/wk	20 hrs/wk
Smoking	8 pks/yr	0 pks/yr

It is entirely understandable that the two groups should be different from one another. Random differences are readily apparent in small groups, and 30+17 patients is not a lot of people. It may well be that the low level of vitamin D levels in Group **A** shown in **Fig. 4.1** contributed to their hip fractures, as the newspaper headline implies. But it is also possible that the low levels are the ***result*** of the fracture (maybe that's what happens when you have stressed bones). Or maybe the much lower physical activity in group **A** (1.5 hrs/wk vs 20 hrs/wk) leads to low vitamin D levels (you can't have a lot of activity with broken hips). Or… (fill in with a host of other possible reasons). The fact is, however, that LeBoff et al definitely observed these 47 patients and saw what they saw. That's truth. What you take from their observations is another matter, one that's open to debate.

A second assertion, published in The Telegraph (a British newspaper), pushed the opposite narrative. It was based on a research article by Grant et al (2005),[9] which concluded this:

The Telegraph: Extra vitamin D and calcium 'a waste of time'

Interpretation The findings do not support routine oral supplementation with calcium and vitamin D3, either alone or in combination, for the prevention of further fractures in previously mobile elderly people.

That's the assertion. How do they know?

Grant et al surveyed 4,481 elderly females people who had suffered a fracture in the previous 10 years. At time 0 they started half of the subjects with daily Vitamin D3 tablets (some with calcium some without) and monitored them over the course of up to 5 years to see if they had an additional bone fracture. The incidence of fracture is shown in **Fig. 4.2**. It didn't seem to matter whether subjects got Vitamin D3 tablets, with or without calcium, or nothing. The rate of fractures over 60 months was about the same.

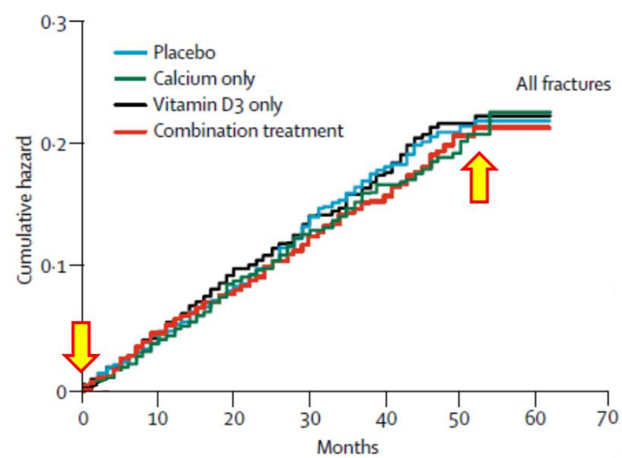


Figure 4.2: Bone fractures with or without Vitamin D. Taken from Ref 9.

[9] Grant AM and 88 others (2005). Oral vitamin D3 and calcium for secondary prevention of low-trauma fractures in elderly people (Randomised Evaluation of Calcium Or vitamin D, RECORD): a randomized placebo-controlled trial. Lancet 365:1621-1628.

This is not at all what the first experiment (LeBoff et al) did! Measuring vitamin D in people who come in with broken hips is not the same thing as giving vitamin D to people who had broken hips many years ago. It is not difficult to imagine an elephant that connects these superficially conflicting results.

And that's the way it is in general with seeming contradictions. It is the assertions that contradict themselves. If you look closely at the observations and the underlying experiments, you find hints of a world rich enough to accommodate them. The authors were just looking at different parts of the elephant, an elephant we can't see.

Thus far, I've contrasted assertions with observations. I've avoided the word "results", even though that word is much more common in the scientific literature than "observations". In fact, most research articles include a major section labeled "Results". I've held off until now because this word is even more confusing than "observation", owing to the different way it is used in science compared to casual speech. "Result" in street English can indicate an <u>outcome</u> caused by something, as in "The result of all this ambiguity was total chaos". That's not what's meant in science articles. Furthermore, you wouldn't be surprised to run across something like this in the popular media:

> *Humans are making global warming worse, all right - but in more ways than you think. That's the result of a study published Thursday by…*[10]

Certainly the study didn't cause global warming, so we have here a different meaning, one that in street English is perfectly valid: 'result' meaning something close to 'conclusion', "*That's the <u>conclusion</u> of a study…"*. This meaning is the precise opposite of how "result" is used in science. A result in science talk is a <u>type of observation</u>, one associated with an experiment. Is the sentence above an observation? How do you know that humans (which humans?) are making (how do you see "make"?) global warming worse (What's global warming? How do you see it? How do you see worse?).

No, it's a conclusion. A conclusion is a <u>type of assertion</u>, one intended to sum up one's views. These terms aren't as important as the ideas behind them: Assertions/conclusions provide no basis for productive discussion of fundamental issues. If one person says "*Vitamin D reduces the number of falls*" and another says "*Vitamin D increases the number of falls*", each assertion is easy to understand, but if that's all there is, then what room is there for discussion?

But if one person says:

> *23 mixed males and females aged 89 years (average) in a long-term care facility in Boston took 800 units of Vitamin D daily and experienced 9 falls over the course of 5 months, while a similar group of 25 mixed males and females did not take Vitamin D supplements and experienced 31 falls over the same period.*[11]

[10] Chris Mooney (2016). The Toronto Star, 10 March 2016. Climate Change's Hidden Catalyst.
[11] Broe KE, Chen TC, Weinberg J, Bischoff-Ferrari HA, Holick MF, Kiel DP (2007). A higher dose of vitamin D reduces the risk of falls in nursing home residents: A randomized, multiple-dose study. Journal of the American Geriatrics Society 55:234-239.

and another says:

Of 45 females aged 78 years (average) living at home in Zurich, Switzerland, and recruited by newspaper ad took 60,000 units of Vitamin D once a month, 67% fell over the course of a year, while in a similar group of 45 females took only 24,000 units of Vitamin D once a month, only 48% fell over the same period.[12]

that's much more difficult to understand – observations usually are -- but you have a basis for seeing how the two sets of results can co-exist.

Observations/results are as close as we can come to a direct experience of reality. Reality is complicated, much more complicated than any assertion. Sifting through reality is hard work! No wonder most settle for the simpler world of assertions.

Practical strategies

For the sake of brevity, I summarized parts of the articles I presented. It is much better for students to go to the articles themselves and find ways to make their conclusions compatible. Research articles are confusing, no doubt about it, but relevant differences in articles of this type are generally easy to understand, so long as you don't fall into despair from the parts you don't understand. In particular, the four research articles that form the basis for the Vitamin D newspaper articles are well within the grasp of middle school students, so long as they focus on the task at hand – how are the experiments different from each other? The first time out with a research article might be a group effort, led by the teacher, so that students can see how to fight through the mysterious parts and hone in on the parts they're looking for.

After this sort of initial outing, students can be broken up into groups composed of four to eight people, each group assigned a single article and charged with the goal of finding one or more critical observations. Of course it is better to give students a day or so to look over their articles. Then the groups are shuffled, so that each group has one or two people assigned each of the four articles. The group collectively can compare notes and focus on areas that may explain the apparent differences in conclusions. These insights can serve as the basis of a group discussion when the groups come together.

I should add that it took me a long time to find these four seemingly contradictory newspaper/research article pairs. Most research articles would pose much greater challenges to naïve readers. We'll return in Chapter 13 to activities that connect students to research articles but do not present insuperable challenges.

[12] Bischoff-Ferrari HA, Dawson-Hughes B, Orav EJ, Staehelin HB, Meyer OW, Theiler R, Dick W, Willett WC, Egli A (2016). Journal of the American Medical Association Internal Medicine 175:175-183.

5. Where can you find observations?

You've probably gotten the idea that I think observations are really important, the basis of scientific discussion and a reasonable basis for any discussion that has as its goal a search for common understanding. If you accept the fundamental value of observations, then the next question might be, Where can I get some?

One obvious answer would be 'the internet', since you find just about anything there. Indeed, I spend most of my working day seeking and digesting observations on the internet. But the truth is, if I throw a dart at my browser (and believe me, I'm often tempted), the likelihood of hitting an observation is miniscule. The internet is swamped by assertions and assertions masquerading as observations. You have to maintain your How-do-you-know deflector shields at full power, and that can get tiring. Later (in Chapter 14), I'll talk about ways of finding observations on the web in a rational fashion.

But for now, where else? Textbooks? Pick up your favorite. You may be surprised at how few observations you'll find. Most textbooks take as their task presenting assertions within the context of a compelling story. That's a good way to make things easier to understand. Understanding these stories certainly has its value, but if disagreement arises, you have no basis for a resolution. "*My story is better than your story*" generally is not persuasive.

Of course there's yourself. Go outside and walk in the park. Observe the trees and the frogs croaking on their lily pads. This is truth. You DO hear the croaks (but maybe they're not from frogs but from cicadas). However, there's a clear problem. What if you don't want to learn about frogs, at least not at the level of croaks. Maybe you want to learn about the rate of disappearance of Amazon rain forests. You can't go to South America, so what then?

We come to the second axiom:

> Axiom 1: We live in the same universe
> **Axiom 2: Observations are taken to be true**

That includes the observations of other people. Accept that and your world suddenly opens up, far beyond the frogs that happen to lie outside your door to anything that lies outside anyone's door at any time! The sum of human experience becomes your experience.

