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978-1-009-01432-8 — Scientific Models and Decision Making
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1 Introduction

1.1 What Is a Model?

If there is anything that could be described as a core question in the philosophy of modelling in science, it is probably *What is a model*? Unfortunately, this question is deceptively complex: as we will see, it is tangled up with numerous other key questions in this branch of philosophy. But since we have to start somewhere, let's give it a shot: what *is* a model? Here's a short list of examples of things scientists call models:

(1) A 'typical' drawing of a cell in a biology textbook, showing the cell to contain a nucleus, a cell membrane, a Golgi body, mitochondria, and endoplasmic reticulum (Downes 1992) (Figure 1).
(2) The standard laboratory rat, *Rattus norvegicus*, depicted in Figure 2, is a model organism which is studied with the goal of understanding a range of biological phenomena, including humans (Ankeny and Leonelli 2021, chap. 2; Leonelli 2010; Levy and Currie 2015).
(3) The solar system, used by Niels Bohr in the early twentieth century as a model of the atom. Bohr argued that the nucleus of an atom is like the Sun, the electrons like planets circling the Sun (Giere, Bickle, and Mauldin 1979).
(4) The Friedmann–Lemaître–Robertson–Walker models of cosmology and the standard model of particle physics. The former is a way of picking out a particular set of conditions that satisfies the equations of the theory of general relativity; the latter a means of fleshing out the mathematical framework provided by quantum field theory (Redhead 1980; Smeenk 2020). This idea of a scientific model bearing the relation to theory that a model bears to a set of axioms in logic goes back to Mary Hesse (1967).
(5) Watson and Crick's famous double-helix models, built from pieces of wire and tin plates (depicted in Figure 3) and ultimately taken to represent the structure of DNA (Giere, Bickle, and Mauldin 1979, 16–29).
(6) A model reconstruction of the Earth's temperature in past geological periods, developed using proxy data from sources like deep ice cores, fossilized shells, tree rings, corals, lake sediments, and boreholes (Parker 2018; Winsberg 2018, chap. 2). An example of this is depicted in Figure 4.
(7) The San Francisco Bay model, depicted in Figure 5 – made of concrete, replete with pumps, and filled with salt water when in operation – used to simulate the behaviour of water in the real San Francisco Bay. The Army Corps of Engineers constructed the model in the 1950s to predict the effects of a proposal to close off the Golden Gate and turn the Bay into a freshwater reservoir (Weisberg 2013).

