The complexity obstacle

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Science and certainty don't always go hand in hand

SCIENCE has suffered some hits to its credibility in recent times. Not enough to have most people ditching their dental anaesthetics for meditation, but enough to curb enthusiasm for emissions trading schemes. Many have been left wondering if scientists really know as much as they say they do when they're asking for large sums of public money.

Remember the Climategate affair. As with WikiLeaks, what was actually revealed in the leaked emails from the University of East Anglia's Climate Research Unit was somewhat underwhelming and mostly consisted of free and frank but reasonable expression of views. No matters of fact came to light that suggested any need for a substantial rewrite of climate science theory. But some minor grubbiness and obstructiveness about sharing raw data was enough to give the impression that something was rotten.

The affair, nevertheless, contributed to a reduction of public support across the world for carbon-reduction strategies. Ross Garnaut, as reported on March 11, admits the public is less convinced about climate science, although the science itself has not changed.

The activities of the world's most famous scientist have not helped. As Oxford's professor for public understanding of science, Richard Dawkins made a career of pontificating on non-scientific topics he plainly knew nothing about, such as religion and philosophy. That confirmed many people's prejudices that scientists are simplistic folk who cannot see past the ends of their microscopes; certainly not to be trusted with important matters such as public policy.

Finally, there have been concerns about the "decline effect", or "cosmic habituation". An alarming proportion of results published in the most respectable journals and supported by the best statistical tests seem to have gradually become false — effects harder and harder to replicate, cures working less and less. Psychoactive drugs are a particularly bad area. The extent of the problem is unclear (it is not as if the charge on the electron has become fuzzier with time), as are its causes, but there is an uneasy feeling of something amiss.

Those developments have taken place against a background of constant sniping from the academic enemies of rationality loosely called postmodernists. In the more rarefied reaches of university humanities faculties, it is de rigueur to describe science as socially constructed, implying that its results depend not on evidence but on the wishes of the great and powerful.

So where is science certain? Or is that the wrong question? Should we be happy with high probability and, if so, where is that available?

Let us take a Cartesian approach and go back to square one. Descartes asked the question: What do we really know? and answered: We are certain at least of our own existence. That is bedrock that cannot be doubted, and we can work out from there.

In science, the bedrock that is beyond doubt is mathematics. No one need accept authority in mathematics because the truth is plain for all to see (at least in simple cases). Consider two rows of three things, such as the ampersands below:

& & &
& & &

The brain provides us with a wonderful scientific visualisation facility, or mind's eye. It allows us to group objects mentally in one way or another. We can see the ampersands as two rows of three (2 x 3), or three columns of two (3 x 2). Since they are the same objects 2 x 3 must equal 3 x 2. We not only know *that* 2 x 3 = 3 x 2, we understand *why* it must be so.

Further, it is clear that the same argument would work for any larger rectangular array. That is a remarkable achievement: certain knowledge, of an infinite number of truths, just by thinking. There are plenty more truths where that came from, proved true in the extensive literature of pure mathematics.

The enemies of rationality, who believe the whole concept of the objectivity of knowledge is a conservative plot, have been quick to contain the damage threatened by the certainty of mathematics. It has not been easy.

A few books have appeared with titles such as *Social Constructivism as a Philosophy of Mathematics*, but the standard irrationalist arguments against objectivity have not worked well; for example, there have not been found primitive tribes who believe that 2 + 2 = 5, or minus 2, or 3.7, so there is no argument from the diversity of beliefs in different cultures.

However, another argument has more initial plausibility and currency. Surely if something is proved, it must be proved from some axioms, which themselves must be arbitrarily chosen? For example, could we not set up alternative number systems in which 2 + 2 does equal 5? In any case, surely whatever certainty mathematics has, it is only about an ideal world (of abstract numbers, or sets, or models), and the certainty does not translate to the messy real world in which we live? What if we put two rabbits in a box, then another two; if we look later, might we not find five?

Those evasions are not correct. The result 2 x 3 = 3 x 2 is true not only of abstract numbers but of real ampersands on paper. Our understanding of why it is true does not depend on any assumed axioms. We could set up an alternative system and call its members numbers, but that has no relevance to the truth about *the* numbers, the ones that measure the quantity of things. (Compare the old children's joke: "How many legs has a dog got, if you call his tail a leg?" Answer: "Four. You can call his tail anything you like,

Energy price must be paid

but it's still a tail, not a leg.") And it is our certainty that 2 + 2 = 4, not 5, that allows us to conclude that the rabbits in the box must have bred.