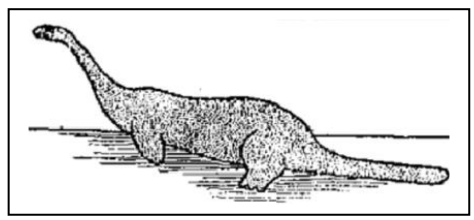
Sounds great, but unless you're bamboozled by the poetry, you'll see some obvious problems here, which we'll consider in the next couple of chapters.

6. Observations are taken to be true – Problem with reliability

Those engaged in science discussions take as an article of faith that if someone says zhe saw something, then zhe saw it. However, everyone has had experiences where that something turned out not to have been seen. Maybe the rewards for claiming to see it were too great to resist. Maybe zhe's insane. But in fact, that something doesn't really exist. Does this mean that Axiom 2 (Observations are taken to be true) is hopelessly naïve?

No. False reports may be commonplace in life, but you may be surprised that it isn't a big problem in scientific communication. One major reason is that by agreement, observations may not be reported unless they're accompanied by a description of the methods behind them, which others can use to reproduce the same observations. An article is a research article only if the results of an experiment come with the description of the experiment, in sufficient detail that a person versed in the art can do it too.

That's not a perfect defense. There are so many experiments described in the literature that they can't all be replicated by others, though the important ones are. Then there are observations that by their nature can't be replicated.

> *I saw the Loch Ness monster!*
>
> I can't give any credit to your claim unless I know how the experiment was performed.
>
> *OK. I stood on the shore of Loch Ness, near Abriachan, Scotland (Latitude N 57.38131; longitude W 4.37536) at 1 am, January 5, 2018. Looking towards the middle of the loch, I saw a large gray blob, wearing a top hat and carrying a cane, doing a soft shoe.*
>
> 
>
> Oh? I went to the same site on January 5th this year at the same time, and I did not see a gray blob.
>
> *Yes, but you did not go there January 5th, 2018.*
>
> (I think I'll put this one in my pocket)

Observations without description of the experiment should not be considered (except as teasers). Observations that cannot be replicated should not be given much weight. That leaves some false observations not worth replicating and a small residue of others. Taken as a whole, we gain far more by accepting Axiom 2, that well described observations are to be taken as true (provisionally) until circumstances demand that we question them.

Practical strategies

People are not accustomed to reporting methods along with their observations, yet this is standard practice in scientific discussions and needs to become a mental habit in students. It takes some getting used to. One way to gain practice is to take a collection of observations and assertions and help the speaker out by providing your own (made up) methods. For example, helping out the author of the poem in Chapter 3:

An adolescent human female (code-named "Mary") was tagged with a fluorescent paint (visible with night goggles) for subsequent identification and then released. In random observations (n=7) over the course of a day, she was repeatedly observed within 2 meters of an animal with morphological characteristics typical of sheep [1]. The length of the animal's ischium (pelvis bone) to the scapula (shoulder bone) was measured repeatedly to be 18.7 cm, to be expected if the measurements were performed on a single specimen. This value places the animal in the smallest 5% of lambs in the 2010 U.S. lamb census [2]. The age of the animal was determined by dental examination.

. . .

References

1. Reece WO (2009). Functional Anatomy and Physiology of Domesticated Animals. Fourth edition. Wiley-Blackwell, Danvers MA.

2. U.S. Bureau of Agronomic Statistics (2010). Morphological Assessment of Livestock. p.47. U.S. Government Printing Office, Washington DC.

Give students assertions that offer the opportunity to create backstories, the observations behind the assertions. Then let groups of students critique each other's made up observations, to identify hidden assumptions and parts that are insufficiently specified.

7. Observations are taken to be true – Problem with triviality

Far more serious than unreliable observations is the problem that observations just aren't very interesting. Yes, I take it as true (per Broe et al, 2011) that a certain unnamed 87 year old male at a certain unnamed long-term care facility did not experience a serious fall over the course of 5 months on a daily regimen of 800 units of Vitamin D daily… but who cares? I want to know whether my great aunt should take Vitamin D. I want to know whether Vitamin D works!

Ultimately, we don't want the specific (provisional) truths of observations. We want something meaningful, general laws, assertions that tell us something. And so we collect those observations and find a way in which they fit together – we imagine the invisible elephant.

In **Fig. 7.1** (top), I imagine a structure composed of observations. One observation (represented by the dot highlighted in blue) might be

> "*37 females aged 76 to 89 in a high-care facility in Yorkshire, who have not had any fractures and not previously taken Vitamin D, were given 800 units of Vitamin D each day and only one experienced a fracture over the course of one year, while 28 females aged 79 to 90 at the same facility did not get Vitamin D and experienced five fractures*".

The structure as a whole might be the assertion:

> *Females older than 70 years of age with no prior fractures who take a moderate level of Vitamin D will tend to get fewer fractures*

We want a meaningful general assertion, and if it is built through strong connections between observations, then it is… ***like*** truth. But we can never be sure. If the blue-highlighted observation turned out to be faulty, the structure may be strong enough to survive, but if you encounter a single observation that contradicts the assertion (**Fig. 7.1**, bottom)…

…you'll fight like hell to attack the validity of that observation. Maybe the Vitamin D was too old. Maybe the labels got mixed up. Repeat the experiment!

But if the observation holds up, you have no choice but to throw away the assertion, no matter how beautiful the structure is. The observations remain – they're still true – and maybe you can think of a different structure that fits them, including the one that killed the previous structure.

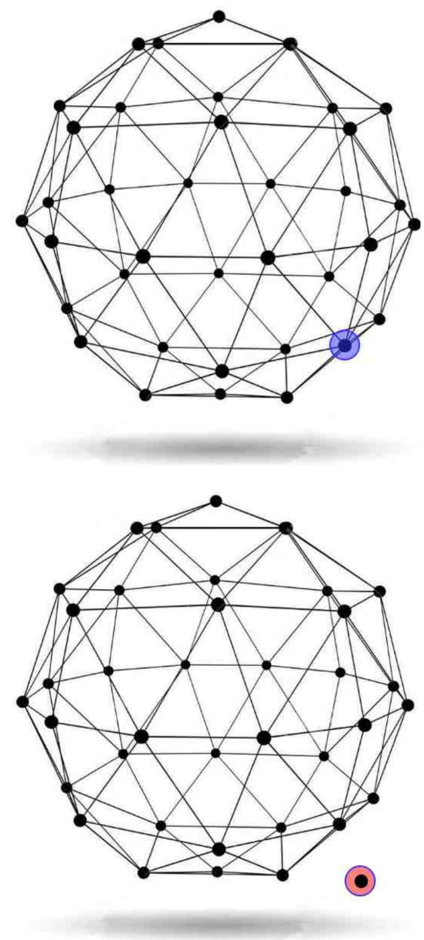


Figure 7.1: Assertions (structure) composed of individual observations (dots). (**Top)** All observations fit into the logical structure. (**Bottom**) Assertion is falsified by a discordant observation (red), maybe.

Practical strategies

We're all full of a large number of rules of thumb that guide our lives. We live by the generality that a red traffic light means you should stop, and a green light means you should go. Students might be invited to consider how these and other specific generalities arose. There was a time when you didn't know such things, and no doubt someone drummed the lore of red and green into your head, but surely it wouldn't have stuck if you did not repeatedly observe actions consistent with the rule. You saw cars stop at a red light and go when it turned green. You no doubt developed confidence that when a light was green in one direction, it was red in the other. What observations might shake your confidence? How might they arise? What greater generality might accommodate the exceptions?

8. Observations are taken to be true – Problem with bias

If observations are taken to be true, then YOUR observations are also taken to be true, and you bear the heavy responsibility of relating them honestly. This is way more than just avoiding lies. That's easy. What's much more difficult is relating what you truly saw rather than what you want to see.

Let's approach this by an example. Look at the four panels in **Fig. 8.1** and put them in order. Which came first? Which came second? Third? Fourth? I'll wait.

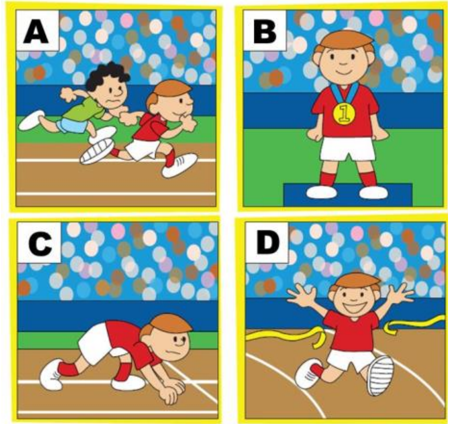


Figure 8.1: Four events in a sequence of events.

I probably didn't have to wait very long. Just about everybody sees immediately that the order is C-A-D-B. Is that because everybody has the ability to see the truth? No, it just means that we share the same cultural norms, which is usually a good thing, as it helps us function within our common culture.

Consider Panel C. What do you see? You DON'T see someone crouching to begin a race. That's your biased expectation talking. For all you know, this person is looking for a lost contact lens. Maybe in his culture, people begin races by standing on one foot with their hands on their heads.

In observing, we must take great pains to guard against such bias, to see what we see, and report what we see, shorn as much as possible from what we expect to see. We humans can't avoid bias completely. We can only do our best.

Practical strategies

Here's a stretching exercise that might help. Scramble the letters A, B, C, and D and make up a scenario that is consistent with that order. For example, if the order is D-A-B-C, you might imagine that a runner was involved in three races: winning the first (D), getting a medal for the second (A-B), and about to see if he can make it three (C). Or further afield: he is at his birthday party (all those balloons in the background), and his friends insist on tickling him with yellow hooks (D). He can't stand it any longer, so he tries to run away, pursued by one of his friends (A) He doesn't get far, and he's brought back, forced to stand on a box with a microphone around his neck to sing Happy Birthday to himself (B). He does his best, sings and sings, until he's so exhausted that he falls over (C).