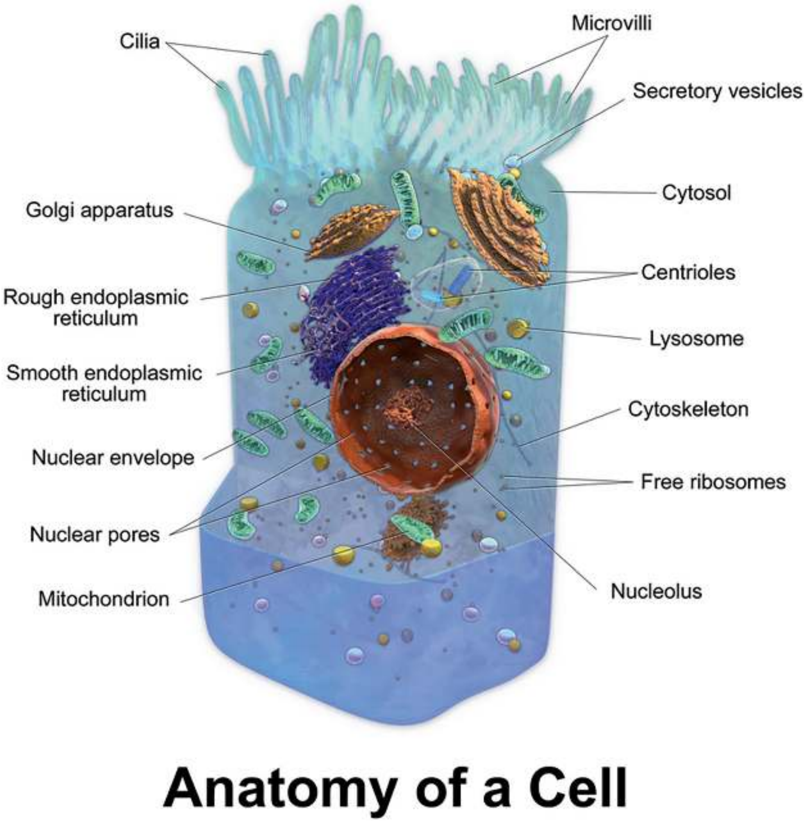

Figure 1 A model of a plant cell.

Source: www.pinterest.ca/pin/plant-cell-vs-animal-cell-whats-the-difference–533746993338085307/.

Figure 2 A model organism, the white lab rat.

Source: Williams (2011).

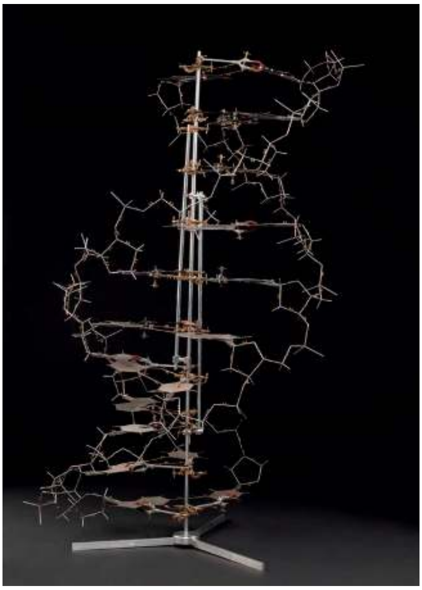

Figure 3 Watson and Crick's tin plate model.

Source: https://collection.sciencemuseumgroup.org.uk/objects/co146411/crick-and-watsons-dna-molecular-model-molecular-model.

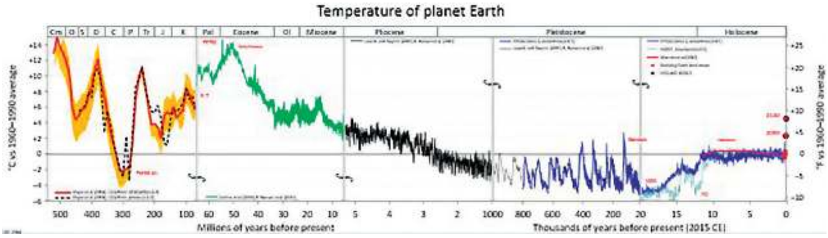

Figure 4 Several different models of the Earth's paleoclimate, presented as one history.

Source: Glen Fergus, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=31736468.

(8) Weather and climate models that run on computers (an example is depicted in Figure 6), which are used to make *predictions* about actual short-term weather conditions and *projections* about possible long-term climate conditions under different CO_2 emissions scenarios (Parker 2018; Winsberg 2018).

(9) Epidemiological models that forecast or explain the spread of an infectious disease (Winsberg and Harvard 2022). An example is shown in Figure 7.

