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IDEALIZATION

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Introduction

Idealization is ubiquitous in science, being a feature of both the formulation of laws and theories and of their application to the world. There are many examples of the former kind of idealization: Newton's first law (the principle of inertia) refers to what happens to a body that is subject to no external forces, but there are probably no such bodies; the famous ideal gas laws do indeed idealize the behavior of real gases (which violate them in various ways, sometimes significantly); and economics refers to perfectly rational agents. Theory application is largely about idealization. Philosophers of science often focus their attention on scientific theories as expressed by a relatively small set of fundamental axioms, laws, and principles: for example, the laws of Newtonian mechanics plus the principle of the conservation of energy in the case of classical mechanics, or some variant of von Neumann's axioms in the case of quantum mechanics. However, if real science were restricted to making use of such resources, then it would be much less empirically and technologically successful than it is. The reason is that often the systems being studied are not amenable to a complete analytical treatment in the terms of fundamental theories. This may be because of the sheer complexity and size of systems in which scientists are interested; for example, it is not possible to use Newtonian mechanics to describe the individual motions and collisions of particles in a gas because there are so many of them. Another factor is that some mathematical problems cannot be solved exactly, as is the case, for example, with the famous three-body problem of classical mechanics.

Scientific knowledge is at least as much about how to overcome these problems with idealization as it is about fundamental theory. This may mean abstracting the problem by leaving out certain features of the real situation, or approximating the real situation by using values for variables that are close enough for practical purposes, but strictly speaking wrong, and/or using approximating mathematical techniques. So, for example, in physics, large bodies such as planets are often treated as if they are spherically symmetrical; in chemistry, crystals are often treated as if they were free of impurities and deformities; and, in biology, populations of reproducing individuals are often treated as if their fitness is independent of how many of them there are in the population.

Indeed idealization is fundamental to the use of language of any kind. Diverse entities are described as if they are all the same in some respect despite the subtle differences between them, and a single sortal term, for example, “dog,” or predicate, for example, “is red,” is applied to them. This is successful if we manage to describe the natural world in terms that readily capture the regularities in the behavior of things, and relevant causal and counterfactual facts. There is a long tradition of arguing that the world is split into a natural kinds structure that our language must reflect. In science, the categorization of the world in terms of complex theoretical languages is carefully designed on the basis of existing theories, and so as to facilitate further successful theorizing. Scientists do not usually deal with phenomena, events in the world, *simpliciter*, but with phenomena interpreted by means of theory and organized in stable patterns. Idealization is necessary to render complex real systems tractable by theoretical descriptions, and, as some philosophers have emphasized, the “raw” data of experiments are passed through a “conceptual grinder” (Suppes 1967: 62) to give data models, each specific to a particular experimental technique and correspondingly theory-laden in a specific way. Models of the phenomena may be inferred from such data models (Bogen and Woodward 1988). For example, it is routine to use exact linear, polynomial, or exponential curves to represent scientific data, rather than plotting the actual data points, as long as the latter are within experimental error of the curve. No real system that is measured ever exactly fits the description of the phenomena that become the target of theoretical explanation.

For these reasons theoretical explanations often contradict the description of the phenomena they were designed to cover. Consider Kepler’s laws of planetary motion; these described the kinematical properties of the paths of the planets in a heliocentric model of the solar system that fitted the extensive data gathered by Brahe. They were explained by Newton’s inverse square law of gravitation; yet the exactly elliptical orbits of Kepler are impossible if the gravitational effects of the planets on the sun and on each other are taken into account in the application of that law.

Mathematical idealization

One of the most ubiquitous forms of idealization in science is the application of mathematics to the world by imposing a precise mathematical formalism on a physical system. For Pierre Duhem, because the theoretical claims of physics are expressed in terms of concepts that are applied only with the help of artificially precise mathematics, the former are quite different from the ordinary truth-valued propositions of everyday life. Hence, he argued that physical concepts are abstract and merely symbolic formulae that describe only imaginary constructions. One perennial example of mathematical idealization concerns the representation of physical quantities as real numbers. The real-number continuum in mathematics has bizarre properties such as having as many points in a unit interval as there are in any other finite interval, no matter how much bigger in extent. Many properties of functions depend on their being defined on such continuous spaces, but if these are used to represent features of the real world it is reasonable to wonder whether a certain amount of falsification follows.

This has become important in recent years as some theoretical physicists have come to think that, although the representation of space–time as a continuous manifold is convenient for applying mathematics to physical problems, it may ultimately mislead us since the fine structure of space–time is discrete.