The certainty offered by mathematical reasoning has been greatly expanded by the development in the past 70 years of sciences that lie between mathematics and the natural sciences. The formal sciences or sciences of complexity, with names such as computer science, statistics, operations research, risk analysis, data mining and cryptography, though not much noticed in popular culture or the humanities, have hugely extended the range of what can be known by pure thought.

Their methods are those of mathematics and computer simulation, not observation and experiment. A computer program, for example, is the same kind of thing as a mathematical proof; the relations between its many parts are logical and subject to inspection. There is no need to inquire whether an if statement in a program might overstress a do-loop and cause it to fail. The relation between lines of code is logical, not physical, hence subject to complete understanding and proof. Those sciences have become the foundation of the knowledge economy, ensuring an endless supply of jobs for graduates in mathematics and related disciplines.

When we move out to the natural sciences that do depend on observation and experiment, that kind of provable certainty is not available.

There are several reasons sciences such as physics, chemistry and biology can reach results that are in principle only highly probable. But they can attain what used to be called practical or moral certainty.

The truths of natural science have an in-principle probabilistic nature. Observations need some theory to interpret them and cannot in themselves fully logically imply the theory. Scientific theory is not a heap of observation reports; it is a story that implies and explains those reports. And in particular there is the problem of induction: one may know by observation only "all observed crows are black", and that does not logically imply "all crows are black". It is logically possible that the next crow observed will be beige.

Even though complete mathematical proof of natural scientific truths (or the commonsense truths of ordinary life) is impossible, we *can* have high confidence in them, confidence of a degree we should call certainty. The reason is that the relation between evidence and conclusion is itself a logical one that we can understand fully. Then if our observations are secure and they support a theory to a degree very close to certainty, that theory is established with near certainty.

Take the theory of the circulation of the blood. It was not an easy theory to discover, since any dissection likely to expose it will probably cause the heart to stop. It was established reasonably convincingly by William Harvey in 1628. Since then, it has become more and more firmly established and accessible to more and more direct observation. It is not going to become undiscovered.

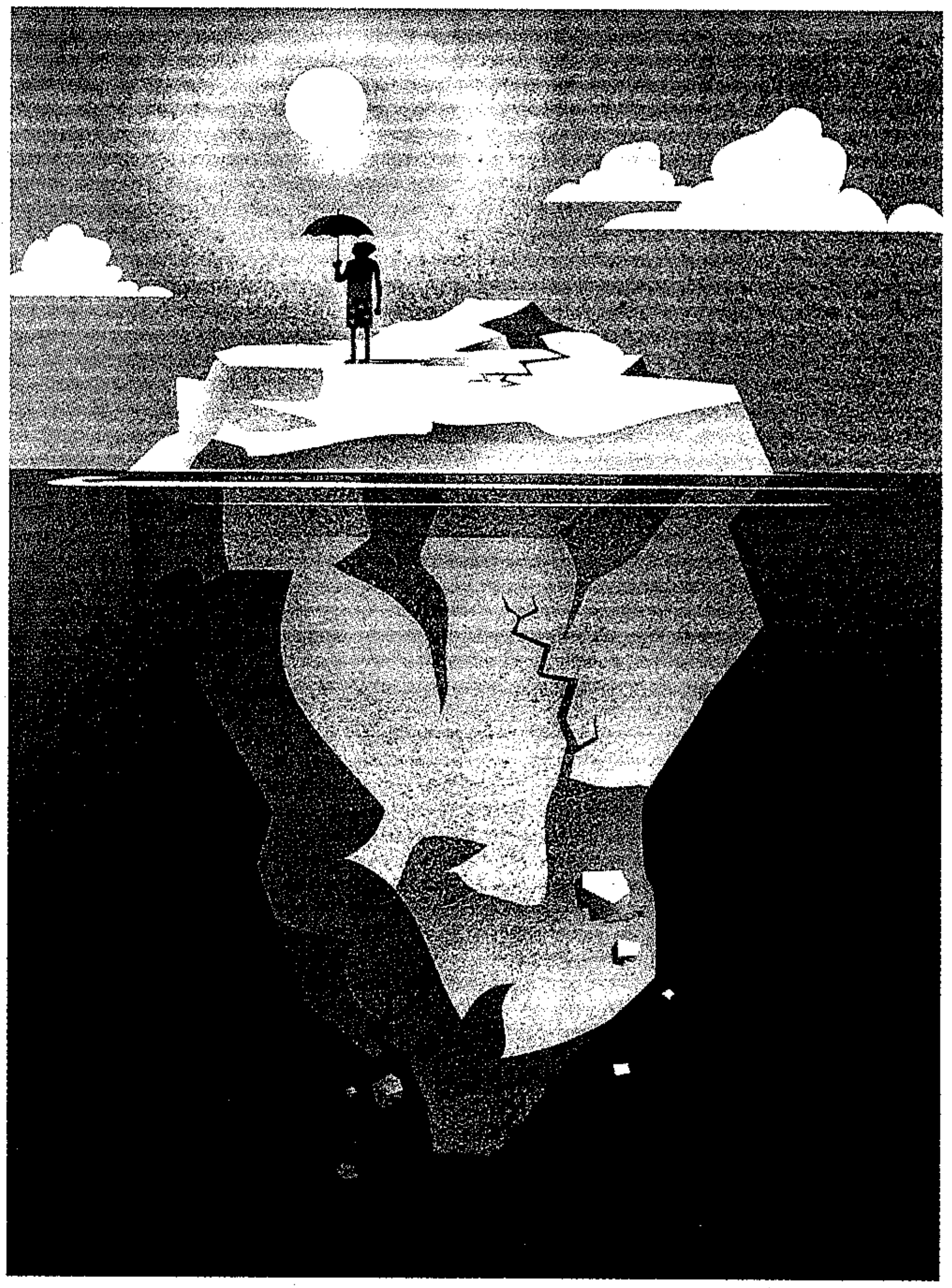
The bulk of science is like that. The sciences of chemistry, agricultural science, anatomy, neuroscience, ornithology, oceanography, geology, solid-state physics, solar system astronomy and so on deal with things of moderate size and complexity, accessible to observation and experiment. Knowledge in these fields tends to be cumulative, as better observational techniques allow theory to extend its range gradually. The best-established results in those sciences count as certain.