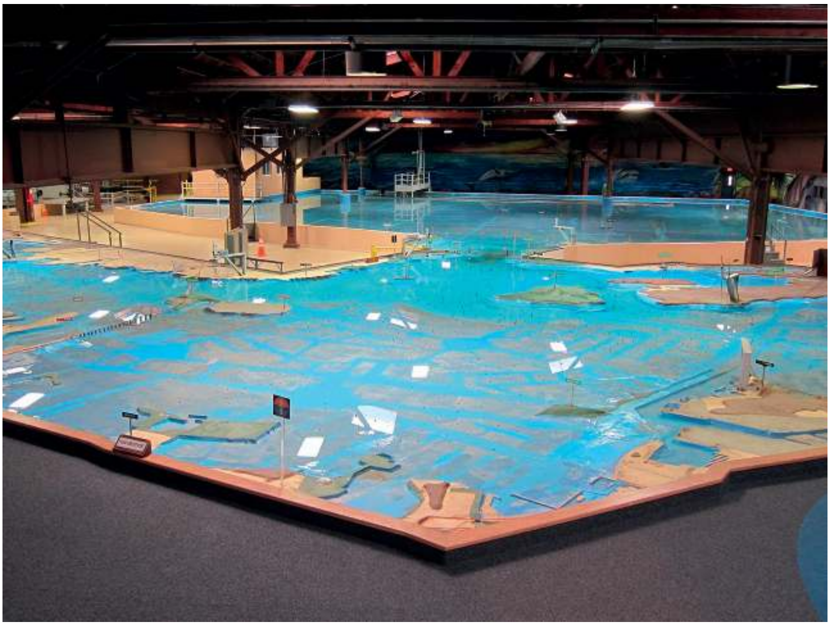

Figure 5 The San Francisco Bay model.

Source: https://commons.wikimedia.org/w/index.php?curid=30086231.

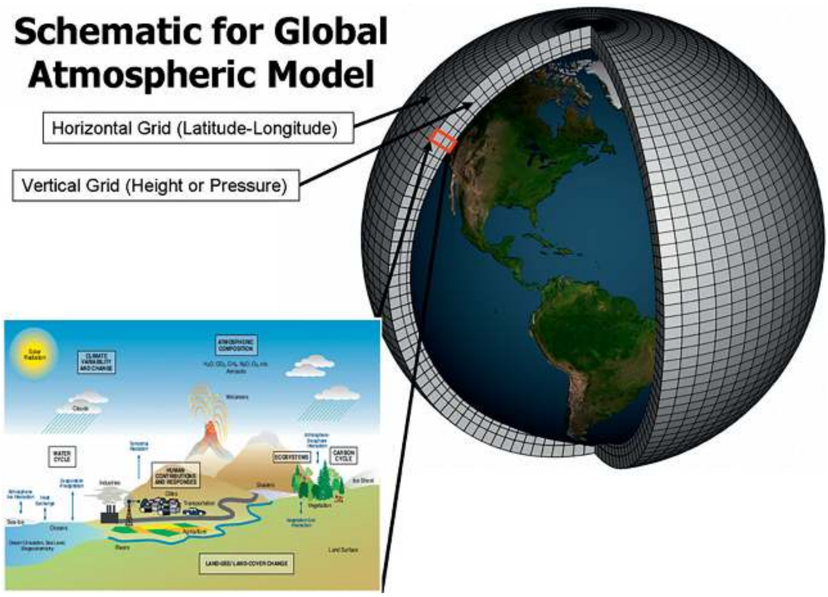

Figure 6 A global climate model.

Source: www.gfdl.noaa.gov/climate-modeling/.

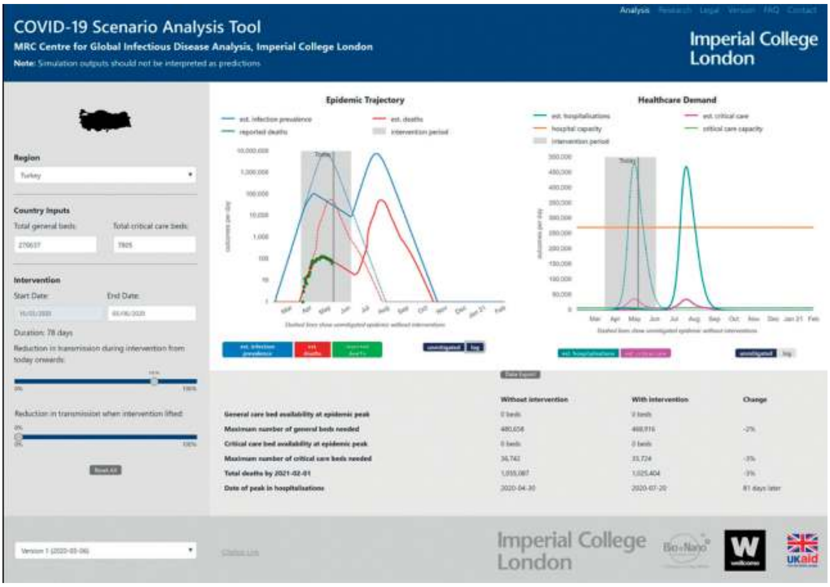

Figure 7 A model run of the Imperial College London Covid-19 model 'Covidsim'.

