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The function of natural laws in science.

Introduction

My thesis in this talk is

- Physics, as an ideal science, tries to develop theories, or one grand theory, based on a very small number of general principles, called fundamental laws.
- These fundamental laws have a two functions;
  - I) they are implicit definitions of theoretical concepts, and
  - II) they enable derivation of low-level empirical regularities.

According to common view the goal of natural science is to discover the natural laws. Another common view is that natural scientists use a empiricist method and proceeds in the following way:

1. We start by empirical observations.
2. We generalise these observations and formulate general hypotheses.
3. We test the hypothesis in a number of different circumstances and if the outcome is positive we conclude that the hypothesis is in fact a scientific law. If we hit upon a counter instance we reject the hypothesis and formulate a new and hopefully better one.
4. When we have arrived at well-supported law we can use it as a starting point for further predictions and explanations.

However, I think this is a misrepresentation of how we proceed in the natural sciences. The gravest fault is that this account completely neglects that concept development is an integrated part of empirical research. In order to better describe the methodology and the function of natural laws it is necessary to start by saying something about concept and concept formation.

Concepts and predicates.

A concept is a predicate with an associated principle of application. A predicate is a grammatical item, a part of a sentence. For our purposes we need not go into the fine structure of sentence; let us simply say that, in the simplest case a complete sentence is made up of a singular term, i.e., a proper name, a pronoun or a description describing one individual object, and the rest, which is the predicate. We can alternatively conceive a predicate as a incomplete sentence; a sentence in which the noun is removed and we have a blank left.

When we join a given predicate with a singular term we get a complete sentence. This sentence is true or false. Hence, when we take a set of objects and join these, one after the other, to the predicate, we get a set of sentences, some true, some false. Hence, the predicate divides the set of objects into two disjoint sets; those satisfying the predicate and resulting in true sentences, those not satisfying the predicate and resulting in false sentences.

There are some very deep technical problems with this account of predicates, but I will neglect these in this context. It doesn't matter for my argument.

We can thus say (with some caveats) that using concepts, i.e., predication, is the same as classification.

Induction and concept formation

Now let's return to our picture of the method of natural science. We suppose that we start with a small set of observations,

- Herrings have gills
- Cods have gills
- Haddocks have gills
- Salmons have gills

After a number of such observations we infer that

- All fishes have gills.

Now we have arrived at something which looks like a general law. It is a universal statement; it is supported by a number of observations and we have so far not met any counter instances. It can be put in the following logical form

For all x, if x is a fish, x has gills

If we take this sentence apart we find two atomic sentences:

X is a fish

X has gills.

Thus, in this law two concepts are involved : the concept of fish and the concept of gill.

I said a minute ago that a concept is predicate with a principle of application associated to it. In order to describe, or explain the concept of fish we must give the rules for something belonging to the class of fish. And the same of course applies to the concept 'gill'.

Here comes my main point: suppose we have tentatively accepted the law that all fishes have gills. Suppose further that we hit upon an object which we, according to our accepted rules for application, count as a fish. But it does not have gills. What to do?

Logically we have two options: either to reject the generality 'all fishes have gills', or to change the criteria of application so that the counter example can be dismissed as not really being a fish.

This has in fact happen. For quite a long time, dolphins and whales were considered to belonging to the category of fish. (Weren't they all swimming in the sea just like other fishes?) But it was found that they do not have gills. And as they deviate from fishes in a number of other aspects, their being classified as fish was rejected. That dolphins lack gills is then no longer a counter example to the universal statement that all fishes have gills, simply because dolphins are no longer considered to be fishes.

We cannot really say that we have falsified the assumption that all fishes have gills. Rather we **have changed the concept of fish, since we have changed the criteria of application.**

In other cases it might seem more reasonable to reject the purported law as false; it all depends on overall simplicity and coherence. Also a certain amount of theoretical conservativeness is operative; we make the smallest possible adjustments in our theory.

The picture I have drawn of theoretical and empirical work is exactly the same as Quine's view expressed in his 'Two dogmas of empiricism:

"The totality of our so-called knowledge or beliefs, from the most casual matters of geography and history to the profoundest laws of atomic physics or even of pure mathematics and logic is a man-made fabric which impinges on experience only along the edges. Or, to change the figure, total science is like a field of force whose boundary conditions are experiences. A conflict with experience at the periphery occasions readjustments in the interior of the field. Truth values have to be redistrbuted over some of our statements. Reevaluation of some statements entails reevaluation of others because of the logical interconnections …..But the total field is so underdetermined by its boundary conditions, experience, that there is much latitude of choice as to what statements to reevaluate in the light of any single contrary experience. No particular experience are linked with any particular statements in the interior of the field, except indirectly through considerations of equilibrium affecting the field as a whole"

Quine picture of the relation between science and empirical experience is thus *holistic*.
It follows that we cannot separate the empirical part and the conceptual part of a theory or statement. And so we have no real ground to distinguish between analytical truths, i.e., statements which are true only in virtue of their meaning, and synthetical truths, whose truth also depends on their empirical content.