If you do enough of these exercises, then you become more adept at reporting something closer to what you actually see – not a person crossing the finish line, but a person with his left foot forward, right foot back, and with two yellow ribbon-like objects on either side of him. That description is highly incomplete and still full of bias, but, again, we do our best.

9. Observations are taken to be true – Problem with bias (Part II)

Our observations are perverted even by our benign cultural biases, like how people run races – that's true, and it's true for everyone. Everyone has a culture. But it's much worse than this. Everyone also has a human brain, and that brain is designed to undermine dispassionate observation and replace it with rapid interpretation. This is ordinarily a good thing. You don't want to be contemplating the spots on a leopard that's rushing at you to make you his next meal.

We routinely form judgments before our contemplative brain is engaged. Here's an example. Consider this question: "*How much risk do you believe global warming poses to human health, safety, or prosperity?*" This is a question rooted in observations of the past and predictions of the future, modulated by opinions one may have about what bar to set for health, safety, and prosperity. It is a question that reasonable people might answer in different ways. But it is not a question that seems related to political philosophy – it doesn't ask what actions government should take. Nonetheless, here is how that question was answered by 2000 respondents said to sample the general population of the U.S. (**Fig. 9.1**).[13]

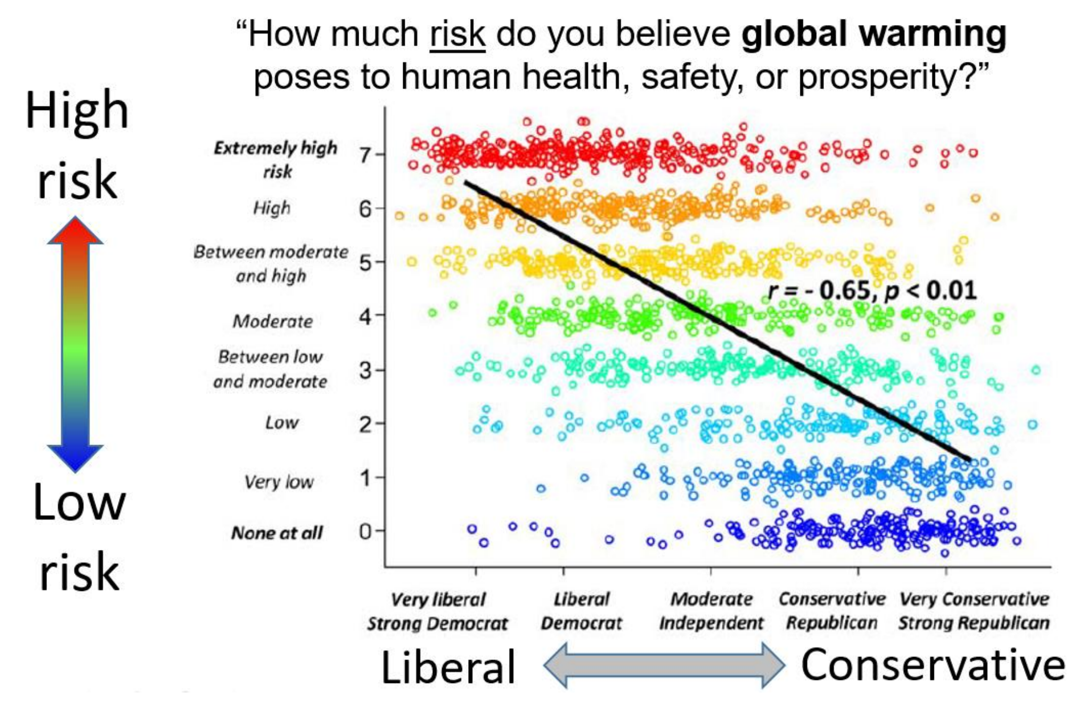


Figure 9.1: Correlation between views on climate risk and self-identified political label. Adapted from Kahan (2015).[13]

Those who self-identified as "liberal" were much more likely to believe that the risks of climate change are high, while those who self-identified as conservative were much more likely to minimize the risks. One might think that the two groups are privy to different sets of information

[13] Kahan D M (2015). Climate-science communication and the measurement problem. [Adv Polit Psychol 36 Suppl 1:1-43](#).

(maybe one is focused on the loss of ice in Greenland and the other on average temperatures in the early 2000's), but it's been shown in other studies that information is not the key difference. For example, Shao & Goidel (2016)[14] asked 3856 residents of the US gulf coast to describe the weather in their local communities over the past 10 years, whether it had been warmer than usual and how many hurricanes had struck. They experienced the same weather, but here too, the answers veered from reality in predictable ways, depending on their professed political leanings.

We like to think that our rational selves direct decisions, but Haidt (2012) has argued that it is more common for our rational self to be in the service of a stronger part of our mind, illustrated by the metaphor of the elephant and its rider (**Fig. 9.2**).[15] The elephant is far stronger than the rider and is usually in control. Seldom does the rational mind direct the elephant where to go. More commonly, it is the elephant directing the rider to find rationales to justify visceral beliefs.

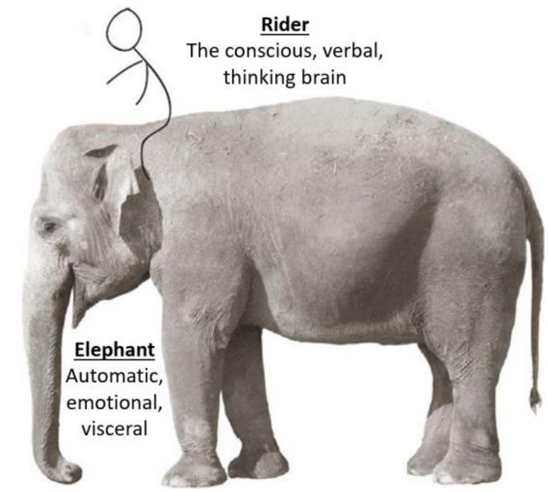


Figure 9.2: The elephant and the rider. Adapted from Haidt (2012).[15]

Don't think you can slay the elephant. You can't do it, and it would be disastrous if you did. You need the elephant for quick and powerful action. But the rider does have some defense. First is to avoid considering evidence when the elephant is most powerful. Let the hate and anger subside before taking up a question. Reason also has a second, more active defense.

I promised three axioms and three questions. Here is the second question:

Question 1: How do you know?
Question 2: How do I know?

Asking this question helps the rider recognize when zhe is being manipulated by the elephant, commonly to find arguments to prop up a chosen group identity.[16,17] It should be said that group identities can be nurturing. They can provide powerful emotional support. Groups can push for outcomes beyond the reach of individuals. All of this is true. However, it must also be said that separating one's group identity from the matter at hand is necessary to reduce bias in assessing evidence.[18] Asking "*How do I know?*" can begin that difficult process.

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[14] Shao W, Goidel K (2016). Seeing is believing? An examination of perceptions of local weather conditions and climate change among residents in the U.S. gulf coast. Risk Analysis 36:2137-2157.
[15] Haidt J (2012). *The Righteous Mind: Why Good People Are Divided by Politics and Religion*. Vintage Books.
[16] Van Bavel JJ, Pereira A (2018). The partisan brain: An identity-based model of political belief. Trends in Cognitive Science 22:213-224.
[17] Martins A C R (2016). Thou shalt not take sides: Cognition, logic and the need for changing how we believe. Frontiers in Physics 4:7.
[18] Cohen GL, Sherman DK, Bastardi A, Hsu L, McGoey M, Ross L (2007). Bridging the partisan divide: Self-affirmation reduces ideological closed-mindedness and inflexibility in negotiation. Journal of Personality and Social Psychology 93:415-430.

That question, *How do I know?*, begins many internal processes in the minds of those doing science. You may have noticed that people who do science for a living are often terrible public speakers. They hem and haw and dice up their assertions until it is a jumble of parentheses. Part of this is internal *How do I know* playing out in real time. ("*Here comes my big dramatic conclusion… Am I really sure? Well, it seems to be true under my laboratory conditions, but I suppose there's a chance that there's a subtle indirect effect I haven't… Uh oh, I need to say something fast!")*

We come to biases at an early age,[19] and we need to work hard to return, as best we can, to the child-like mind that is at the core of discovery

Practical strategies

Asking students to question deeply held views or identities can be perilous. One approach is to provide the safety of distance and let them get closer to their own internal minefields at their own pace. Discussing the 1986 ad, "The Whole Picture",[20] by the newspaper *The Guardian* may provide this distance. It is presented in three short segments. You might present each segment and ask for interpretations, suggesting after each that the respondent answer the question *How do I know?*

[19] Vasilyeva N, Gopnik A, Lombrozo T (2018). The development of structural thinking about social categories. Developmental Psychology 54:1735-1744.
[20] The Guardian (1986). *The Whole Picture.* An ad available on YouTube.

10. Everyone does science (…until they stop)

Our powers of observations are contaminated by labels. We label Vitamin D as a preventer of bone fractures and in so doing cover up the detailed circumstances essential to the actual observation. We label ourselves progressives or conservatives, thereby inviting in without resistance the host of assertions that commonly accompany those labels. We are all labelists. It's built into our brains.