Source: https://covidsim.org.

(10) Health-economic decision models, which compare the costs and consequences of implementing different healthcare programmes, interventions, or technologies (Briggs, Sculpher, and Claxton 2006).

One thing that is noticeable about this list is that it is extremely heterogeneous. Take, to begin with, the standard models of cosmology and particle physics: while they are very commonly called models, they are really complements to physical *theories*. Compare these to climate models and epidemiological models: although the construction of these models is in part *guided by theory*, they are more like stand-alone bits of *mathematics*. With regard to the San Francisco Bay model and Watson and Crick's double-helix models, these are *actual physical entities*, which were *built* by humans for scientific purposes. The standard laboratory rat is a variety of a biological species *bred* by humans for these purposes, while the solar system is a *found object* that Bohr used to articulate his conception of what the atom looked like. And, unlike these physical entities, a reconstructed record of the Earth's temperature in a past geological period is a *data model* (Bailer-Jones 2009; Bokulich 2011; Hartmann 1995; Laymon 1982; Leonelli 2016, 2019; Mayo 1996, 2018; Suppes 1962, 2007): 'a corrected, rectified, regimented, and in many instances idealized version of the data we gain from immediate observation, the so-called raw data' (Frigg and Hartmann 2012).

In fact, our short, yet extremely heterogeneous list of models reflects a key source of confusion about models: *there is very little one can say about scientific models that will be generally true of all of them*. In this Element, instead of trying to work our way through this confusion, our plan is to live with it, so we can focus on other issues. In this section, we will simply zero in on a few features that *many* models have, so we can later explore how those features are important for understanding philosophical issues that arise in connection with certain models – especially those that play a role in helping policy-makers to craft policies that affect us all.

There is one more source of confusion that we must address before we move on. This is the rather haphazard way in which ordinary language use in science invokes a famous triad of terms: *model*, *theory*, and *experiment*. As we noted, the 'standard model of particle physics' is really a part of theory – but is a theory different from a model? This is far from clear, especially since when we talk about our best *theories* of how diseases spread or of how turbulence arises, what we are really talking about are things that involve *modelling*. Furthermore, there is an influential line of thought in philosophy of science that asserts that theories are nothing more than families of models (Suppes 1960; Suppe 1972; van Fraassen 1980). Nancy Cartwright (1983, 1989) argues that theories are incomplete without accompanying models – models are involved whenever a mathematical theory is applied to the real world. Finally, experiments are often described as being carried out under a 'model' of what the experimental system is and how it is manipulated in the laboratory (Suppes 1969).

In light of this, how can we possibly distinguish between a theory, a model, and an experiment? In fact, attempting to draw the line between these has been a central activity in the philosophy of modelling for many decades. For the purpose of this Element, however, it will suffice to employ a very simple distinction between theory, model, and experiment. Here, we take the word 'theory' to mean a particularly well-supported, widely-respected, and successful – in other words, *well-credentialled* – way of understanding how the world works (we will set aside the question of whether such an entity comprises a family of models, a syntactic structure, or whatever else (Suppe 1972)). In comparison, models and experiments can be more or less well-credentialled; that is, neither term flags a particular level of epistemic support or record of success. With regard to the difference between models and experiments, we will not draw any particular distinction in this Element: we simply use the word 'modelling' to convey a scientific process carried out either with paper and pencil or on a computer, and the word 'experiment' to convey a scientific process, the canonical form of which takes place in a laboratory by poking and prodding at a sample of the kind of system that is of interest.