Natural laws.
Natural laws are generally conceived as universal conditional statements. Some typical examples are
All metals expand when heated.
All material objects accelerate when acted upon by forces
All fishes have gills.
Quite a number of natural laws doesn't seem to fit. For example
The law of gravitation, Maxwell's equations, or Pauli's exclusion principle. However they can all be put into the canonical form when fully expressed. For example, the law of gravitation says,
For all pairs of material objects with masses m1 and m2 and with distance r, the force between these bodies is given by

$$F = G\frac{m_1 m_2}{r^2}$$

……..
Similarly for all other laws usually given as equations relating two or more quantities to each other. Such equations are the core of the consequent in the complete law formulation.
Unfortunately, being a universal conditional is not sufficient for being a law. It is quite easy to construct sentences with this form which no one would call a law. One famous example, given by Goodman, is 'all coins in my pocket is made of silver'.
Hence we need to introduce a distinction between *natural laws* and *accidental generalisations*.
Much work has been invested into the task of spelling out a set of criteria which enables us to distinguish between laws and accidental generalisations. Unfortunately, the efforts have not so far succeeded. The astonishing fact is that we can easily agree on a number of examples of natural laws, but we have no idea how define the concept.
I will leave it with that and take for granted we can agree on quite a number of examples.

Fundamental laws and empirical laws.

Suppose we have found a natural law by using induction. We have observed a number of particular cases and concluded that the general case in fact obtain. Suppose that the conclusion in fact is true. Isn't the existence of such laws a bit astonishing: Why is it the case that an *indefinite number of objects* satisfy two logically unrelated predicates? Is not the most reasonable assumption that the probability for such a state of affairs is zero?

History of science suggests two ways of explaining such regularities. The first possibility is to derive the regularity, or some version close to it, from a set of more fundamental and independently acceptable principles. A telling example is the general law of gases. This law began life as Boyle's observation that the product of pressure and volume of a portion of gas is constant. Charles in 1787 and Gay-Lussac in 1808 found that this constant depends on temperature and still later the complete general law of gases was formulated when the concept of mole was available. For some time this law appeared to be an empirical regularity, a brute fact. However we now know that it can be derived from the principle of energy conservation, given the identification of absolute temperature as mean translational kinetic energy among the particles making up the gas. So it is not just an empirical fact that the two predicates 'x is nearly an ideal gas' and 'the pressure, volume and temperature of x satisfies the equation $pV=nRT$' are both satisfied by the same objects. It follows from a basic principle, given some auxiliary assumptions.

This brings us to the second way explaining the remarkable fact that an indefinite number of objects all satisfy two unconnected predicates. All scientific predicates start their lives as part of our vernacular and as science advances vague notions are sharpened and changed into scientific predicates with explicitly defined criteria of application. And, of course, many new predicates are introduced by explicit definitions. The crucial point is that in this process of concept development a well-established regularity is normally not given up. Suppose we have a well-established generality, 'if A, then B', and hit upon a putative counter example. Logically we have two options; either to drop the regularity and accept it being falsified, or to change the criteria of application of the predicate in the antecedent so that the putative counter example can be rejected as no real counter example. A simple example of the latter is the history of the concept of fish. Although Aristotle knew that dolphins and whales are not fishes, his insights were forgotten and for a long time these mammals were thought to be fishes. But all fishes have gills, so what to do when learning that dolphins have no gills? Our predecessors did not give up the generality ‘all fishes have gills’; instead dolphins were reclassified as not being fishes.

Another example is the atomic theory and in particular the law of definite proportions. This law entails that all elements have atomic weights which are integer multiples of the atomic unit, equivalent to the mass of a hydrogen atom. However, soon after the formulation (beginning of 19:th century) of this law it was found that the atomic weight of Chlorine is 35.5, in flat contradiction to the prediction. But the law of definite proportions was not given up; instead one guessed, correctly, that chlorine samples extracted from naturally existing compounds is a mixture of two isotopes, hence naturally existing chlorine is not really one single substance.

These are two examples of a possible and sometimes reasonable strategy, viz. to keep the regularity and redefine the criteria of application of the predicate in the antecedent. New counter examples might trigger new adjustments of criteria of application of predicates. The logical endpoint of this process is when the set of necessary conditions for applying the predicate in the consequent is a subset of those for the predicate in the antecedent; in such a case no further counter example is possible. We have arrived at a fundamental law, of which more later.

Inductive reasoning is intimately connected with theory development, but both inductivists and falsificationists have told a distorted story. The inductive process also involves concept development.

Inductive reasoning is our way of finding out the structure of the world. The success of empirical science and in particular the usefulness of induction is explained fundamentally in the same way as other evolutionary processes; it is the result of adaptation and competition, in this case adaptation of concepts to the way world is and competition among theories.

Fundamental laws as implicit definitions.

An example.

Consider the two fundamental dynamical laws of classical mechanics:

$$F = G\frac{m_1 m_2}{r^2}$$

F=ma

These contain four concepts; mass, distance, acceleration and force. Two of these, distance and acceleration, are kinematical and can be defined using observations of only one physical body. The other two, mass and force are dynamical, i.e., we use them for describing *interaction* between objects. Despite the fact that the mass unit is given by ostension, the dynamical meaning of mass, that it represents the inertia of a body (inertial mass) and its gravitational effects on other bodies (gravitational mass) are theoretical concepts. And it is Einstein great insight that these two concepts could be identified: inertia and gravitation are on close analysis the same thing, according to the general theory of relativity. Force, obviously, is a theoretical concept, used for describing interactions between bodies.

So we have two fundamental laws, and two theoretical concepts; clearly these laws together determine the value of both mass and force, when distance and acceleration is given. Hence we can view these laws as joint being *implicit definitions* of these two theoretical concepts.

Conclusion: At least some fundamental laws have a two-fold function: they introduce theoretical concepts and they are axioms in the theory.

The conceptual and the empirical aspect of these laws cannot be separated.

Tentative lesson: if we think that a science should try to emulate physics in discovering laws in its domain of application, we should put not forget that fundamental laws at the same time determine (some of) the concepts used in these laws. We cannot hope to arrive at a fruitful theory by first inventing concepts and then try to establish lawful connections between these concepts.