The use of mathematics in science is nonetheless often appealed to as the main reason to be some kind of realist about the abstract realm of mathematical entities such as functions and sets, geometrical and topological spaces, and abstract algebras. All these and other mathematical structures are apparently indispensable in physics and increasingly so in all other sciences too. It also seems to many, including, famously, the physicist Eugene Wigner (1953), that the effectiveness of mathematics has been surprisingly successful given the weirdness of the mathematical flights of fancy that have come to find application. It is not to be forgotten that the mathematical precision of much of contemporary science is extraordinary compared to what was achievable a few hundred years ago. Galileo famously said that the book of nature is written in the language of mathematics, but others have pointed out that the attempts we have made to copy the book must be regarded as literally false. The above *indispensability argument* for mathematical realism will be undermined if scientific realism cannot be justified. Conversely, if scientific theoretical descriptions of the world ineliminably involve mathematical idealization, and yet mathematical entities and properties are not correctly thought of as real, then this might give grounds for rejecting scientific realism. (The final section briefly returns to these issues.)

One particularly productive form of reasoning in science depends on idealizing physical structures so that they are treated as obeying exact symmetries. For example, someone calculating how many tiles will be needed to cover a certain area assumes the tiles to be exactly symmetrical; but, of course, there are imperfections in any production process and each tile is distorted in numerous ways compared to a geometrical object such as a square. Similarly, Galileo provided a dynamics that made the hypothesis of a heliocentrism intelligible. It depends on treating physical systems that are moving more or less uniformly as if they are moving exactly uniformly, and then reasoning about their behavior on the assumption that they obey the symmetries now known as the "Galilean group." For example, the behavior of a system that is at rest with respect to the surface of the earth is idealized and treated as an inertial system, even though the earth is in fact rotating. This is acceptable only when the relative distances in the model are small compared to the diameter of the earth, so that the earth is effectively flat from the point of view of the system. The search for symmetries was fundamental to the development of the various quantum field theories united in the *standard model* of particle physics.

Idealization and representation: models and theories

Idealization seems to give approximate truth. Many thought-experiments are based on idealized symmetry reasoning, yet they are essentially falsifying in nature. It is not clear what distinguishes legitimate idealizations from outright falsehoods. For example, a perfectly reversible (or maximally efficient) Carnot engine is impossible to build in practice, and yet is considered a respectable part of the subject matter of thermodynamics. On the other hand, a perpetual-motion machine of the second kind, the sole effect of which is the complete conversion of heat into work, is regarded as fundamentally impossible. What is the difference between an impossibility that can be considered possible in ideal circumstances and an impossibility that remains so no matter how idealized the scenario we envisage? A possible answer to this question is that a perpetual-motion machine of the second kind is incompatible with the laws of nature (in particular the *second law of thermodynamics*), whereas a perfect Carnot engine is compatible with the laws of nature. This does not get us very far, however, since the laws themselves involve idealizations. Other examples further complicate matters. In thermodynamical modeling it is common to make use of devices such as frictionless pistons, yet that there are no such real pistons is surely a law-like rather than an accidental fact.

Mathematical logic, developed in the early twentieth century, has ever since been used by many eminent philosophers of science to represent scientific theories. At one stage, the emphasis was on syntax, and theories were treated as linguistic entities. Confirmation, explanation, and laws, among other important features of science, were all analyzed by formulating theories as sets of axioms using a combination of observation and theoretical languages. This *syntactic* account of scientific representation is rivaled by the *semantic* approach due to Patrick Suppes and others. Suppes emphasizes models rather than sets of sentences. Many of those who developed the semantic approach were concerned to do justice to scientific practice and, in particular, to the application of fundamental theory to real systems by the construction of models. For example, Ronald Giere's *Explaining Science* includes detailed analyses of models of concrete systems such as the simple harmonic oscillator in classical mechanics, which he describes as a "constructed," "abstract" entity having certain features ascribed in the standard physics texts (1988: 6). The construction is situated within a model in which those features are related, these relations being expressed at the syntactic level by the force law $F = -kx$, for example. Such idealized systems in physics provide exemplars for the application of the theory. In the sciences the term "model" usually refers to a description of a specific system or kind of system. So, for example, there are models of the earth's atmosphere that describe it as a large number of cells and seek to predict large-scale phenomena by computing the interaction between those cells; there are models of populations of predators and prey that describe them as if the animals in each species were all identical to each other; and there are models of physical systems like the famous billiard-ball model of a gas. In each case, the laws and principles of theories are applied to a real system only by being applied to a model of it. Clearly, models are usually less general than theories; theories often apply to idealized systems; and models are used to make real systems theoretically tractable. R. I. G. Hughes (1989: 198) provides a formulation of the semantic approach that makes the concept of idealization central: "On the semantic view, theories present a class of mathematical models, within which the behavior of ideal systems can be represented."

