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Why do we need theories?

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ABSTRACT

Theories organize knowledge and construct objectivity by framing observations and experiments. The elaboration of theoretical principles is examined in the light of the rich interactions between physics and mathematics. These two disciplines share common principles of construction of concepts and of the proper objects of inquiry. Theory construction in physics relies on mathematical symmetries that preserve the key invariants observed and proposed by such theory; these invariants buttress the idea that the objects of physics are generic and thus interchangeable and they move along specific trajectories which are uniquely determined, in classical and relativistic physics.

In contrast to physics, biology is a historical science that centers on the changes that organisms experience while undergoing ontogenesis and phylogenesis. Biological objects, namely organisms, are not generic but specific; they are individuals. The incessant changes they undergo represent the breaking of symmetries, and thus the opposite of symmetry conservation, a central component of physical theories. This instability corresponds to the changes of the environment and the phenotypes.

Inspired by Galileo's principle of inertia, the "default state" of inert matter, we propose a "default state" for biological dynamics following Darwin's first principle, "descent with modification" that we transform into "proliferation with variation and motility" as a property that spans life, including cells in an organism. These dissimilarities between theories of the inert and of biology also apply to causality: biological causality is to be understood in relation to the distinctive role that constraints assume in this discipline. Consequently, the notion of cause will be reframed in a context where constraints to activity are seen as the core component of biological analyses. Finally, we assert that the radical materiality of life rules out distinctions such as "software vs. hardware."

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"Nothing is more practical than a good theory"

attributed to Ludwig Boltzmann

1. Introduction

Broadly speaking, the aim of science is to improve our understanding of nature. Scientists seek this knowledge for its own sake and also for guiding us to act responsibly when using this knowledge. Given that the scientist does not have direct access to the world outside her and because the consequences of action are far from obvious, these are not easy tasks. Centuries ago the founders of mechanics were strongly committed to Christian faith, and thus circumvented this problem by believing and asserting that the infinite goodness and perfection of God justified the agreement between their theoretical reasoning, and the phenomena observed by them (Cottingham, 2013). In other words, since God does not intend to deceive us, we, as Her creatures, can trust our own senses and rationality. Moreover, God could be viewed as a legislator both of nature and of human activities; thus, the notion of "law" could be extended from divine will and human societies, to the dynamics of nature. In the last 150 years scientists stopped relying on religion as a means to determine objectivity. Darwin's book "The origin of species" was a main contributor to this profound change in philosophical stance in science. From our perspective, this modern viewpoint implies that scientific objectivity should be conceived of as constructed by a human activity.

In spite of Descartes' Meditations, both physicists of yore and todays' practitioners put forward ideas and methods that are counterintuitive and usually contrary to common sense (Bachelard, 2002; Wolpert, 1994). The frame of reference we use as scientists is thus different than the one we all use in everyday situations, for example when we talk about "sunrise" and "sunset". Remarkably, common sense notions are useful in our everyday lives; this is probably why we still talk about the sunrise today, half a millennium after Copernicus proposed the notion of a heliocentric planetary system, a notion we are exposed to from childhood. This example also illustrates why the naïve perception that facts exist independent of any reference frame is incorrect. There is no observation devoid of theoretical content; sunrise and sunset refer to the sun rotating around the earth as in Ptolemy's theory. As put by the philosopher DC Dennett: "There is no such thing as philosophy-free science; there is only science whose philosophical baggage is taken on board without examination" (Dennett, 1995).

Scientists purposely suspend the common sense world view used by all in our everyday life when constructing theories and contrasting them with experiments. Scientific theories provide organizing principles and construct objectivity by framing observations and experiments. Even research performed within the frame of one "wrong" theory sooner or later will result in the demise of such a theory, thus advancing our knowledge. This goes with one caveat, that the theory in question has to have clear enunciates that allow their demise by both theoretical and experimental considerations.

Physics provides the best example of why theory is central to the success of a scientific discipline. It also provides examples of how "wrong" theories such as the "luminiferous ether theory" which was conceived to explain the propagation of light, was useful in framing observations. A comment by H. Poincaré, published before the dismissal of the ether theory illustrates the role of theories: "Whether the ether exists or not matters little - let us leave that to the metaphysicians; what is essential for us is, that everything happens as if it existed, and that this hypothesis is found to be suitable for the explanation of phenomena. After all, have we any other reason for believing in the existence of material objects? That, too, is only a convenient hypothesis; only, it will never cease to be so, while some day, no doubt, the ether will be thrown aside as useless," (Poincaré, 1905). Indeed, the "luminiferous ether theory" ceased to be useful at the beginning of the 20th century. Light was found to have both wave and particle properties; particles do not need a medium to travel. Moreover, the speed of light was supposed to be set with respect to the ether, but instead it was shown to be always the same in the 'vacuum', whatever the viewpoint of the observer is. This finding paved the way to special relativity.

2. Principles of conceptual construction and principles of proof in Mathematics, Physics and Biology

A brief excursion into Mathematics may help to clarify some general ideas about the foundation of natural sciences. Euclid's work is a permanent blend between constructions and proofs: Euclid traces lines, constructs plane figures and, by means of rotations and translations, gives proofs. Logic is also crucial to proof, as exemplified by proofs "per absurdum". Euclid proposes mathematical structures, of which the main one is the line with no thickness. Then, he builds on these structures by tracing, intersecting, rotating and translating. By means of these transformations, composite mathematical structures are obtained.

For more than two millennia from Euclid to Grothendieck, the proposal of new concepts and structures as well as the singling out of *"principles"* for these constructions, was at the core of mathematical activity. The construction of concepts and structures is followed by the development of suitable *principles of proofs* by means of logic. The job of these principles is to preserve the "meaning" of structures along proofs. For example, deriving by "modus ponens" (if A, and "A implies B", then B) preserves the "sense" (or truth) of the assumptions being examined. In a sense, principles of proof are formal transformations that preserve the mathematical meaning as an invariant of the proof.[1]

The transfer of mathematical tools to another discipline should always take into consideration the origin and the constitutive dynamics of these tools. Specifically, these mathematical tools are far from neutral because they carry with them a specific organization of phenomena and a specific way of reasoning that cannot be separated (dissociated?) from them. Similarly, experimental tools such as sequencing techniques tend to force the search for answers to all kinds of biological questions in terms of sequences. Furthermore, animal models are far from neutral; S Gilbert discussed how the adoption of animal models that reproduce all year long in carefully controlled laboratory conditions obliterated the effects of the environment on the construction of the phenotype (Gilbert, 2005). This omission resulted on the adoption of the idea of a developmental "program" totally contained in the genome. "Modern" biologists became oblivious to the previously entrenched notion that the environment plays a major role on the determination of phenotypes. In fact, polyphenism (one genome, multiple phenotypes) was discovered well before genetics entered the biological scene (Weismann, 1875).

[1] The differences between principles of construction and of proof as well as those between generic and specific objects are discussed in detail elsewhere (Bailly and Longo, 2011; Longo and Montévil, 2014).