Know your limits

In his book *Science and the Modern World*, the British philosopher Alfred North Whitehead identified a fundamental problem afflicting scientific thinking, indeed all thinking. He called it 'the fallacy of misplaced concreteness'. "You cannot think without abstractions," Whitehead noted; that is, without focusing on some details of a problem while ignoring others. This is good, but also potentially problematic.

"The advantage of confining attention to a definite group of abstractions," he wrote, "is that you confine your thoughts to clear-cut definite things, with clear-cut definite relations." However, the disadvantage is that, by the nature of the case, you have abstracted from the remainder of things." In other words, a model — formal or informal, no matter how detailed and specific — is not reality. Scientists (and everyone else too) ought to pound this into their heads.

Although Whitehead's point is obvious, it is also too often forgotten. The problem is more acute now than ever with the allure of large-scale computer models and rich visual displays that make simulations of anything from heart dynamics to global climate seem like watching the 'real thing' develop before your eyes.

So, obvious or not, Whitehead's point still carries instructive value. It becomes even more important in any setting — climate change being one — where policymakers or the public demand or crave more certainty than science can deliver. Indeed, a convincing argument for awareness of uncertainty and unavoidable 'unknown unknowns' is among the most valuable things science can offer.

The US economist Frank Knight, the intellectual father of the famous Chicago school of economics, famously distinguished 'risk' from 'uncertainty'. Risk, in his usage, is what we face when we at least know what's possible, and can assess the likelihood for different things to happen. We encounter risk in a game of roulette at the casino, assuming the wheel is fair.

In contrast, 'uncertainty' is a more serious form of unknowing, unpredictability untamed and unconstrained, where probabilities can't be given and we can't even be sure of the range of possible events. Uncertainty is living with the likelihood of true surprises and unimagined twists.

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Scientists generally feel more comfortable calculating risks and putting numbers on things, using models and living in Whitehead's confined world of abstractions. Indeed, modelling anything from the weather to the fatigue of an aircraft wing is largely an effort to reduce uncertainty and turn its wildness into mere calculable risk — something we can understand and plan around. But success is always only partial, and danger lies in mistaking the map for the territory. Simulations of an aircraft wing may give a probability of failure of 1 in 100 million on each flight. But this is only for failure in known modes, and through mechanisms reflected in the model's physics.

Such limitations affect all models. But, as Lenny Smith and Nicholas Stern have argued (*Phil. Trans. R. Soc. A* **369,** 1–24; 2011), they take particular prominence in the context of climate change and the consideration of policies to deal with it. Weather predictions and climate models ultimately depend on the numerical integration of the Navier–Stokes equations for fluid dynamics, yet simulations of such equations in three dimensions often blow up in finite time; no one has yet proved that these equations even possess smooth meaningful solutions.

Likewise, every simulation has limits — a regime of parameters in which it can be considered adequate, and outside of which it cannot. Or, a time after which errors will accumulate to make the output misleading. As Smith and Stern point out, climate science gives a good first-order understanding of the likely effects of an increasing concentration of greenhouse gases. Yet even the best of today's climate models fail to simulate rainfall patterns accurately on the spatial scales of large forests. As forests play a huge role in the climate system, these models become inaccurate in the long term. This isn't just a possibility, but a certainty.

But this isn't a problem to be eliminated — uncertainty is unavoidable. We can only shift the boundary between risk and true uncertainty, never eliminate it. Smith and Stern suggest that we benefit from making clear statements of the limitations of science, of what we know and also of what we do not. "A clear statement of limits," as they put it, "is of much greater aid to policy-makers than the statement that these are the 'best available' models."

By tradition, training and experience in science hammers the search for certainty into our heads. We're loathe to speculate and determined to make cautious statements backed by evidence, and otherwise remain silent. Unfortunately, this strips away much of what is valuable in science, even if it is speculative. What exactly will happen to the Earth's climate if the global average temperature rises by 5 °C? Will California become a desert unable to support crops? Will sea levels rise 10 centimetres — or instead perhaps 5 metres, driven by positive feedbacks and melted ice caps that absorb more sunlight than the ice does now? No one can say. But science can say with strong certainty that the effects, whatever they will be in detail, will be huge, not insignificant.

This in itself is valuable knowledge, and might help dissuade a policymaker from deciding that an increase of 5 °C might not be so bad — after all, imagine the economic benefits of so many more holiday destinations.

The most valuable knowledge exists as shreds of insight almost totally obscured by vast uncertainty. Scientists engaged with policy have to get used to this. As Smith and Stern put it, "When asked intractable questions, the temptation is to change the question, slightly, to a tractable question which can be dealt with in terms of imprecision and probability, rather than face the ambiguity of the original, policy-relevant, question. Science will be of greater service to sound policy-making when it handles ambiguity as well as it now handles imprecision." ❒

MARK BUCHANAN

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