A number of different kinds of idealization in science are described by Ernan McMullin (1985). Both Cartwright (1983) and McMullin emphasize the distinction between theories and models. McMullin (1985: 255) argues that Galileo originated the contemporary methods of idealization in science, and that "Galilean idealization can proceed in two very different ways, depending on whether the simplification is worked on the conceptual representation of the object, or on the problem situation itself." The former is *construct* idealization, whereas the latter is *causal* idealization. Examples of the former given by McMullin include the idealization that represented a small part of the earth's surface as flat, or the idealization that weights suspended from a beam hang at exact right-angles to it. Construct idealization is performed within a model and, according to McMullin, divides further into *formal* and *material* idealization. The former is a matter of simplifying factors for mathematical–conceptual tractability, even where those factors are known to be relevant to the situation, as, for example, when the sun is treated as being at rest in a calculation of the orbits of the planets, even though its motion will in fact affect their paths. The latter is a matter of completely leaving out irrelevant factors, for example, the fact that the sun is made of gaseous and not solid matter is not relevant to its gravitational effect on the planets and the model of the solar system simply leaves unspecified the composition of it and the planets. Causal idealization, on the other hand, is the simplifying of the *tangle of causal lines* present in real situations by separating them out, either in an experiment designed to minimize or eliminate the contribution of some causes to the effect (*experimental* idealization) or in the imagining of counterfactual circumstances (*subjunctive* idealization).

Nancy Cartwright (1983) makes much of the distinction between idealization of concrete objects or situations and idealization where the simplifying assumptions involve abstracting so that we are no longer dealing with concrete, but rather with abstract (and fictional), entities. The former she calls "idealization," and characterizes it as the theoretical or experimental manipulation of concrete circumstances to minimize or eliminate certain features. For example, a real surface is idealized to become a perfectly flat and frictionless plane, and a coefficient for friction with a convenient mathematical form can be reintroduced to make the idealized model more accurate. In such cases, the laws arrived at are approximately true, and in the laboratory it is possible to apply them directly, if approximately, to very smooth surfaces. Hence, she argues that the laws arrived at by idealization are still *empirical* or *phenomenological*, and concern *concreta*. The second kind of idealization she calls "abstraction." This often involves eliminating details of the material composition of real systems and, importantly, eliminating interfering causes. The laws that are produced by this kind of idealization are *fundamental* laws.

Newton's first law, as mentioned above, refers to the behavior of bodies which are not acted on by external forces, despite the fact that there are no such bodies. Thermodynamics refers to systems in equilibrium despite the fact that no real system is ever genuinely in equilibrium. In her well-known *How the Laws of Physics Lie* (1983), Cartwright turned traditional philosophy of science on its head by arguing that fundamental laws depend on abstracting from the real causes that operate in the world, and which therefore achieve their generality only by losing their empirical adequacy. They describe not the world but only abstract and general features of theoretical models. Hence, she argues that fundamental theories are so idealized as not even to be candidates for the truth, whereas models with all their messy details are capable of describing the world accurately, but at the expense of universality: "The phenomenological laws are indeed true of the objects in reality – or might be; but the fundamental laws are true only of the objects in the model" (1983: 4).

Cartwright also argues that the fundamental laws, because of their abstract nature, may be explanatory, but they do not describe what happens at all, unless they are interpreted as *ceteris paribus* laws. However, Cartwright maintains that the list of ways in which things might not be equal is potentially infinite and does not admit of explicit characterization. Hence, fundamental laws are linked to the appearances only by phenomenological laws, which are non-explanatory but descriptive, and at the theoretical level scientists construct models that are overtly of a sort that the real things do not fit. In order to relate those models to specific phenomena, they have to carry out a two-stage "theory entry" process (*ibid.*: 132–4), whereby the phenomena are connected to theoretical models through a description that is overtly incorrect. Hence, says Cartwright, the fundamental laws are not even approximately true since relevant causal features have been subtracted and the laws are therefore not about concrete situations. They can be interpreted as *ceteris paribus* laws, but since all other things are never equal, they are not true of any actual, concrete situation. Hence, she denies that any single set of fundamental laws describes the world.

