Preface: Virtual Entities in Science

Robert Harlander (RWTH Aachen University), Jean-Philippe Martinez (RWTH Aachen University), Friedrich Steinle (Technische Universität Berlin), Adrian Wüthrich (Technische Universität Berlin)

Preface: Virtual Entities in Science

Not only since the sudden increase of online communication due to the COVID-19 situation has the concept of the "virtual" made its way into everyday language. In this context, it mostly denotes a digital substitute of a real object or process. *Virtual reality* is perhaps the best-known term in this respect. With these digital connotations, "virtuality" has been used also in science and research: Chemists use virtual laboratories, biologists do virtual scanning of molecular structures, and geologists engage in virtual field trips. But the concept of the "virtual" has a much longer tradition, dating back to long before the dawn of the digital age. Virtual images and virtual displacements were introduced in classical physics already in the late 17th and 18th centuries, respectively. They represent auxiliary objects or processes without instantiation, with the purpose of efficiently describing specific physical systems. In today's physics, the term *virtual* is mostly associated with the quantum world, first and foremost with the "virtual particle" of quantum field theory. It has become such an integral part of modern high energy physics that its ontological character may be considered to go beyond the purely auxiliary, which is typically associated with the virtual.

In other disciplines, however, use of the term *virtual* without a digital connotation is much rarer. While concepts like "virtual adrenaline" show up in physiological research around 1940s, and Charles Darwin, in a private note in

January 1840[1], spoke of “virtual change” in the context of embryology, these examples seem to be rather singular occurrences of entities that were explicitly called “virtual.” The basic idea behind the terminology of the virtual, however, might be much more common, even outside of physics. The “invisible hand” in economics, or the “vital force” in biology, for instance, may carry aspects of a virtual entity, even if they have not been called that way.

These different observations raise several questions about the status of virtual entities in science. What has led scientists to call one entity "virtual" and not another? Do all virtual entities in science have the same roots and meet the same characteristics? Are they more than auxiliary objects or processes? Why does physics seem to occupy a specific position with respect to the use of the notion of virtuality? These are some points that led us to discuss virtual entities in science during a workshop, out of which grew the present collection. We invited contributions that addressed the historical formation and philosophical interpretation of concepts of virtual entities in physics and other disciplines—in whatever terms they may come. The main goal of the workshop was to bring to the fore similarities and differences in the meanings and functions of these concepts, so as to be able to precisely characterize why certain entities are considered virtual in specific contexts,

[1] https://cudl.lib.cam.ac.uk/view/MS-DAR-00205-00006/24 (accessed January 3, 2023)

why a different terminology was often used in each individual case, and in what sense the virtual entities relate to the real world.

The organization of the workshop was part of our project “The formation and development of the concept of virtual particles,” a subproject of the Research Unit “The Epistemology of the Large Hadron Collider,” funded by the *Deutsche Forschungsgemeinschaft (DFG)* and *Der Wissenschaftsfonds (FWF)*. The workshop took place online on four consecutive Fridays in March 2021. It brought together contributors who discussed the role of the concept of the virtual in theoretical as well as experimental activities, and investigated into the origins of the terminology of the virtual as it was applied to the various disciplines of natural science. Dealing with historical, philosophical, but also methodological questions, the presentations covered a wide time scale, from the Middle Ages to the present day, and while physics naturally emerged as the dominant field, natural philosophy, computer science and biology were also addressed. The papers in this volume were contributed by participants in this workshop and approach the subject from different angles.

First, **Friedrich Steinle** (Technische Universität Berlin) provides us with an introductory piece that reflects on the specific meaning of the use of the term ‘virtual’ in science. He highlights and contextualizes Charles Sanders Peirce's 1902 contribution, which has become a reference for many scientific uses, past and recent. Steinle details Peirce's sharp thinking, which draws on contrasting views of the ‘nature’ and ‘efficacy’ of a thing, as well as virtuality and potentiality to defend an approach in which “the virtual entities are considered or imagined to have certain effects, while the entities themselves were clearly not present.”

