



Physics and Its “Metatheoretical Belt”

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Introduction

The prevalent social representations of physics associate this discipline with the *discovery* of some rather cryptic universal laws that are supposed to be governing nature. Physicists' professional activity is usually imagined –and consequently *portrayed* in mass media and social networks– as the design of (tremendously sophisticated) experiments with the subsequent construction of abstract, counterintuitive theories (see these common-sense representations on physics discussed and confronted in Tahp [1], and Ramos Guasca [2]). Laypeople firmly believe in the declared aim of physics to *understand* the material world at all its scales without any ulterior social, economic or political motivations (a sort of *scientia gratia scientiae* where physicists just work for the thrill of knowing). Physics is also almost invariably looked up as a tough school subject, reserved to a minority of (white, male, middle-class) “illuminati” who have the desire to participate in its formalist games and are brilliant enough to join them.

Yet, the community of researchers in physics engages in a much broader, and more intricate, intellectual and social enterprise that extends beyond the limits of the direct and indirect study of the so-called *physical* phenomena –those that are “thinkable” with the concepts of matter and energy. For instance, besides the intimate connection of physics with the design of advanced technology, the field has always been busy with questions pertaining to *ontology* (the examination of the very nature of the objects existing in the universe), *metaphysics* (the study of problems that seem to lie just outside the reach of empirical investigation), and *ethics* (the concern for deeply transcendental moral, normative and behavioral issues).

In addition to these rather strange endeavors, a number of professional physicists also systematically contribute –either part-

time or, in some cases, full-time– to three prestigious scholarly domains closely related to “pure” physics –domains that can be located at its disciplinary “belt” [2,3]. These are the *philosophy of physics*, the *history of physics* and the *didactics of physics* (often called “physics education research”, or PER). Together, these three fields deepen our understanding of the physical theories themselves, and of how these are (and should be) interpreted by practitioners, how they relate to real phenomena, how they have emerged and evolved historically, and how they can be more effectively taught and learned in the different educational levels.

Argument

Philosophy of physics (see, for instance, Crease, [4]) stabilized as an independent discipline alongside, and *probably due to*, the great changes in physics in the 1930s; it strives, with a wide variety of aims, to organize and critique the conceptual foundations of the discipline. The philosophy of physics deals with classical *interpretative* questions that arise during the production of physics theory, and poses new questions that are deemed to be important for the sane development of the field. While for centuries academics with a background in philosophy were, from the other side of the fence, traditionally appointed to analyze a number of issues concerning the nature of physics –many times with scarce formal training in the subject–, in our days, career physicists more and more often reclaim for themselves a central role in such kind of work, because they possess, as a *boundary* condition, the technical expertise required to engage with the concepts, mathematical tools and empirical support belonging with modern physics theories. The treatment of questions about the “predication” of classical and quantum mechanics, the nature of spacetime in relativity theory, the interpretation of probability

in statistical mechanics, or the status of Noetherian symmetries in field theory require sophisticated physics knowledge to sustain good-quality philosophical reasoning. Physicists working in the specific philosophy of their discipline analyze the assumptions embedded in theories, elucidate concepts, unravel puzzles and paradoxes, and assess competing interpretations. Their contributions are expected to help illuminate what physics explanations actually *mean* about the world, how scientific models function in practice, and what the reach and limits of physicists' assertions and predictions may be.

A second discipline, which has always been closely related to the previous one, is history of physics (see, for instance, Evangelisti [5]), a professional field that is probably recognizable as such from the periods immediately preceding or following World War 2. Historians of physics investigate how terms, models, interventions and institutions in the discipline have developed and transformed over the centuries. There exist trained physicists who are drawn to historical research because they expect that knowing the *evolution* of theories will shed light on present problems concerning the production and communication of physics. Studying the development of mechanics, optics, thermodynamics, special relativity or solid-state physics, among other chapters of physics, reveals how scientific concepts change, how experimental practices *modulate* theoretical work, and how scientific communities respond to what Thomas Kuhn (himself a physicist turned into a philosopher and historian of science) construed as anomalies and *paradigm shifts* [6]. Physicists who engage in historical scholarship frequently disinter seminal papers, laboratory notebooks and correspondence between scientists that will work as raw materials for their rational reconstructions of the work done by their predecessors. Their task involves reconstructing arguments from the past in order to ascertain how earlier scientists understood each other's work. The history of physics as a scientific discipline has in its turn evolved in time –from chronicling admired discoveries to studying scientific reasoning, discourse and practice in *context*.

The third discipline in the belt of physics is didactics of physics (see, for instance, Ješková & Hanc [7]), or physics education (research), as it is usually named in Anglo-Saxon academia. Didactics of physics, born in the 1970s, is much younger than its sister disciplines; its inaugural aim was to understand how students of different ages and in different settings (can) learn the models of physics. This field builds theories on innovative teaching methodologies that can serve the imperative of *physics literacy for all*. Physicists working in didactics of physics combine their background in the discipline with other fields such as cognitive science, educational research, linguistics and anthropology to investigate how learners develop their conceptual understandings of the physical principles included in the curriculum. Foundational didactical studies revealed that students bring into the classroom scientifically incorrect, yet very much rooted and valued, ideas

about motion, current, force, temperature, energy, etc. Results of careful intervention followed by critical assessment help researchers in didactics design instructional materials, teaching strategies, and even programs and curricula that would help children, adolescents and young people build school scientific models [8] that are much more adjusted to the knowledge established in the physics community. Large and ambitious innovation projects in didactics of physics have influenced physics education worldwide.

At first sight, philosophy, history and didactics of physics might appear very distinct in concepts and methods from one another and from mainstream physics research. But the former three are strongly cohered together by the fact that they all exhibit a strong *metatheoretical* nature, i.e., they establish their theoretical discourse on physics as a product and as a process (this is why we could talk about the existence of a genuine “metatheoretical belt” around physics). In turn, these three *meta-disciplines* are firmly bonded to physics as follows. Although their main objects of analysis –the function and validity, historical evolution and teaching of physics ideas– are located in the cultural realm, these appear interconnected with the material objects studied by physics through physicists' *theory-ladenness* of their own concepts and interventions [9]. Objects in philosophy, history and didactics are mental, social or linguistic, but it is by means of them that the pieces of material world reclaimed by physics as units of analysis are scientifically constructed. Philosophical enquiry on scientific theories, historical studies of communities of practice, and educational research concerning science teaching result in *validated knowledge* that can shape the work of the new generations of physicists (and of course of citizens).

It is not uncommon that physicists who contribute to these three academic areas can move between them and back into physics; this eloquently shows that understanding the world around us requires more than producing original scientific results –it almost unavoidably involves decodifying, contextualizing and disseminating those results. The participation of physicists in the metatheoretical belt of physics and, more broadly, in research of multi-, or even inter-, disciplinary character highlights an important feature of the practice of science: that it is a *self-reflecting activity*. The praxis of theoretical calculation and experimental measurement should be accompanied by consistently pondering their meanings, methods, origins and pedagogies. Physicists who actively engage in conceptualization, historization and education are contributing to a richer and more overarching understanding of their discipline. This more open perspective on the production of physics that is presented here has the capacity not only to strengthen its magnificent intellectual edifice, but also to assist to its progress as a socially valuable enterprise.

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