But perhaps the most pernicious label is the one most people avoid: Scientist. Let's see this label in action (**Fig. 10.1**):

Just who ARE these people??? They seem to be able to do anything, pronounce definitive verdicts on all matters of any importance. Are they an alien race? A select few who have been bitten by a spider?

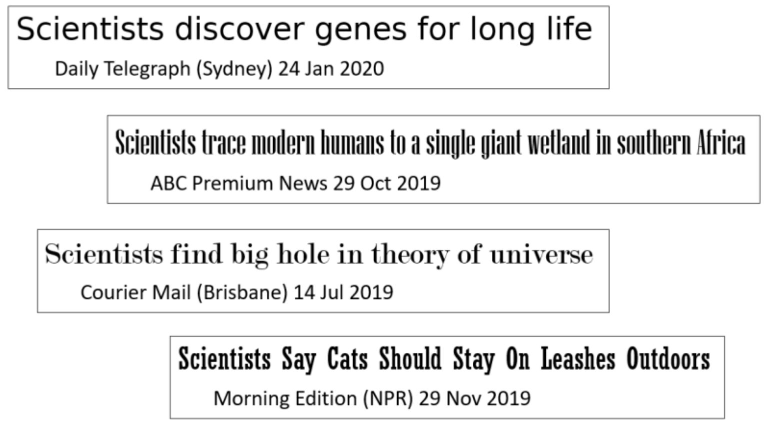


Figure 10.1: Headlines about scientists

Figure 10.2: A bike rider

Is this (**Fig. 10.2**) a scientist? No, that's just someone riding a bike. Science is not who you are but what you do. I suppose that someone who does science is a scientist, in the same trivial way that someone who eats is an eater.

In **Fig. 10.3**, you see a person doing science,[21] feeling a sense of wonder and acting on it. Each one of us has gone through a tremendously fertile period of doing science, figuring out how the world around us works.

Figure 10.3: A person doing science.

The problem is that many of us later absorb the false lesson that science is done by others, magical creatures who perform marvelous feats we read about in books. In fact, science is done by anyone who asks "How do you know?" and doesn't stop. Some people get paid to do this (some people also get paid to eat – restaurant critics). It's nice work, if you can get it. But anyone who becomes a child again can do science, whether the object of study is galactic centers or the best way to stack soup cans.

What's wrong with having heroes? If that's all it is, fine, but it is all too common to take the next step and believe that science is for scientists – people who are not me. That's a tragedy.

[21] Gopnik A (2012). Scientific thinking in young children: Theoretical advances, empirical research, and policy implications. Science 337:1623-1627.

11. Observations are taken to be true – Problem with bias (Part III)

Untold number of generations of middle school science students have learned that the way to do science is to make up your hypothesis, test it by experiment, and then… there are a few other steps I don't remember exactly what. Fortunately, by the time the few students that go into science careers reach graduate school, they've forgotten all of this and just do science, governed by the ethos of the discipline as modeled by their mentors.

I'm not saying that hypotheses are not important, just not in the way students believe they are. They say, "I must formulate my hypothesis. I shall find evidence to support my hypothesis. I shall prove my hypothesis. I shall defend my hypothesis to the death. I shall never surrender!" And that is as far as can be from one of the fundamental principle of science culture -- that there is no ownership of ideas. We are called on to be dispassionate about one explanation vs another and, with our colleagues, sift through the merits and demerits of each, never mind who thought of them.

The big problem with the common student view of hypotheses is that a person intent on proving a hypothesis tends to do it. They find what they're looking for, whether it's there or not. Latching onto one idea biases the mind away from alternatives, and calling it "mine" is even worse.[17]

Hypotheses are there not to be proven but **dis**proven, and not just one but as many as we can think of. Hearken back to the four cartoon panels about some runner (**Fig. 8.1**). We underestimate reality unless we're prepared to examine every possible order of the frames (each being a hypothesis). Someone who does science well will have multiple competing hypotheses in mind at the same time. I should add that disproving a hypothesis is just as impossible as proving it, but it is a more fruitful exercise, as it broadens our view of possibilities and deepens our view of probabilities.

One common manifestation of forming unhealthy attachments to hypotheses is the ritual of debates. When I say "common", I do not mean they are common amongst those who live in scientific inquiry. I've gone to many dozens of scientific meetings and not once have I seen a debate, let alone participated in one (**Fig. 11.1**). Discussions, yes. Vigorous arguments, certainly. But the goal of a debate is to win. The goal of a productive scientific argument is to arrive at a closer approximation to reality.

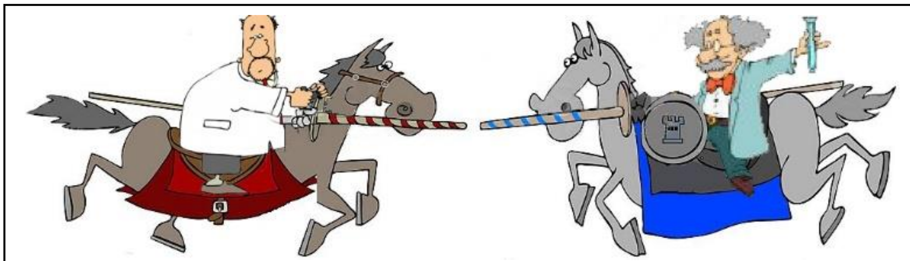


Figure 11.1: Two people who do science for a living debating (which they don't do in real life).

People who do science are human and are just as likely to be vain and self-serving as people who run for public office (maybe). So you will find within science those who attach themselves to ideas and market them for their own benefit. Nonetheless, the norm of science as a whole is that this should not be done, and to a surprising degree, it isn't.

12. Observations… Too much trouble. Why not Reliable Sources?

It takes some effort to distinguish observations from assertions, and they generally require much more care to understand them. So why bother? Why not let the experts worry about them? Why not seek out reliable sources who (because they're reliable) will have sifted through the observations for you and told you what is the truth?

It's not so easy. Who is reliable? Who is an expert? Who knows the truth? As it turns out, deciding who is an expert itself is a culturally biased decision.[22] And no one knows the truth.

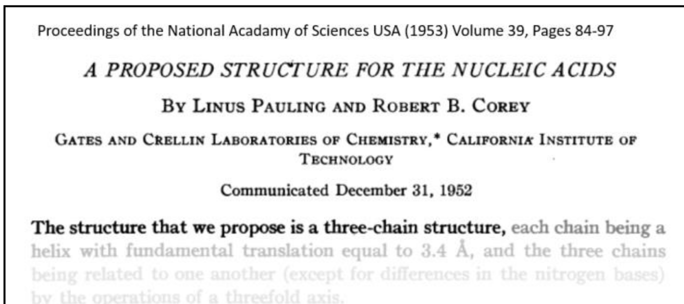
Science has adopted a different approach. According to the ethos of science, there is only one reliable source – Nature – and it isn't talking (**Fig. 12.1**). Each of us has access to the one reliable source through observation, and each of us struggles to put observations together to construct meaning.

Figure 12.1: The one reliable source

The first continuous scientific society, the Royal Society of London was born at a time (1660) when intellectual revolution was in the air, the burdensome authority of the church and that of the ancient sages were being thrown off, replaced by the motto of the society, "*Nullius en verba*" – take nobody's word for it, believe no one.

That's the way science works. This is the ***Norm of Universalism***: All are equal in scientific discussions. It doesn't matter how many degrees you have, where you went to school, who's your daddy. Gender, culture, country… it all makes no difference (at least in the ideal conception of science).

Despite this norm, we're often advised to trust reputable sources. Oh? "Reputable sources"? Try this one (**Fig. 12.2**):



Proceedings of the National Acadamy of Sciences USA (1953) Volume 39, Pages 84-97

A PROPOSED STRUCTURE FOR THE NUCLEIC ACIDS

BY LINUS PAULING AND ROBERT B. COREY

GATES AND CRELLIN LABORATORIES OF CHEMISTRY,* CALIFORNIA INSTITUTE OF TECHNOLOGY

Communicated December 31, 1952

The structure that we propose is a three-chain structure, each chain being a helix with fundamental translation equal to 3.4 Å, and the three chains being related to one another (except for differences in the nitrogen bases) by the operations of a threefold axis.

Figure 12.2. Misstep by a highly reputable source.

You've no doubt heard of the double helical structure of DNA (a two-chain structure) first proposed by Jim Watson and Francis Crick in 1953.[23] Less well known is that a few months before their publication, a three-chain structure was proposed by Linus Pauling and Robert Corey. Pauling and Corey were at Cal Tech, a reputable institution. Pauling was a member of the US National Academy

[22] Kahan DM, Jenkins-Smith H, Braman D (2011). Cultural cognition of scientific consensus. Journal of Risk Research 14:147-174.
[23] Watson JD, Crick FHC (1953). Molecular structure of nucleic acids. Nature 171:737-748.

of Science (a reputable body) and by 1953 had already won the first of two Nobel Prizes (a reputable prize). Corey was also no slouch. He was later elected to the National Academy. These two were reputable sources if ever there were any. The article was published in one of the most prestigious journals in science. You've never heard of a triple helix? Their conclusions were totally wrong.

The lesson from this is that reputable sources – even geniuses – can be wrong. The other side of the coin is that idiots can sometimes be right (and no, I won't give an example).