A crucial role in the establishment of certainty in these sciences — a role neglected even by the defenders of science — is played by the absolutely objective relation of evidence to conclusion. The relation deals in probabilities but is in itself logical and certain. It is the relation spoken of in law under names such as proof beyond reasonable doubt. A model of it is the argument form called the statistical syllogism, such as:

■ The great majority of airline flights land safely.
■ I am taking off.
■ Therefore, it is very probable (I can have rational confidence) that I will land safely.

The premises do not make the conclusion certain. It is *possible* that my flight is one of the small minority that do not land safely. But on the evidence, as a matter of logic, that is not likely. So my confidence on take-off is rational.

Reasoning of this probabilistic kind can explain why inductive arguments are rational though uncertain, arguments such as that from "all observed crows are black" to "all crows are black". Bertrand Russell dramatised the problem with inductive arguments in his example of the Christmas turkey. Each morning it is fed. Being a good inductivist, it grows to expect that it will be fed every morning. On Christmas Eve, however, matters are unfortunately otherwise. In the rush to emphasise the turkey's one error of inductive prediction, it is easy to forget that it was right most of the time. Necessarily so, since if the confidence of one's predictions increases with the amount of evidence, then the disappointment of that expectation is necessarily a rare event.



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As we move out from the core of well-established science, some degree of scepticism becomes reasonable. Many halfway decent and accepted scientific theories turned out to be false, and science has an unfortunate history of giving the impression that certain things are more or less known or known but for a few details to be filled in, when they are not.

Take the question, Why is the sun hot? Einstein's answer, that mass is turned into huge amounts of energy according to the equation

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$E = mc^2$, was discovered in time to be included in the celebrated and scientifically authoritative 1911 edition of the Encyclopaedia Britannica. What, then, do earlier editions say about this important question? Do they tell the truth, namely, "Sorry, we haven't a clue?" Certainly not. The 1887 edition avoids the question and simply writes about the sun's size, mass and structure. The 1902 supplementary edition mentions the only known possible cause of heating, contraction of the sun, calculates how much heat that would produce, and says nothing about whether that would be enough. Something similar took place several times with the theory of evolution, where problems such as the age of the Earth and the evolution of altruism went from the status of "quibbles inflated by religious fundamentalists for their own purposes" to "good question, we now know the answer", without going through an intermediate phase of "difficult question, we're hoping an answer turns up".

Four serious obstacles stand in the way of establishing the truth in science, even in properly scientific fields (as opposed to fields such as ethics, where scientific methods are in principle unable to decide). It is hard to investigate the very old, the very small, the very large and the very complex. Astrophysicists are doing their best with the very big and very old distant universe, but it would not be wise to bet on anything written in the journals about dark matter. The difficulties are what make the problem interesting, of course, but there is no point attempting to defend science by claiming certainty before it has been achieved.

