What exactly is the scientific method and why do so many people get it wrong?

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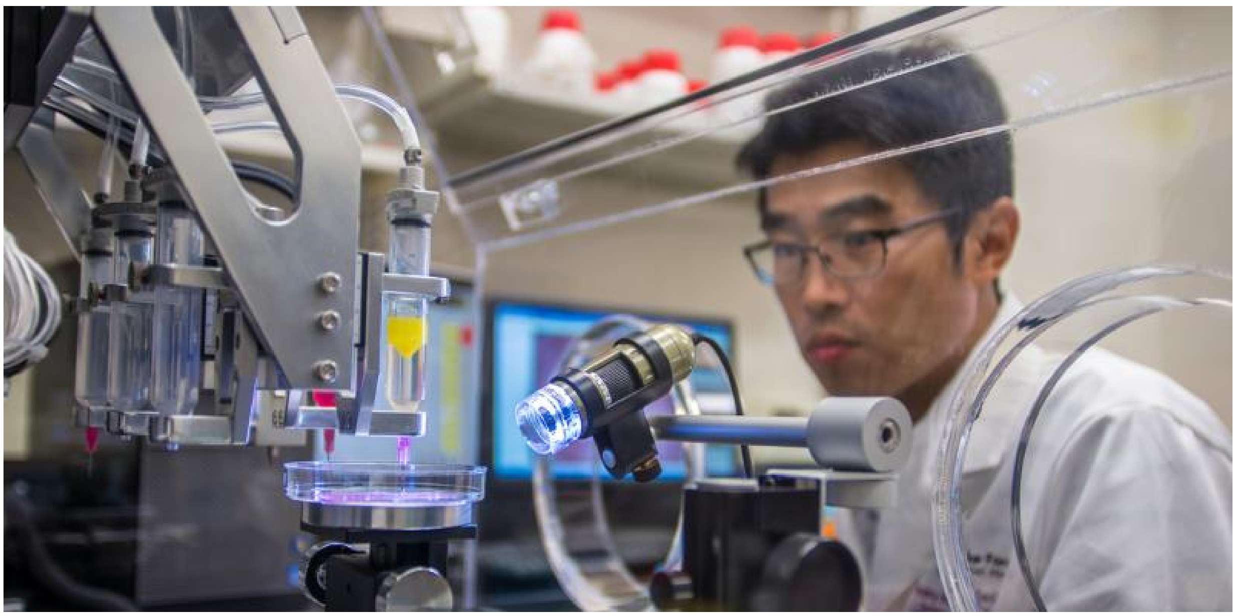

Science works in ways that reflect our rationality. Credit: armymaterielcommand/flickr, CC BY

Claims that the "the science isn't settled" with regard to climate change are symptomatic of a large body of ignorance about how science works.

So what is the scientific method, and why do so many people, sometimes including those trained in science, get it so wrong?

The first thing to understand is that there is no one method in science, no one way of doing things. This is intimately connected with how we reason in general.

Science and reasoning

Humans have two primary modes of reasoning: deduction and induction. When we reason deductively, we tease out the implications of information already available to us.

For example, if I tell you that Will is between the ages of Cate and Abby, and that Abby is older than Cate, you can deduce that Will must be older than Cate.

That answer was embedded in the problem, you just had to untangle it from what you already knew. This is how Sudoku puzzles work. Deduction is also the reasoning we use in mathematics.

Inductive reasoning goes beyond the information contained in what we already know and can extend our knowledge into new areas. We induce using generalisations and analogies.

Generalisations include observing regularities in nature and imagining they are everywhere uniform – this is, in part, how we create the so-called laws of nature.

Generalisations also create classes of things, such as "mammals" or "electrons". We also generalise to define aspects of human behaviour, including psychological tendencies and economic trends.

Analogies make claims of similarities between two things, and extend this to make new knowledge.

For example, if I find a fossilised skull of an extinct animal that has sharp teeth, I might wonder what it ate. I look for animals alive today that have sharp teeth and notice they are carnivores.