If you can't rely on credentials, what can you rely on? Peer review? Peer review is great. It's always a good idea to have fresh eyes evaluate work submitted for publication. However, passing peer review cannot possibly guarantee truth. I review many articles per year. I take great pains to make sure that the experiments are sufficiently described so that someone could replicate them. I look to see that the observations are set forth in a way that the reader can understand what they are. I also offer my usually vigorous opinion as to the conclusions the author draws from the observations. However, my view is that once the authors have conveyed their observations and experiments in a fair and complete fashion, they've bought the right to spout whatever nonsense that may make sense to them. I don't reject articles just because I think the conclusions are misguided. The fact that an article is peer reviewed absolutely does not mean the authors' conclusions are correct – far from it!

So not credentials, not peer review. That leaves the reader's own wit and ability to separate the observations from the assertions. But that takes work! Lots of work! If I come to the intersection described in Chapter 7, should I be expected to examine the wiring of the green traffic light before deciding whether or not to trust that it's safe to proceed? Imagine everyone getting out of their cars to do this at every intersection! Of course it isn't possible to critically examine every assertion. But it would be prudent as you provisionally trust the green traffic light to bear in mind that it might be wrong. Maybe the wiring got crossed and it's green in both directions.

So it is with scientific assertions. There's not enough time in our lives to examine every assertion. Those that are the most important to us, we examine. The others we throw into one container or another: (1) Probably true, (2) Maybe true, (3) True in some conceivable universe, (4) Uninteresting – ignore. The decision is based on all sorts of things. Have I read anything by this person before? Have I checked similar assertions? Does the assertion mesh with anything I've checked? That sounds a lot like trusting Reputable Sources, and it's true, we all take that short cut. But one must never forget that provisionally taking in an unexamined assertion is necessitated by the finite lengths of our lives. It is not a good way of finding truth.

13. *How can we find out?*

Discussion is an exchange of knowledge. Argument is an exchange of ignorance.
Robert Quillen

I've presented two axioms and two questions. I promised three of each. So I still owe you. I also owe you something bigger. I promised all of this had something to do with productive discussions and more effective societies. But consider for a moment… imagine two people coming in to discuss climate change. One's a believer in Science and the other says it's all a hoax. Do you think this is going to end well?

It can! Suppose that these two, before diverging to very different lives and outlooks, sat in the same 7th grade class where they absorbed the ethos of science and practiced it enough that they could play it out themselves. They also adopted (at least at the time) a framework for discussion that supplement the ethos of science:

1. **Science norms:** All participants share (at least for the purposes of this discussion) the axioms and norms of science and the guidelines listed below
2. **Discovery:** The purpose of the discussion is discovery, not victory. The unit of discovery is us, not me.
3. **Everybody plays:** Everyone has something to discover. Everyone has something to offer.
4. **Everybody's fallible:** Whatever ideas you bring in with you may be incomplete, misleading, even wrong
5. **All ideas worthy:** Every idea that is presented, even the most repulsive to you, is held by a fellow human and may contain some kernel of truth. Every point raised deserves a meaningful response before moving on to another point

Let's run the tape (hypothetical), a discussion between Cassandra (C)and Holden (H):

C: Look around you! Droughts! Record temperatures! Sea level rise… how can you doubt the reality of climate change?

H: The fearmongering media has done nothing but spread propaganda and fake science.

Let's pause for the moment, because Holden has already drifted away from #5, and Cassandra may have crossed the line set by #2.

H: Uh, OK. Record temperatures? How do you know?

C: Have you ever even heard of the Intergovernmental Panel on Climate Change? …I mean, maybe we should consider what the IPCC has to say.

C: And to respond to your point, how do you know the science is fake?

H: I found a report that says the Earth hasn't warmed since 1997.

An article and a report draw opposite conclusions, but (**Axiom 1**) *We live in one universe*, so there must be some way of accommodating them.

C: I guess we need to look at the reports. Here's mine.[24]

H: Here's mine.[25]

C: ... Wait a second! Published by the Heartland Institute? The group that took money from Big Tobacco and spread lies about smoking? Why should we pay any attention to this?

H: I don't know how they're funded, but I'll bet all those editors on the IPCC report get big bucks in research money. It would be a shame if the climate change hoax were exposed and they lost it all.

Maybe they're all spawn of Satan. Doesn't matter. **Axiom 2** says "*Observations are taken to be true*". When there's possible conflict of interest, you might weaken the axiom a bit: observations are taken to be true but not necessarily representative. Cherry picking data may come to the front of your mind in such situations, but really, you should be wary of it even if there is no obvious conflict of interest. So,… observations?

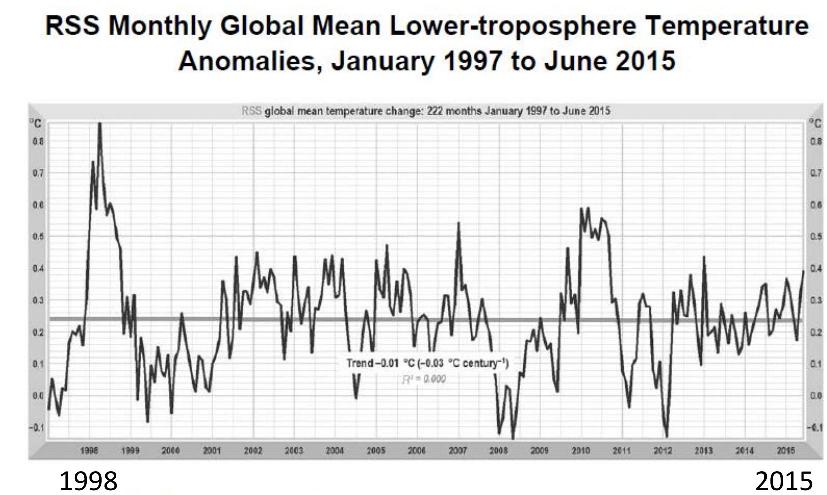
C: There's over 500 pages of observations in this report! What am I supposed to do with all of that?

H: Mine has only about 100 pages, but even so… OK, I found something about how there's been no warming the past 20+ years. Maybe we can focus on that. Do you have anything?

C: Maybe... probably... I'm not sure. I'll look.

The next time Cassandra and Holden meet, they come armed.

H: OK. Look at this (**Fig. 13.1**). From 1997 to 2015 temperature was flat. No global warming here. Flat.



Source: Monckton *et al.*, 2015.

Figure 13.1. From Fig. 6, Reference 22.

C: That doesn't look anything at all like the graph I found from the IPCC (**Fig. 13.2**). Are we looking at the same thing? Your graph doesn't have a label on the Y-axis. Where did this come from?

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[24] Masson-Delmotte V and 18 others, editors (2018). Intergovernmental Panel on Climate Change, 2018 Global Warming of 1.5°C.

[25] Idso CD, Carter RM, Singer SF (2016). Why Scientists Disagree About Global Warming: The NIPCC Report on Scientific Consensus. Heartland Institute.

H: I thought you'd ask that, so I looked it up. The graph says it came from "Monckton et al (2015). I went to the article they cited in the references, by Christopher Monckton of Brenchley…

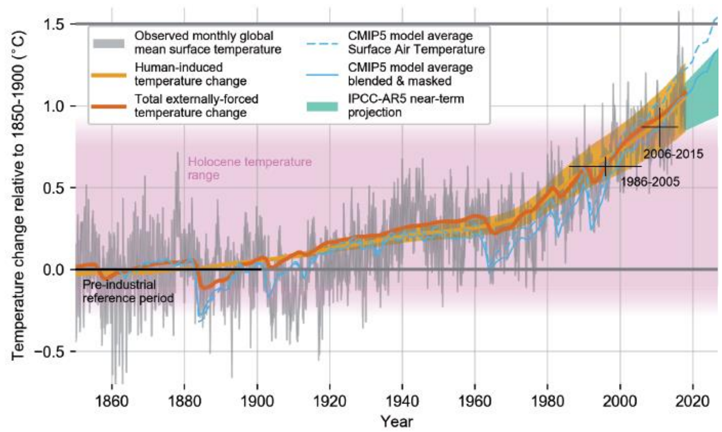

Figure 13.2. Monthly mean global mean surface temperatures (gray line -- the other lines are predictions and can be ignored. From Figure 1.2, Reference 21.

C: Monckton of Brenchley…??? Is this Game of Thrones? [Hmm… I really want to believe that this Monckton person is a fraud and his graph nonsense. How do I know that?]

H: It doesn't matter who he is.
The article says the data came from Morice et al (2012).[26] So I went there and found a graph based on the HadCRUT4 data set (**Fig. 13.3**). It said it was the annual global average temperature anomalies, which was how Monckton of Brenchley described his graph.

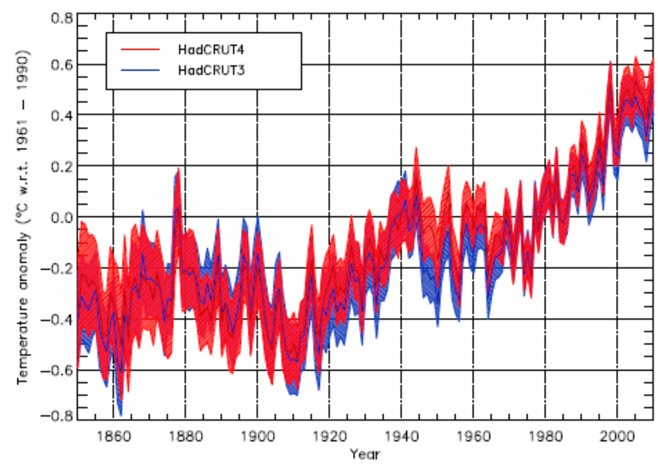

Figure 13.3. Comparison of annual, global average temperature anomalies 1850–2010. 95% confidence interval shaded. Red=HadCRUT4 (blue = HadCRUT3). From Figure 7, Reference 23.