Cartwright says that fundamental laws refer to entities that are abstract and to which we ought not to be ontologically committed, for example, Hilbert spaces, inertial systems, and incompressible fluids. She proposes that fundamental laws be understood as being about causal dispositions, powers, or capacities: the "converse processes of abstraction and concretisation have no content unless a rich ontology of competing capacities and disturbances is presupposed" (1989: 184). She goes on to state that "laws in microphysics are results of extreme abstraction, not merely approximating idealizations, and therefore are best seen as laws about capacities and tendencies" (*ibid.*: 188). Scientists construct theoretical models that real things cannot satisfy, and the metaphysics of capacities explains "why one can extrapolate beyond ideal cases" (186).

This has profound implications for the plausibility of a very influential account of explanation in science, namely the covering-law model of Hempel. According to this account, to explain something is to subsume it under the laws of nature together with a number of initial conditions. In the context of determinism, this means that the *explanandum* must be deduced from a set of premises that includes at least one law of nature. If Cartwright is correct that laws are abstractions from concrete causal structures, and if we assume that scientific explanation needs to specify the causes of things, then it seems as if the task of deducing real-world occurrences from fundamental laws is hopeless, for if the extra premises undo the abstraction of the law then the presence of the law in the explanation will become redundant. If this is so, then perhaps the right account of explanation will not mention fundamental laws at all, in favor of singular causes, and only phenomenological laws will feature in scientific explanations. This would be a radical discovery because most scientists and philosophers of science have thought that one of the great successes of science is the explanation of natural phenomena by the fundamental laws of nature.

Many philosophers agree with Cartwright that there is a fundamental distinction between theories and models, and that the former are so abstract as not to be candidates for the truth but rather are about fictional objects. Nowak (1995), for example, adopts the extreme stance that idealization terms should be taken as referring to entities which exist in other, possible, worlds. In recent philosophy of science it has become common to emphasize models as the locus of scientific knowledge, and to treat theories as tools for model-building rather than as true claims about the deep structure of reality (Morgan and Morrison 1995).

However, this view has several problems. Firstly, it is not true that only *derivations* from fundamental laws involve abstraction as well as approximation. As Cartwright herself claims, "idealization would be useless if abstraction were not already possible" (1989: 188). If idealization presupposes abstraction, and if, as Cartwright thinks, abstraction by its nature is inconsistent with the approximately true representation of concrete reality, then phenomenological laws and models cannot represent concrete reality either.

Secondly, the distinction between theories and models, and that between the abstract and the concrete, are plausibly matters of degree rather than of kind. Indeed Cartwright sometimes talks of the "more or less concrete." If they are indeed only matters of degree then they may not be able to bear the metaphysical weight attached to them. The same equivocation affects examples of the concrete objects that phenomenological laws describe, "concrete objects in concrete situations, such as the simple pendulum, a pair of interacting harmonic oscillators, or two masses separated by a distance" (Cartwright 1993: 262). However, these objects are not conceptually free of abstraction as opposed to idealization. For example, the so-called "concrete" functional law of the simple pendulum holds only when the angle of displacement of the bob is less than 10° (so that $\sin\theta \approx \theta$ approximately). So, concrete objects are not simple pendula if they are oscillating with a greater amplitude. Or the other way round: simple pendula are not concrete objects but abstract pictures of concrete objects under some circumstances. Furthermore, models too often involve idealizations, as when the effects of particular forces, such as those resulting from air resistance, are treated as negligible or when a system is described as internally homogeneous, even though no real systems are exactly so.

Thirdly, Cartwright talks as if phenomena, and thus the laws about them, are concrete, while capacities, and the theoretical laws that describe them, are abstract. Yet even the so-called "phenomenological laws" need *ceteris paribus* clauses. No phenomenological law will ever be exactly descriptive of concrete happenings.

Idealization and scientific realism

The discussion above suggests that idealization occurs at every level of representation, from the *phenomenological* to the *theoretical*, with the consequence that, if Nowak were right, all reference in science would be to entities existing in other, possible, worlds.

A metaphysically more conservative account is suggested by Grobler (1995: 42) who asserts that "idealization consists in specifying in advance the kinds of predicates expected to occur in claims being made in a given context about objects of a given kind, rather than in referring to some fictitious, idealized objects." Thus, for example, describing an electron as a mass-point does not amount to adopting some Platonic object as a substitute; rather the description merely indicates the relative irrelevance of the particle's dimensions in the theoretical context, since we are obviously excluding spatial dimension from the list of predicates characterizing it. Nevertheless, other properties (like mass, spin, charge, and so on) of the electron are retained (otherwise, we would not refer to what is being described as "an electron"); and that description features in, and is part of, the construction of an appropriate model. Anti-realists may seize on this and argue that on such a view scientific theories are, if taken literally, either false or, if they are not to be taken literally, not even candidates for truth about the world.

