Learning from the impossible

Philip Ball reviews *The Science of Can and Can't* by Chiara Marletto

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Alternative reality
If a lifeboat is never used, because the ship it is on never sinks, is it still a lifeboat?

The Science of Can and Can't
Chiara Marletto
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If a 1 kg mass is dropped from a height of 100 m, what is its velocity when it hits the ground? My eldest daughter is currently grappling with such thorny questions in her physics lessons, but one answer she is not expected to give is: when, exactly, did this happen? It's a purely hypothetical scenario, in which we freely change the details (what if that mass were 2 kg?).

But in her provocative new book *The Science of Can and Can't*, Chiara Marletto, a physicist at the University of Oxford, looks again at how physics treats these hypothetical scenarios. The "traditional conception of fundamental physics", she says, has no room for such hypotheticals, nor for counterfactual, alternative versions of "what actually happens". While abstract laws of physics (such as Newton's) are all very well, a widespread view is that they operate in conjunction with unique and specific initial conditions to create a universe in which only one inevitable thing ever happens at each moment. (This was exemplified in some responses to my recent *Physics World* article on free will (January p17).)

However odd it might seem at first encounter, this traditional, reductionistic view seems to insist that anything that doesn't actually happen must be impossible. Yet "there are questions that this approach cannot answer", Marletto argues – "questions that are deep and important for understanding the full reality of a physical phenomenon". She offers a delightful metaphor. Suppose we ask what the purpose is of the little rowing boats attached to a ship. Why, they are lifeboats to be used in the event of sinking, of course. But if the ship never sinks over all its working life, so they are never used, were they ever truly lifeboats? Their function can be defined only in terms of a counterfactual scenario – an alternative to the observed reality. Yet surely that's still the right answer.

Marletto has developed this science of counterfactuals – of what "can and can't" be – in collaboration with fellow Oxford physicist and author David Deutsch, for whom it supplies a central plank of his "constructor theory". That theory is an attempt to reformulate laws of physics in terms of fundamental statements about what is and is not possible. As Deutsch has put it: "This central role for the impossible is not only a formal implementation of the Popperian idea that the content of a scientific theory is in what it forbids. It is also an important difference between the constructor-theoretic conception of the physical world and the prevailing one: what actually happens is seen as an emergent consequence of what could happen, rather than vice-versa."

In other words, we currently deduce general laws on the basis of specific observations of things that do happen, but perhaps it would be more fruitful to understand observations as consequences of fundamental laws about what can and can't occur in principle.

In fact, some quantum theorists are attempting to do precisely that. They try to formulate quantum phenomena such as entanglement in terms of so-called "no-go theorems": statements about what is impossible. One such principle is quantum no-cloning: it is impossible to make an identical copy of an unknown quantum state. Remarkably, from such statements one can recover all the familiar tenets of quantum mechanics, such as superposition and Heisenberg's uncertainty principle.

At root, these theorems are statements about the allowed transformations of quantum information. This is potentially one of the most fertile applications of the counterfactual approach, although it is a little disappointing that Marletto does not explicitly make the connection between the route she and Deutsch are taking here, and what others are doing in this field of "quantum reconstructions".

More generally, counterfactuals might help to clarify the emerging links between physical theory and information. This puzzle goes back at least to Maxwell's demon (oddly absent here); Erwin Schrödinger's musings on life and thermodynamics; and the developing nexus of information and computation theory, cognition and biology. The information-carrying potential of

a system like a microchip or DNA, Marletto explains, comes from a counterfactual property: they could be in other states than they are, and we can only interpret their state as informational with reference to those counterfactuals.

The programme of the "science of can and can't", or constructor theory, is thus tremendously ambitious, seeking a reformulation of quantum and classical physics, the theory of computation, emergence and complexity, and more. It points to the enticing notion of a "universal constructor". By analogy with Turing's universal computer, which "can be programmed to perform any calculation that is physically allowed", a universal constructor could enact all transformations that are physically possible. I think these ideas are onto something – but only because they seem to be steering towards much the same goal as a lot of other work coming along different routes. So it's frustrating that Marletto overlooks the connections.

Her argument here is also somewhat undermined by a littering of sloppy claims. It's really no longer good enough to see organisms described as readouts of genes, each "coding for a different trait", nor to see genes portrayed as "replicators". The assertions that art "advances" via a Popperian correction of errors, or that natural selection "cannot perform jumps" and can "stagnate" to produce mass extinctions, don't inspire confidence. We get the old, flawed story about Copernicanism resulting from an "irremediable clash" of geocentrism with observation, and the misleading suggestion that memory entails the mere copying of signals from the environment into the brain for later retrieval, as if in a filing cabinet.

The "science of can and can't" is tremendously ambitious, seeking to reformulate quantum and classical physics

Meanwhile, some readers may be as puzzled as I was by long passages stating the obvious in a laboured fashion without any indication of what question is supposedly being addressed. There are also too few examples of concrete advantages the counterfactual perspective brings; without more, Marletto's claim to use "can and can't" to produce a "theory of knowledge" seems little more than a redefinition of knowledge to fit the theory. The book exemplifies a common flaw of works that expound the author's pet theory: a failure to capitalize on, or even to recognize, what other viewpoints could contribute to it.

Do counterfactuals, though, clarify free will? "We do not yet know how to accommodate exactly free will in physics," Marletto writes, "but that only means we have to think harder." I look forward to the thinking.

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