C: My graph also came from HadCRUT4… but I didn't know what that is.

H: I googled it. It stands for **Had**ley Centre, which contributed sea surface temperatures and **C**limatic **R**esearch **U**nit, which contributed land surface temperature. **T** stands for temperature.

C: I don't care so much about that. How do they know the temperatures of the entire world?

H: They talked a lot about that. I didn't really understand.

C: Maybe we don't need to! If both graphs used the same data source, then that's not the reason they're different. Wait, how do I know they're different… <u>are</u> they different? Look at this (**Fig. 13.4**). If you consider just the years in common, 1997 to 2010, the three graphs

[26] Morice CP, Kennedy JJ, Rayner NA, Jones PD (2012). Quantifying uncertainties in global and regional temperature change using an ensemble of observational estimates: The HadCRUT4 data set. Journal of Geophysical Resesearch 117:D08101.

are pretty much the same. The IPCC graph and the Morice graph have four peaks spaced about every four years. Everyone has the troughs in about the same positions.

H: The Monckton graph really doesn't have a second peak around 2002. He didn't say how he used the HadCRUT4 data.

C: Maybe we have to go to some website and look at the HadCRUT4 raw data ourselves?

H: Why worry about the details? The three graphs basically agree. It's flat.

C: If Monckton's first peak weren't so big, in contrast to what's in the other graphs, then... OK, it's still flat. But there's a lot of noise. Maybe you can always pick out some short period in history that happens to be relatively flat. Maybe if we had some statistics.

H: I don't know statistics.

C: If this is really important someone must have talked about it. How can we find out?

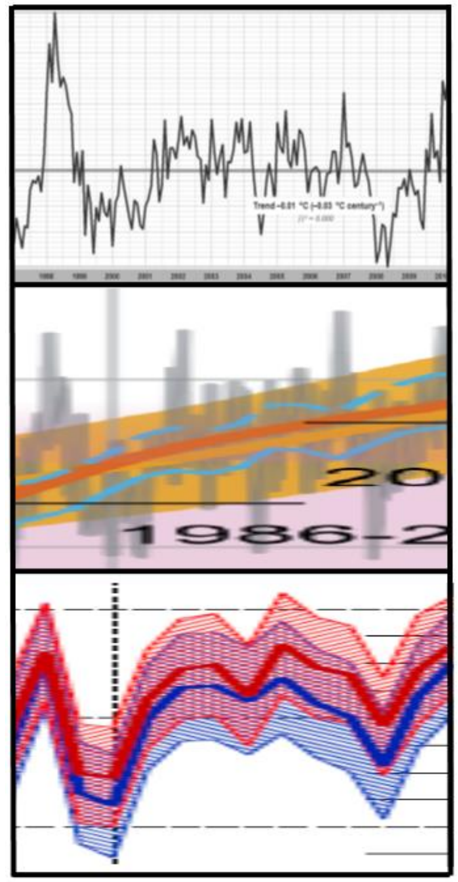

Figure 13.4. Mean surface temperature, 1997 to 2010. Top: From NIPCC graph (**Fig. 13.1**). Middle: From IPCC graph (**Fig. 13.2**). Bottom: From Morice et al, 2012 (**Fig. 13.3**).

They each go into their own computers for a while.

C: My IPCC article talks about a period in the 2000's – they call it a 'hiatus'. ?

H: A hiatus in global warming? Let me look… Google says there's a lot on this.

C: I found a lot on PubMed too. We need to think about this.

Cassandra and Holden have made considerable progress, carving out a focused question from what started out as vague positions governed more by their personal biases than any substance. They haven't come up with an answer, but now they have defined a path that should lead them to insight. I think the questions and axioms that make up the ethos of science played a part here. They made progress by putting aside thoughts of vanquishing the misguided opponent and instead entering the discussion with the humble admission, "I don't know" (at least they got there eventually). With that, anything is possible, including learning from each other.

One guiding question – the third – emerged through their discussion. It is this: "*I don't know, you don't know… How can we find out?*" For this question to make sense, it must be undergirded by an assumption, the third axiom, that finding out is possible, that **the universe is knowable** in an important way.

This may be a good time to put in one place all the questions and axioms I've introduced (**Table 13.1** and illustrated in **Fig. 13.5**).

Table 13.1: The three questions and axioms

Focus	Questions	Axioms	Fleshed out
You	1. How do you know?	1. We live in the same universe	Assertions may contradict each other. Observations, properly constrained, cannot.
Me	2. How do I know?	2. Observations are taken to be true	We are all beset with biases. Seeking out our own may help us cut through a compromised assertion to the observation within it.
Us	3. I don't know, you don't know… how can we find out?	3. The universe is knowable	The proper goal of a discussion is not to convince but to discover.

Fig. 13.5. The Three Questions. Graphic courtesy of Leaf Elhai.

14. Where can you find observations? (Part II)

Throughout the previous chapters I've mentioned instances where it would be useful to find pertinent research articles. In the last chapter, Cassandra says she looked for articles on PubMed. What's that? It is a freely available, online collection of links to the scientific literature, millions of articles. Let me immediately spare you two misconceptions that might occur to you. First, despite its name, PubMed is not confined to the medical literature. Its database includes articles concerning biological research without medical implications, e.g. in the areas of ecology or botany, as well as many articles related to pure chemistry or physics.

The second misconception may be a harder sell. You may believe that real research articles are beyond the reach of middle schoolers. Of course your typical student will not fully understand a random article describing the discovery of cagelike sesquiterpenoids from *Artemisia atrovirens*. Neither will I. That's not the point. The point is that all of us can feel our way through darkness until we find a ray of light that illuminates a small but interesting part of our world – ***a part we choose to examine*** (and trash the rest). The lot of those who do science is to filter reality in just this way. The odds of success are made much higher by the use of tools that sift through articles and pass on to us only those likely to have the part of the world we seek. That's what PubMed tries to do.

Let me show you the directed use of research articles, PubMed in action, by reimagining the encounter between Cassandra and Holden. Dialing back…

C: Look around you! Droughts! Record temperatures! Sea level rise... how can you doubt the reality of climate change?

H: **The fearmongering media has done nothing but spread propaganda and fake science.**

C: To respond to your point, how do you know that the fearmongering media has done... Wait... what am I saying? Are they fearmongering if they're telling the truth? Never mind what the media is saying, 97% of scientists say the same thing: Climate change is real!

H: **How do you know that?**

C: Not from the media. Here's a scientific study -- Cook et al (2013)[27] -- that showed the 97% figure, by looking at thousands of articles.

H: **I know that number! The paper I'm reading by the Nongovernmental International Panel on Climate Change[25] has an entire section on it. They say the number isn't 97% but 0.03%.**

C: That's ridiculous!

H: **Yeah, obviously someone is cooking the books, heh heh.**

C: Or maybe they were just observing different things, different parts of the whole? How can we find out? Where did 97% and 0.03% come from?

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[27] Cook J and 8 others (2013). Quantifying the consensus on anthropogenic global warming in the scientific literature. Environmental Research Letters 8:024024.

H: I guess that would mean actually reading the articles.

C: (I don't know how we're supposed to do that)

They come back, articles in hand.

C: That was a lot easier than I thought! The last line of their Results section said very clearly, "Over the period of January 2004 to February 2007, among 'global climate change' papers that state a position on AGW [anthropogenic global warming], we found 97% endorsements.", and...

H: What do you mean "endorsements"?

C: ...and they clearly define "endorsement" to mean one of three things: (1) it says humans are the main cause of global warming, or (2) it says humans are a cause of global warming (not necessarily the main cause), or (3) it implies that humans are causing it. They made these three categories, but in the end, they lumped the numbers together and called it endorsement.

H: Well, that explains a lot. I had to go back to my original article.[28] They counted only what you called Category 1. They called it the Standard Definition, not sure why.

C: Does that really explain it? 97% vs 0.03%? I can look it up, because Cook provided an Excel file with all of the papers they looked at and the categories. So, if I go there... Hmmm. Category 1 is 1.6%, so not a lot but still far away from 0.03%.

H: Two things about that. The NIPCC paper talks about 0.03% but the article they got it from says 0.3%. I'm guessing it's a typo. But another thing, the article makes a big deal how unfair it is that Cook threw out articles that they said have no opinion, so they divided by the total number of articles, not just those that state a position on AGW.

C: That might do it.

H: But also, they say that Cook et al were biased and counted too many articles as favoring AGW.

C: So who's right? Are we supposed to find another article? Best two out of three?

Excuse me? I wonder if I could break in here. The question you're asking is how much consensus there is, and consensus is not really a solid thing you can measure. It's not like the density of iron. But that's OK. You could go outside and say, "This is really a sunny day", but if you try to measure it, you get into questions like what you should measure. The amount of shade? Light intensity at some wavelength? You could argue forever, but the fact is, everyone outside agrees it is unquestionably a sunny day.

H: So you're saying we should forget the whole thing?

Not at all! I'm suggesting that you go outside and look. Do what Cook et al did. Find articles related to global climate change and decide for yourself if the authors believe it exists and if humans have

[28] Legates DR, Soon W, Briggs WM, Monckton of Brenchley C (2015). Science and Education 24:199-318.

anything to do with it. You won't be able to go through 10,000 articles like they did, but you'll get a good feel for what the answer is.

C: How do we do that?