The debate about scientific realism is usually couched in terms of claims about our best scientific theories. In particular, realists claim that we ought to believe in the unobservable entities posited by the latter. (Although a proper appreciation of the role of idealization in the application of theories to phenomena may induce some skepticism about the degree of confirmation that theories really enjoy.) Those who follow Cartwright in regarding the empirically adequate parts of science as models rather than theories may also abandon realism about theories in favor of realism about models, and so defend entity realism against theoretical realism. On the other hand, some have argued, against Cartwright, that theories and models are not so different and, in particular, that even the latter involve abstraction and not just approximation. If this is right, then models are no less problematic and abstract in principle than are theories, and the latter are simply higher-order representations (rather than being non-representational). This is taken by some to motivate a unitary account of scientific representation with respect to both theories and models. According to the *partial structures* account of scientific representation developed by Newton da Costa and Steven French (2003), these models of the phenomena are then related by means of partial isomorphisms and homomorphisms through a hierarchy of further models to the high-level theoretical structures. It has been argued that these fit best with structural forms of realism emphasizing the relational structure that scientists attribute to the world (Worrall 1989; Ladyman 1998).

See also Essentialism and natural kinds; Explanation; Laws of nature; Mathematics; Models; Realism/anti-realism; Representation in science; Structure of scientific theories; Symmetry.

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Further reading

Cartwright’s *How the Laws of Physics Lie* (1983) is a classic critique of received views of scientific representation, laws, and explanation. Her *Nature’s Capacities and Their Measurement* (1989) is a follow-up work in which she develops a metaphysics of capacities. Mary Hesse, *Models and Analogies in Science* (Oxford: Oxford University Press, 1966) is a classic account of theory application. Suppes’s 1967 article is a classic early defense of the semantic approach to scientific representation. McMullin’s “Galilean Idealization” (1985) is a beautiful analysis of idealization in physics. Giere (1988) is a thorough introduction to the semantic approach, with numerous examples of models and idealizations. Herfel et al. (1995), N. Shanks (ed.) *Idealization in Contemporary Physics*: *Poznan Studies in the Philosophy of the Sciences and the Humanities*, 63 (Amsterdam: Rodopi, 1995), and Morgan and Morrison (1995) are all collections of papers by philosophers who emphasize the importance of models and idealization in science. Da Costa and French (2003) is a recent, comprehensive defense of the semantic approach to scientific representation in terms of partiality and pragmatism. Worrall (1989) is a classic appraisal of the scientific realism debate and an introduction to structural realism. Ladyman (1998) is an attempt both to develop Worrall’s structural realism that introduced the – now standard – distinction between epistemic and ontic versions and to defend the latter.

THE ROUTLEDGE COMPANION TO PHILOSOPHY OF SCIENCE

Edited by
Stathis Psillos and
Martin Curd

Routledge
Taylor & Francis Group
LONDON AND NEW YORK

First published 2008
by Routledge
2 Park Square, Milton Park, Abingdon, OX14 4RN

Simultaneously published in the USA and Canada
by Routledge
270 Madison Ave, New York, NY 10016

This edition published in the Taylor & Francis e-Library, 2008.

"To purchase your own copy of this or any of Taylor & Francis or Routledge's
collection of thousands of eBooks please go to www.eBookstore.tandf.co.uk."

Routledge is an imprint of the Taylor & Francis Group, an informa business

British Library Cataloguing in Publication Data
A catalogue record for this book is available from the British Library

Library of Congress Cataloging in Publication Data
The Routledge companion to philosophy of science / edited by Stathis Psillos and Martin Curd.
p. cm. -- (Routledge philosophy companions)
Includes bibliographical references and index.
1. Science--Philosophy. I. Psillos, Stathis, 1965- II. Curd, Martin.
Q175.R68 2008
501--dc22
2007020000

ISBN 0-203-00050-1 Master e-book ISBN

ISBN10: 0-415-35403-X (hbk)
ISBN10: 0-203-00050-1 (ebk)
ISBN13: 978-0-415-35403-5 (hbk)
ISBN13: 978-0-203-00050-2 (ebk)