Markus Ehberger (Technische Universität Berlin), drawing on his own experience in investigating the formation and development of the concept of virtual particle, makes a proposal on how to study virtual entities historically. He argues “for conceiving of concepts as tools embedded in historically situated constellations and practices, which in turn means that their application, fruitfulness, and epistemic power depends on the framework in which they are put to use.” In this sense, Ehberger invites historians “to shift their attention from the characteristics of virtual entities to their functions and the way in which their representations are put to use.” For him, looking at virtual entities through the lenses of practice and representations could help find conceptual overlaps through the role they play in the reasoning process, and thus improve our understanding of the class of virtual entities in science.

In her contribution, **Arianna Borrelli** (Leuphana Universität Lüneburg) discusses the complex premises underlying the distinction between real and virtual images in the early modern period. Reassessing in particular the optical work of Johannes Kepler, among others, she demonstrates that this period was characterized by a transformation of the notion of image, which was detached from sensual perception. The distinction real/virtual image appeared from then on as “an expression of the multiple tensions between geometrical-optical constructions and experiences of vision.” More specifically, this distinction implies a reference to visual perception which, while unnecessary to the practice of geometrical optics, proved somewhat useful as a means of introducing the geometrical notion of image to young students and a wider audience. Ultimately, as Borrelli asserts, the virtual image bridges the gap between geometrical optical constructions and visual experience, allowing for the “eye [to] stay in the picture.”

Alexander Blum (Max Planck Institute für Wissenschaftsgeschichte) and **Martin Jähnert** (Technische Universität Berlin) in their joint paper develop historical reflections on virtual entities before quantum field theory. More precisely, they discuss the 1924 theory of electromagnetic radiation by Niels Bohr, Hendrik Kramers, and John C. Slater, commonly known as the BKS theory. With the introduction of the concepts of ‘virtual oscillators’ and ‘virtual radiation field,’ this theory represents the first significant use of the term *virtual* in 20th century physics. Blum and Jähnert claim that these concepts made it possible to "provide a detailed dynamical picture of the radiation process and energy transfer, without running afoul of the less and less negotiable need for fundamental discontinuity." As a result of this analysis, they argue that the virtualization undertaken in the BKS theory provided "far more than a fancy name for a hypothetical entity," but actually helped to "succinctly describ[e] the separation of (quantum) effect from (classical) essence." For them, it was first and foremost the symptom of a tension, that of an unsolved conceptual problem in Bohr atomic theory, namely the introduction a coupling mechanism between distant atoms through radiation.

As a direct follow up, the meaning of the notion of virtuality in modern particle physics is explored by **Jean-Philippe Martinez** (RWTH Aachen University). His contribution develops considerations on the introduction and establishment in nuclear physics of two independent concepts at the turn of the 1920s and 1930s, for which the BKS theory, he claims, may have served as an inspiration: that of 'virtual state,' used in the context of neutron scattering studies, and that of 'virtual transition,' useful for the theoretical understanding of strong nuclear forces, which is the basis of what we call today virtual particles. The comparative analysis of the historical developments of these concepts, still relevant in present-day physics, highlights the theoretical nature of virtual entities and processes in modern physics. In his approach, Martinez also exposes how, in the course of their application, virtual entities and processes of modern physics have been endowed with physical characteristics, which has tended to give the notion of virtuality a form of polysemy. This ultimately allows him to defend that “virtual entities and processes cannot be characterized by certain necessary and sufficient physical conditions.”

Joseph Wilson (University of Toronto) in his paper analyses the early use of the terms *virtual* and *artificial* in post-WW2 computer science. He argues that they helped people conceptualize the immaterial operations unfolding inside computers, “as part of the ‘vocabulary searching’ phase of the burgeoning field of computer science where new concepts were debated in the scientific community through a shifting set of metaphors and words borrowed from adjacent fields like psychology or physics.” Metaphors play a central role in Wilson’s contributions, since “tracing the metaphorical roots of arguments laid out in the scientific literature of the time we can uncover the relationships between our scientific models and our cultural models.” This allows us finally to understand the strategies used by scientists to give meaning to immaterial and abstract concepts. The virtual world of computer science is thus presented as a new ontological reality to think and play with. As Wilson argues, virtual objects on the screen “serve as emissaries between the real world and the artificial one emerging from the depths of the machine.”