Reasoning by analogy, I conclude that the animal was also a carnivore.

Using induction and inferring to the best possible explanation consistent with the evidence, science teaches us more about the world than we could simply deduce.

Science and uncertainty

Most of our theories or models are inductive analogies with the world, or parts of it.

If inputs to my particular theory produce outputs that match those of the real world, I consider it a good analogy, and therefore a good theory. If it doesn't match, then I must reject it, or refine or redesign the theory to make it more analogous.

If I get many results of the same kind over time and space, I might generalise to a conclusion. But no amount of success can prove me right. Each confirming instance only increases my confidence in my idea. As Albert Einstein famously said:

No amount of experimentation can ever prove me right; a single experiment can prove me wrong.

Einstein's general and special theories of relativity (which are models and therefore analogies of how he thought the universe works) have been supported by experimental evidence many times under many conditions.

We have great confidence in the theories as good descriptions of reality.

But they cannot be proved correct, because proof is a creature that belongs to deduction.

The hypothetico-deductive method

Science also works deductively through the hypothetico-deductive method.

It goes like this. I have a hypothesis or model that predicts that X will occur under certain experimental conditions. Experimentally, X does not occur under those conditions. I can deduce, therefore, that the theory is flawed (assuming, of course, we trust the experimental conditions that produced not-X).

Under these conditions, I have proved that my hypothesis or model is incorrect (or at least incomplete). I reasoned deductively to do so.

But if X does occur, that does not mean I am correct, it just means that the experiment did not show my idea to be false. I now have increased confidence that I am correct, but I can't be sure.

If one day experimental evidence that was beyond doubt was to go against Einstein's predictions, we could deductively prove, through the hypothetico-deductive method, that his theories are incorrect or incomplete. But no number of confirming instances can prove he is right.

That an idea can be tested by experiment, that there can be experimental outcomes (in principle) that show the idea is incorrect, is what makes it a scientific one, at least according to the philosopher of science Karl Popper.

As an example of an untestable, and hence unscientific position, take that held by Australian climate denialist and One Nation Senator Malcolm Roberts. Roberts maintains there is no empirical evidence of human-induced climate change.

When presented with authoritative evidence during an episode of the ABC'S Q&A television debating show recently, he claimed that the evidence was corrupted.

Yet his claim that human-induced climate change is not occurring cannot be put to the test as he would not accept any data showing him wrong. He is therefore not acting scientifically. He is indulging in pseudoscience.

Settled does not mean proved

One of the great errors in the public understanding of science is to equate settled with proved. While Einstein's theories are "settled", they are not proved. But to plan for them not to work would be utter folly.

As the philosopher John Dewey pointed out in his book Logic: The Theory of Inquiry:

In scientific inquiry, the criterion of what is taken to be settled, or to be knowledge, is [of the science] being so settled that it is available as a resource in further inquiry; not being settled in such a way as not to be subject to revision in further inquiry.

Those who demand the science be "settled" before we take action are seeking deductive certainty where we are working inductively. And there are other sources of confusion.

One is that simple statements about cause and effect are rare since nature is complex. For example, a theory might predict that X will cause

Y, but that Y will be mitigated by the presence of Z and not occur at all if Q is above a critical level. To reduce this to the simple statement "X causes Y" is naive.

Another is that even though some broad ideas may be settled, the details remain a source of lively debate. For example, that evolution has occurred is certainly settled by any rational account. But some details of how natural selection operates are still being fleshed out.

To confuse the details of natural selection with the fact of evolution is highly analogous to quibbles about dates and exact temperatures from modelling and researching climate change when it is very clear that the planet is warming in general.

When our theories are successful at predicting outcomes, and form a web of higher level theories that are themselves successful, we have a strong case for grounding our actions in them.

The mark of intelligence is to progress in an uncertain world and the science of climate change, of human health and of the ecology of our planet has given us orders of magnitude more confidence than we need to act with certitude.

Demanding deductive certainty before committing to action does not make us strong, it paralyses us.

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