With that said, let's begin by zeroing in on three features that many models have. First, models are almost always integrated into a *triad*. In other words, when we talk about modelling, we are almost always referring to three things: (1) a system or other phenomenon in the world, which we call the *target*; (2) the model itself, which *represents* the target (more on this shortly); and (3) the model *user*. These three things must be understood in relation to each other: in particular, the model user cannot be ignored because it is her *intentions* that ultimately determine the model's target system and the model's purpose. In other words, models are only representations of their target systems because a model user says they are. For example, the solar system has been around for billions of years – but it only became a model that represents the target system 'the atom' when a human agent, Niels Bohr, singled it out and said 'that's a model of the atom'. Similarly, a particular computer model has the cognitive function of predicting the weather tomorrow rather than of projecting the climate at the end of the century because its user says so. Indeed, a model only has a cognitive function at all, rather than the function of being a video installation in an art museum, because its user says so.

Second, as noted, models are almost always *representations* of target systems. What exactly it means for something to be a scientific representation is another core area of inquiry in philosophy of modelling, with a rich literature that we will not review here (Frigg and Nguyen 2021). For our purposes, it will suffice to say that a model *represents* a target system if a model user takes it to stand for that target system in a way that helps the model user reason about that system (Morgan and Morrison 1999; Morrison 1999); R. I. G. Hughes' (1997) 'Denotation–Demonstration–Interpretation' account of modelling is especially useful here. Some have even argued that there is a kind of use of models along these lines that gives rise to its own style of 'model-based reasoning' (Magnani, Nersessian, and Thagard 1999; Knuuttila 2005, 2011; Magnani and Nersessian 2002; Peschard 2011) in which 'inferences are made by means of creating models and manipulating, adapting and evaluating them' (Nersessian 2010, quoted in Frigg and Hartmann 2012).

Furthermore, because models are representations of target systems – not perfectly complete and entirely accurate depictions of those systems – the modelling process involves pragmatic choices about what to represent and how to represent it, which we call *representational decisions* (Harvard and Winsberg 2022). A well-worn analogy is useful at this point: models are like

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maps. Think about a subway map: the choices that go into how to represent the world in a subway map have a great deal to do with how the map will be used. The purpose of a subway map is to help people figure out how to get from station A to station B ('Is there a single line that takes me there? Am I going to have to make changes along the way?'). So, a subway map is designed to represent the features of the world that are salient to being able to decide how to get from point A to point B. Subway map users don't particularly care how far the different stops are from each other, nor do they care if the path between two stops is a straight line or if the subway takes a curved path to get somewhere. The key to making a good subway map is carefully choosing the most useful information to represent and using representational conventions that, together, make it as easy as possible for users to reason about and identify the best way to get from A to B.

Models are a lot like this. Like maps, they are things that we build to represent the world and to help us reason about it. And they reflect *choices* about how to represent the world: model developers decide 'we're going to include this, we're *not* going to include that'. Think of Watson and Crick's tin plate and wire model of DNA. It was very important for them to represent, in their model, the length of the four nitrogen-containing nucleobases (cytosine (C), guanine (G), adenine (A), and thymine (T)), but not their internal molecular structure. That is because they were trying to reason about how these four nucleobases could fit together like a puzzle. So they used a (3D) puzzle-piece–like representational toolkit to build the model and to help them do that reasoning.

This brings us to our third extremely important feature of many models. Their criterion of adequacy is most often not that they are 'true' to the world. It is not an important criticism of a subway map that the Broadway line 'isn't really orange', or that the map doesn't show that some subway lines cross bodies of water by going under them in tunnels while others go over them on bridges. Yet it *would* be an important criticism of a subway map if it were to represent two nearby stations by the exact same dot on the map. After all, this would make users think they could change lines at that stop without leaving the system, and avoiding this kind of mistake is what subway maps are supposed to facilitate. Part of a subway map's intended purpose is to help users make accurate inferences about where and how to change subway lines. With models, as with maps, the criterion of adequacy is that they are good enough for the purposes we intend to use them for. Sometimes meeting certain purposes requires that the representational relationship between the model (or map) and the world is verisimilitude. But often it does not. And adequacy for purpose is the telos of a model and a map, not truth.