How did Cook's group do it? Do pretty much what they did. You can get articles for free by going to PubMed.[29]

So I take them there, and they see something like **Fig. 14.1**. There are more complicated ways of doing this, but I suggest just typing into the search box whatever search terms Cook et al used. What were they?

Figure 14.1. Frontpage of PubMed. Basic search facility. More options are available by clicking **Advanced**.

C: That would be 'global climate change'.

OK. Type those three words (no quotes) into the **Search PubMed** search box, and then press **Enter** or click the magnifying glass icon. That will get you to something like **Fig. 14.2**.

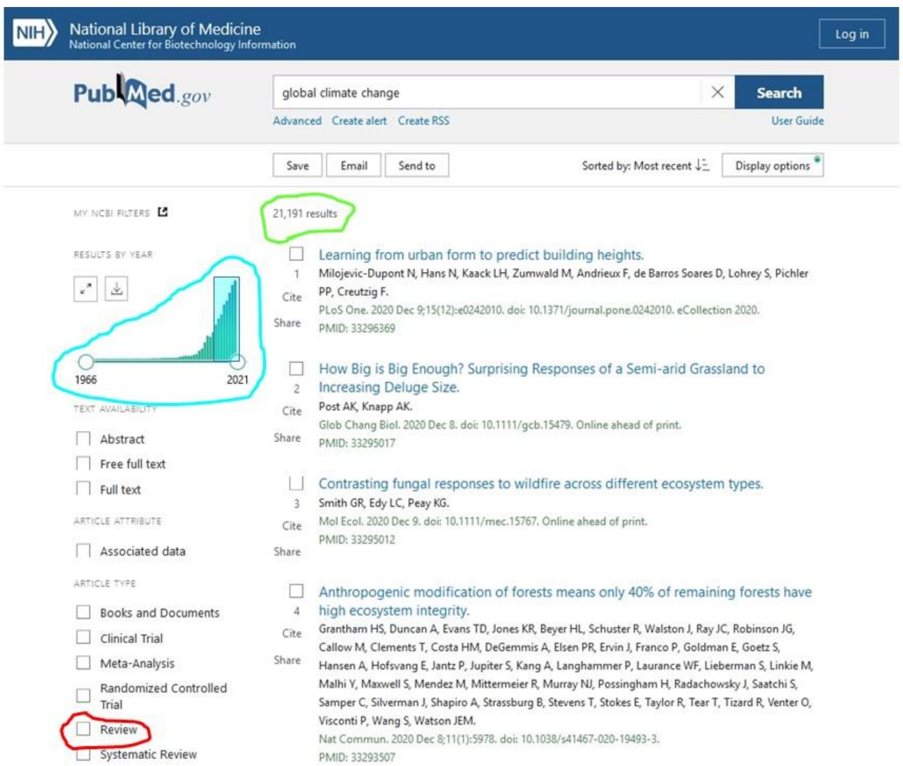

Figure 14.2. Results of PubMed search for 'global climate change'. First few of displayed links to articles found by the search. The total number of articles is shown above the results (circled in green). The number of found articles by year is shown in a graph (circled in cyan), with those articles published after the work of Cook et al (2013)[27] highlighted in cyan. An option to confine the articles to review articles, one of many ways to filter the results is shown (circled in red).

[29] PubMed. National Center for Biotechnology Information, National Library of Medicine, National Institutes of Health. Screen shots were taken 9 December 2020.

H: That's not too many articles.

Well, you're at the top of a very very long list. Note that it tells you there's a total of over 21,000!

C: That many? Cook et al found only about 12,000.

Look at the graph at the left of **Fig. 14.2**. Climate change has been a pretty hot topic in the several years since Cook et al was published. But it doesn't matter, you probably don't have time to look at even a small fraction of them. How about the first? Just click on the title (getting **Fig. 14.3**).

> PLoS One. 2020 Dec 9;15(12):e0242010. doi: 10.1371/journal.pone.0242010. eCollection 2020.

Learning from urban form to predict building heights

Nikola Milojevic-Dupont [1, 2], Nicolai Hans [3], Lynn H Kaack [4], Marius Zumwald [5, 6], François Andrieux [7], Daniel de Barros Soares [7], Steffen Lohrey [2], Peter-Paul Pichler [8], Felix Creutzig [1, 2]

Affiliations + expand

PMID: 33296369 DOI: 10.1371/journal.pone.0242010

Abstract

Understanding cities as complex systems, sustainable urban planning depends on reliable high-resolution data, for example of the building stock to upscale region-wide retrofit policies. For some cities and regions, these data exist in detailed 3D models based on real-world measurements. However, they are still expensive to build and maintain, a significant challenge, especially for small and medium-sized cities that are home to the majority of the European population. New methods are needed to estimate relevant building stock characteristics reliably and cost-effectively. Here, we present a machine learning based method for predicting building heights, which is based only on open-access geospatial data on urban form, such as building footprints and street networks. The method allows to predict building heights for regions where no dedicated 3D models exist currently. We train our model using building data from four European countries (France, Italy, the Netherlands, and Germany) and find that the morphology of the urban fabric surrounding a given building is highly predictive of the height of the building. A test on the German state of Brandenburg shows that our model predicts building heights with an average error well below the typical floor height (about 2.5 m), without having access to training data from Germany. Furthermore, we show that even a small amount of local height data obtained by citizens substantially improves the prediction accuracy. Our results illustrate the possibility of predicting missing data on urban infrastructure; they also underline the value of open government data and volunteered geographic information for scientific applications, such as contextual but scalable strategies to mitigate climate change.

Figure 14.3. First article in list of those found in search for 'global climate change'.

H: An article on architecture?

C: I wasn't expecting that!

It must mention the words 'global', 'climate', and 'change' somewhere, or else your search wouldn't have found it. Look at the end of the abstract.

H: That's pretty weak. They're just saying that their results could ***apply*** to the effects of climate change.

C: Maybe so, but they wouldn't make that claim if they didn't think climate change was real.

H: OK, but that's just climate change. Everyone already knows the climate is changing...

C: (You didn't seem to know this a few days ago.)

H: What I mean is that Cook et al were claiming that the scientific consensus is 97% favoring ***man-made*** climate change.

C: Maybe we could have two categories: favoring climate change and favoring man-made climate change. Look at the fourth article (**Fig. 14.4**). That one is about anthropogenic – man-made – modification. The abstract says that limiting climate change has to do with retaining forests, and retaining forests is affected by human actions.

H: These people believe that humans are responsible for some degree of climate change, I'll agree with that. I suppose you can put this article in that category. But it doesn't make the connection between forests and climate change. They just make the assertion. And it looks like all the rest are talking about the ***effects*** of climate change. Maybe they're just parroting a popular belief about climate change.

C: But that's all Cook et al were saying – the overwhelming majority of the scientific community believes it's real.

H: But WHAT scientific community? Architects? Fungal biologists? Maybe they really don't know any more than we do!

C: Could we look at just the articles by people who study the connection between humans and climate change?

H: How could we do that?

> Nat Commun. 2020 Dec 8;11(1):5978. doi: 10.1038/s41467-020-19493-3.

Anthropogenic modification of forests means only 40% of remaining forests have high ecosystem integrity

H S Grantham [1], A Duncan [2], T D Evans [2], K R Jones [2], H L Beyer [3], R Schuster [4], J Walston [2], J C Ray [5], J G Robinson [2], M Callow [2], T Clements [2], H M Costa [2], A DeGemmis [2], P R Elsen [2], J Ervin [6], P Franco [2], E Goldman [7], S Goetz [8], A Hansen [9], E Hofsvang [10], P Jantz [8], S Jupiter [2], A Kang [2], P Langhammer [11, 12], W F Laurance [13], S Lieberman [2], M Linkie [2], Y Malhi [14], S Maxwell [3], M Mendez [2], R Mittermeier [11], N J Murray [13, 15], H Possingham [16, 17], J Radachowsky [2], S Saatchi [18], C Samper [2], J Silverman [2], A Shapiro [19], B Strassburg [20], T Stevens [2], E Stokes [2], R Taylor [7], T Tear [2], R Tizard [2], O Venter [21], P Visconti [22], S Wang [2], J E M Watson [2, 3]

Affiliations + expand

PMID: 33293507 DOI: 10.1038/s41467-020-19493-3

Abstract

Many global environmental agendas, including halting biodiversity loss, reversing land degradation, and limiting climate change, depend upon retaining forests with high ecological integrity, yet the scale and degree of forest modification remain poorly quantified and mapped. By integrating data on observed and inferred human pressures and an index of lost connectivity, we generate a globally consistent, continuous index of forest condition as determined by the degree of anthropogenic modification. Globally, only 17.4 million km^2 of forest (40.5%) has high landscape-level integrity (mostly found in Canada, Russia, the Amazon, Central Africa, and New Guinea) and only 27% of this area is found in nationally designated protected areas. Of the forest inside protected areas, only 56% has high landscape-level integrity. Ambitious policies that prioritize the retention of forest integrity, especially in the most intact areas, are now urgently needed alongside current efforts aimed at halting deforestation and restoring the integrity of forests globally.

Figure 14.4. Fourth article in list of those found in search for 'global climate change'.

The discussion has now gone beyond Cook et al (2013). H & C are now looking for ways to scratch their own itch, which, of course, is very good! I will show them how to use PubMed's advanced interface to filter articles by different criteria. There's no filter for 'articles-by-people-who-know-what-they're-talking-about', but it's possible to use what filters there are in creative ways. For example, they could take only those articles that has an author from a department whose name includes 'meteorology' or 'meteorological'. That will throw away a lot of useful articles, but those that remain should be enriched for what they're looking for.

