On the Cognition of Laws of Nature

Paul Weingartner, Salzburg

In this paper I shall discuss the problem of cognition of laws of nature on the following different levels of understanding:

First level of understanding of laws of nature: the Greek Ideal of Science

Second level: Space Time Invariance

Third level: Dynamical Laws

Fourth level: Statistical Laws

Fifth level: Laws and Causality

Sixth level: Chaotic Motion

Seventh level: Initial conditions and Constants of Nature

Before I shall begin with the first level of cognition or understanding a short clarification of different meanings of the expression 'law of nature' will be given:

L1 the "law" as it "is" in the thought of the inventor or discoverer

L2 the "law" as it "is" in the things which are ordered or described by it

L3 the "law" as a law statement formulated in some scientific language

L4 the "law" as an ideal true law, w.r.t. which laws known at present in the sense of L3 are approximations

L5 the "law" as ideal conceptual entity more or less independent and separated from law statements.

First Level: the Greek Ideal of Science

In order to be able to describe and explain movement we need to distinguish something which changes relative to something which does not change. This important distinction is pointed out by Aristotle also as a criticism of Parmenides' theory of the universe which assumes only one being and nothing else. That what changes, moves was thought to be contingent (not necessary) in respect to the not changing (or even not changeable) necessary principle or law. In general this idea belongs to the Greek Ideal of Science which was more or less manifest in several Greek thinkers from Thales on but was elaborated in detail by Plato and Aristotle:

To describe and explain the visible (observable), concrete, particular, changing, material contingent world by non-visible (non-observable) abstract, universal, non changing immaterial and necessary principles.

Second Level: Space Time Invariance

Whereas the first level of understanding a law is concerned with invariance in general the second level of understanding is concerned with finding out a specific kind of invariance. Among these the oldest and most famous one is the invariance w.r.t. space and time. Or in other words: the invariance under changes of place and time.

Third Level: Dynamical Laws

D1 the state of the physical system S at any given time t_i is a definite function of its state at an earlier time t_{i-1}. A unique earlier state (corresponding to a unique solution of the differential equation) leads under the time evolution to a unique final state (again corresponding to a unique solution of the equation).

D2 condition D1 is also satisfied for every part of the physical system, especially for every individual body (object) as part of the system even if the individual objects may differ in the classical or in the quantum mechanical sense.

D3 the physical system S is periodic, that is the state of S repeats itself after a finite period of time and continues to do so in the absence of external disturbing forces.

D4 the physical system S has a certain type of stability which obeys the following condition: Very small changes in the initial states, say within a neighbourhood distance of ε lead to proportionally small (no more than in accordance of linearly increasing function of time) changes $h(\varepsilon)$ in the final state. This kind of stability which survives small perturbations and leads to relaxation afterwards is called *perturbative stability* and holds in many linear systems.

Fourth Level: Statistical Laws

S1 the state of the physical system at t_i is not a definite function of an earlier state at t_{i-1} . The same initial state may lead to different successor states (branching).

S2 Statistical laws describe and predict the states of the whole physical system but they do not describe or predict the individual parts (objects) of this system.

S3 Statistical laws describe only physical systems which are non-periodic, i.e. systems with extremely un-probable recurrence of the whole state of the system.

S4 the loss of information (and consequently the difficulty of prediction) about the state of an individual object (or a small part) of the whole system increases exponentially with the complexity of the system. On the other hand: the (accuracy of the) information about the average values of magnitudes (parameters) of the state of an individual object (or small part) increases also with the complexity of the system.

Fifth Level: Laws and Causality

Causal condition for dynamical laws:

CD The same initial state leads – under the same conditions – to the same series of successor states.

Causal condition for statistical laws:

CS The same initial state may lead to different successor states. But those successor states which belong to the same initial state obey the same statistics.

Sixth Level: Chaotic Motion

The discovery of chaotic motion showed something new which was not understood in connection with laws of nature so far. It showed that initial conditions, boundary conditions or mathematical proportions are not necessarily accidental but can play an important role w.r.t. several properties of the laws. The new discovery was that even within the area of relatively simple physical systems which perfectly obey dynamical laws of Classical Mechanics, like the spherical pendulum, such systems can change radically its behaviour. Thus a dynamical system obeying Newton's laws with strict predictability can become chaotic in its behaviour and practically unpredictable just by changing slightly some initial conditions. Experiments which prove such a behaviour of dynamical systems have been made since the seventies.

Seventh Level: Initial Conditions and Constants of Nature

The understanding of what a law is depends on the distinction between laws and initial conditions. This goes back to the Greeks (see first level of understanding). The deeper problems of such a distinction are very well described by the following quotations of Wigner and Wheeler (Wigner (1967), 3; Milne (1948), 4):

> "The world is very complicated and it is clearly impossible for the human mind to understand it completely. Man has therefore devised an artifice which permits the complicated nature of the world to be blamed on something which is called accidental and thus permits him to abstract a domain in which simple laws can be found. The complications are called initial conditions; the domains of regularities, laws of nature. … The artificial nature of the division of information into "initial conditions" and "laws of nature" is perhaps most evident in the realm of cosmology. Equations of motion which purport to be able to predict the future of a universe form an arbitrary present state clearly cannot have an empirical basis. It is, in fact, impossible to adduce reasons against the assumption that the laws of nature would be different even in small domains if the universe had a radically different structure."