Finally, in their joint contribution, **Daphne Broeks** (Radboud University), **Tarja Knuuttila** (Universität Wien), and **Henk de Regt** (Radboud University) examine how scientific understanding is enhanced by virtual entities, focusing on the case of the synthetic cell, the construction from biological components of a living cell. Although the synthetic cell is not currently described as "virtual," they argue that it has a virtual dimension, "in that it is functionally similar to living cells, though it does not mimic any particular naturally evolved cell (nor it is constructed to do so)." Broeks, Knuuttila, and de Regt thus clarify that synthetic cells possess some of the effectiveness of naturally evolved cells, which is crucial to the scientific understanding they provide of living cells. On this basis, the authors then extend their considerations to other fields and defend that virtuality in science is a route to understanding reality. For them, it allows epistemic access "to complex reality by reducing complexity and enhancing intelligibility, also offering possibilities for intervention by representational, experimental and technological means."

As an attempt to get an overview of the role played by the notion of virtuality in science, focusing on a number of virtual entities appearing in different contexts, this special issue allows us to sketch some common features of its application. Of course, as Steinle's introductory piece suggests, Peirce's approach to the notion of virtuality proves to be predominant in most authors' discussions. With it, the idea of efficiency of virtual entities appears as their main essential characteristic. Different in nature from the entities with which they are associated with, virtual entities nevertheless manage to mimic some of their roles and functions. This collection of articles also gives important clues about the specific context in which they arise. It is striking here that Borrelli, as well as Blum and Jähnert, have both emphasized in their work that virtual images and virtual oscillators were the expression or symptom of tensions in their respective fields of introduction. This approach can naturally be extended to the emergence of the concept of "virtual transitions," discussed by Martinez, forged between classical and quantum physics, as well as to the challenge of making sense of immaterial and abstract concepts in computer science, presented by Wilson. In the end, all the articles gathered here present virtuality as a deeply useful and valuable notion for the needs of scientific practices. Whether it is distinguished by its pedagogical value (Borrelli), its capacity to describe phenomena (Blum and Jähnert, Martinez), to give meaning to abstract concepts (Wilson), or to provide epistemic access to complex systems (Broeks, Knuuttila, and de Regt), virtuality is a powerful tool for scientists. For all these reasons, Ehberger's proposal to shift attention from the characteristics of virtual entities to their functions during their study is highly meaningful.

Given the limitations of a single volume on the topic, it is obvious that many questions remain open, and that its temporal and disciplinary extension are necessarily incomplete. Perhaps the most important missing aspect is Early Modern statics and classical mechanics, fields in which uses of "virtual" had been introduced early on.[2] Besides, possible future editions should include reflections on the medieval scholastic philosophy, for example, and extend to other scientific fields. Similarly, further research could provide hints about the prevalence of the term *virtual* in physics and how it has actually spread over time and across disciplines. In addition, the complex relationship between virtuality and reality would deserve a detailed discussion. We hope this special issue will open perspectives that can serve as a basis for a more systematic analysis of the historical and philosophical implications of the notion of virtuality in science.

As editors, we would like to thank all authors for their time and effort in preparing their contributions, and to express our gratitude to all those who have participated in this volume, directly or indirectly, as speakers and discussants during the workshop, or referees for the individual articles.

[2] The interested reader is invited to turn to the following literature on the concept of virtual work and on statics: Capecchi (2012); Renn and Damerow (2012); Goulding (2022).

References

Capecchi, Danilo. 2012. *History of Virtual Work Laws. A History of Mechanics Prospective*. Science Networks. Historical Studies 42. Basel: Birkhäuser.

Goulding, Robert. 2022. “The Harvest of Optics: Descartes, Mydorge, and Their Paths to a Theory of Refraction.” *Annals of Science* 79(2):164–214.

Renn, Jürgen, and Peter Damerow. 2012. *The Equilibrium Controversy: Guidobaldo Del Monte’s Critical Notes on the Mechanics of Jordanus and Benedetti and Their Historical and Conceptual Backgrounds*. Berlin: Edition Open Access.