Practical strategies

Literature searches of the type illustrated in this chapter are wonderful tools to promote self-efficacy. With no need for much prior knowledge, students sift through findings at the edge of what is known. One effective way of doing this is to invite students to choose a topic –their favorite disease, for example – and find every article that has ever been written on the subject. They'll find, in most cases, that this is impossible. There are too many articles for most topics we think up. But if they progressively confine the search, then they'll approach a usable number.

For example, suppose someone chooses 'sickle cell anemia' and uses the terms to search PubMed:

Search terms	Articles found
sickle cell anemia	25,148 articles
sickle cell anemia teenage	6,836 articles
sickle cell anemia teenage sports injury	8 articles

Now it's possible to get the general gist of the 8 articles found through a search that very few, if any, have ever performed, even those who study sickle cell anemia. The student won't understand most of the articles, but zhe will be able to say that this is everything that can be pulled from Pubmed on this subject. For this (admittedly tiny) slice of knowledge, the student is the world's foremost authority on what is known. That can be a pretty heady feeling.

Presenting a short summary of what is known to peers, with context to make the area comprehensible, can reinforce gains in self-efficacy.

15. The ethos of science

Suppose you are in a foreign country, in the back seat of a taxi. You're stuck in traffic, but worse – much worse – so is an ambulance two cars in back of you. Its lights are flashing, its sirens blaring, but no one will move out of the way! You ask the taxi driver, how can we make room for the ambulance? He responds, forget about it. Ambulance drivers make extra cash driving rich passengers places with their sirens on to beat traffic. "Are you kidding me?" you say. "Yeah, that's what I heard." In this dystopia, it doesn't matter whether ambulance drivers actually do side gigs. It matters what people believe and what they do not believe.[30]

A functioning military relies on a set of core values, for example loyalty, courage, integrity. It goes without saying that there are soldiers that fail to live up to a value on one or more occasions. That hurts, but it is not lethal to the organization. What holds it together is the common belief that these core values exist, even if the believer sometimes falls short. If that fabric breaks, you get the cynicism that leads to the military equivalent of paralyzed ambulances.

A functioning society also rests on core values. I'll call this the ethos of society. Those who do science for a living are, of course, part of society, and many outsiders tacitly presume that they are special people, imbued with powers to do science, but still operating within the usual ethos. Actually it's just the opposite. Those who do science have no special powers, but they absorb an ethos that differs in significant ways from that of society at large.

You often hear in the media how a research team at Ivy University made some great discovery. This formulation conjures up a team of players true to their school, intent on getting to the goal line before Northern State, and heroically doing whatever is necessary to prove their key hypothesis. There is unquestionably competition in scientific research, but loyalty to a team, much less a school, and still less a hypothesis, is antithetical to the ethos of science. While those in science sometimes sell out their values -- as do humans in other areas -- nonetheless the ethos persists and governs how those in science view their work and how scientific discussions proceed. Otherwise, the fabric would break.

I've hinted at this ethos throughout the book. Now I'll set forth what I think it is, drawing on the highly influential formulation of Robert Merton,[2] recast more succinctly by John Ziman.[3] The Three Questions and Three Axioms lie squarely within this ethos. If you liked the Three and the Three, you'll love these, the Five Norms:

- **Communalism** – The fruits of scientific discovery belong to all
- **Universalism** – What counts is the idea, not the person who voices it
- **Disinterestedness** – What matters is not what you want but what Nature says
- **Originality** – Contributions must go beyond what is already established
- **Skepticism** – Don't believe it until you have no choice

[30] Idov M (2017). Russia: Life after trust. New York Magazine (23 Jan 2017).

I must stress that these concepts are related to the pure pursuit of knowledge -- basic science -- not necessarily to the exploitation of knowledge, such as what takes place in medicine and industry. Let's go through each norm.

Communalism

Every observation implies an observer, but once the observation is published, the observer recedes into the distance. True, we refer to Cook et al (2013) as the source of an observation, but that's just a bookkeeping device so we know where to find details. According to the Norm of Communalism, the observation no longer belongs to the observer. It's everybody's. We all live in the same universe (Axiom #1), and it's ours, equally.

The public must have its heroes, so it invents Newtons, Einsteins, and Pasteurs, but the ethos of science regards their victories as personal and ephemeral. What they discovered was already there before they were born and continues to exist long after they pass. They were discoveries, not inventions, once hidden, then glimpsed by one, now seen by all. And if still unseen … A communal question: How can we find out? (Question #3)

Universalism

Over the years, I've had collaborators in China, the Soviet Union (in the day), and Russia (now). The country didn't matter, except to add spice to side conversations. According to the Norm of Universalism, status doesn't matter either. When Watson and Crick went head to head with Linus Pauling to determine the structure of DNA, it didn't matter that Pauling was probably the most respected chemist on Earth, with an armload of publications, while Watson had just gotten his PhD degree, with one obscure publication, and Crick was still a graduate student.

We can't appeal to human authorities as arbiters of truth, so then to what? The answer is that all go to Nature to decide whether an idea has merit. We take observations of Nature to be as close to the truth as we can get (Axiom #2). Who are the scientists? Whoever attempts to access Nature. Who is reliable? Whoever provides observations, along with a description of how they were obtained. Anyone can play. Everybody's fallible.

Disinterestedness

A politician might find success in pressing the attack, never backing down, exploiting every advantage to reach ultimate success. However, for those who act within the Norm of Disinterestedness, backing down is common. Maybe my idea is closer to reality, maybe yours, maybe it doesn't matter.

We all live in the same universe, but we also live in the same species, and humans aren't built for disinterestedness. Whose idea it is ***does*** matter. The Elephant in our lives runs roughshod over a pure pursuit of knowledge. To conform to the ethos of science, the Rider must adopt strategies that constrain the Elephant, asking 'How do I know?' (Question #2) and examining as many hypotheses as possible, not just the Elephant's favorite.

Originality

There's a lot to be gained by focusing on our tiny slice of the world, to spend much of our lives counting the wrinkles on the part of the elephant leg we see or measuring with increasing accuracy the density of its tusk. But to visualize the invisible elephant, it is necessary to jump out of the here and now and imagine an experiment that can reveal the shape of what can't be seen. The ethos of science values both activities, but according to the Norm of Originality, the latter is given special recognition. This requires faith that even when unseen, the universe is knowable (Axiom #3)

Skepticism

This may be the norm most closely associated with scientific thought. Of ***course*** people who do science are skeptical! It follows that the common "I believe science", taken at face value, is not an assertion that fits very well with the ethos of science. But neither does the other extreme, "Nothing can be proven, so I reject everything!". The Norm of Skepticism is more practical, like a person climbing the face of a cliff. There you are reaching for a rock that theory says is supposed to be OK. You're not so sure, so you test the rock gingerly. It seems to be solid, and you make your move, but you're still not completely convinced. Maybe if the temperature were much higher, that rock wouldn't hold.

So it is with science. Observations are the stepping stones to build a path. The rock's good? How do you know? (Question #1). "I tested it myself" says your co-climber. The path seems to work, so you go forward. It's quite a bit different to be skeptical than to reject everything and make no progress at all.

You have probably already surmised that these norms are by no means independent of each other. We ask 'How do you know?' (Skepticism) because there is no refuge in authority (Universalism). We care to ask, because the pursuit of truth is a group activity (Communalism). Since I place myself in this community I must protect others against my biases and therefore ask 'How do I know?' (Disinterestedness). All would be to no avail without the faith that there is something new to see and that I can see it (Originality). Above all, scientific activities presume a shared commitment to common norms, without which we could not have productive discussion but only single-minded assaults, evoking equal zealotry in response.

But according to the norms of the society in which we live, zealotry is exalted. There is applause when a self-righteous voice shouts down an idea, not for its lack of merit but because it is perceived to attack the group identity of the audience. This practice is not compatible with finding solutions to complex societal problems. Taken to an extreme, it isn't compatible with democracy.

Throughout American history, education has been touted as the bulwark of democracy. Franklin Roosevelt wrote "*The real safeguard of democracy… is education*".[31] John Dewey wrote "*Democracy has to be born anew every generation, and education is its midwife*".[32] It is difficult to see how education can have the desired effect on democracy by cramming into student heads the names of the moons of Jupiter. Rather it confers power by promoting not facts but abilities:

[31] Roosevelt FD (1938). Message for American Education Week, September 27, 1938. The American Presidency Project.
[32] Dewey J (1916). *The Need of an Industrial Education in an Industrial Democracy.* Found in Wikiquote, John Dewey.

- The ability to understand the written words of others and make use of their experiences
- The ability to use words to clarify one's own thoughts and to express them to others
- The ability to inhabit abstract worlds and connect them meaningfully to our own

That takes care of reading, writing, and arithmetic. In this volume, I have proposed another ability that should be in the mental toolbox of every student living in a democracy:

- The ability to achieve understanding of complex phenomena by separating what is observed from what is merely asserted and engaging in productive discussion with peers

…in other words, absorbing a shared ethos of science. There are certainly other valid ways of establishing the basis of belief and action, and the results of many are on daily display. But in the divisive world in which we find ourselves, with siren calls to the young to tie their souls to one identity group or another and to join the glorious battle against evil, an ethos that provides a framework for combining seemingly contradictory views might serve as an antidote to the poisonous rhetoric that courses through the veins of society. It's worth a try.