It is the complexity obstacle that creates trouble for climate science. The science is not difficult to understand, by and large, it is just that there is a lot of it and the global climate system is very complex. Doing climate science is hard work, but the results and the evidence for them can be understood by anyone with the skills of a normal lawyer in evaluating evidence and a feel for quantitative data. But it does need a great deal of time, since the evidence ramifies indefinitely and has gaps, controversies and uncertainties. Even to consider the evidence for a comparatively small question of some minor possible significance, such as whether the medieval warm period extended to the southern hemisphere, is extremely time-consuming. That is a problem for everyone, not only outside observers but climate scientists busy with their own corner of the work.

However, one fact is very well established. Climate change is a reality: in simple terms, it became hot in the 1990s and it has stayed hot. Recent years have been very warm (measured by an array of different methods), and there has been melting of glaciers and tundras, despite a La Nina phase, which is normally cooler. If anything, the change has been more rapid than most climate scientists expected. The Arctic is warming faster than the rest of the world and that is enough in itself to cause notable sea level rises in a few decades. Since the observational evidence is there, it is not satisfactory to say: "The surf at Bondi doesn't look higher to me than 50 years ago; it'll all blow over like bird flu." The Climategate emails affair was a storm in a teacup that made no real difference to the observational evidence.

That the Earth has become hot is a reason for thinking that it may stay hot. (That's induction.) This is so irrespective of whether the causes are known or whether any computer models of climate are credible. Therefore, precautions are in order, since it is very difficult to reverse effects such as warming seas.

The problem is that there is still substantial uncertainty about the causes. Inferring causality from observations is much harder than is usually realised. The problem is at its worst in sociology, where it is normal to infer from "people in poor suburbs are observed to be less healthy" to "poverty is a cause of bad health" (without investigating how much of the effect is due to healthy people making enough money to move to better suburbs). But it infects all efforts to work out what is causing what in complex systems.

Climate science does have a head start because causal physical principles, such as the greenhouse effect itself, are known. But filling in the gap between known physical principles and the conclusion that the burning of fossil fuels is the main cause of global warming has not proved easy. It is a reasonable enough theory on all the evidence, but it is far from definitively established. There are uncertainties in establishing that carbon dioxide is the main cause of warming and that the rise in carbon dioxide is largely caused by burning fossil fuels (although human activity since the Industrial Revolution certainly plays a large role). A short list of the main uncertainties includes water vapour multipliers, cloud formation, deforestation, soil carbon, aerosols and paleoclimate. It is true that there is no serious alternative theory as to why the world has become hot. That does support the fossil fuel theory, but only up to a point.

A further causality problem arises in considering how much difference any climate change policy will make. Many who have been loudest in saying "We must do something or there will be sea level rises, extreme heat events and so on" have been very coy about whether any achievable policies will make much difference.

Even if carbon increases have been the sole cause of global warming, reducing carbon emissions is a very difficult and expensive way to keep temperature down, and not necessarily the most effective. If the climate sceptics are right, there will be no effect, and if the climate scientists are right, very little.

So what should the rational person do, faced with the genuine threat of global warming, and given the doubtful effectiveness of achievable carbon reduction strategies? Sacrificing a goat and hoping for the best is one plan, which present government policies approximate. Surely science can suggest something more rational? Indeed it can. Since the problem is that the planet is heating up, some research effort should be put into how to cool it down. That is, cool it down directly, by geoengineering methods such as shadecloth in space, sulphates in the upper atmosphere or methods to increase the albedo, or reflecting power, of some of the Earth's surface so as to radiate more heat into space. If those methods sound flaky, that is a function of the lack of research on which if any of them may be feasible. It is true that no existing field of geoengineering comes close to promising an answer; but, then, neither did any method of powered flight in 1900 look close to success. A good deal of information is available on global shading from the natural experiments of volcanic eruptions, but the narrow focus of climate science has diverted concern and research funds into ineffective methods to maintain the status quo. Of course research on carbon reduction and alternative energy sources should continue, but more diversity is needed.

When in a few decades it turns out that there is an urgent need to cool the planet down (or to warm it up, as the case may turn out to be), we may regret that the steps obviously required by scientific rationality were not taken early, and instead a scientific consensus and a crowd of earnest activists stood on the beach and exhorted the waves to go back. Science can offer certainty — sometimes. In other cases, it can offer rationally grounded probabilities, which are the best available foundation for public policy. When probabilities have to be relied on, then, as they say in the science of risk management, "Don't put all your eggs in one basket." ✱