Scientonomy

The Challenges of Constructing a Theory of Scientific Change

Edited by

Hakob Barseghyan, Paul Patton, Gregory Rupik, & Jamie Shaw

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Hasok Chang is the Hans Rausing Professor of history and philosophy of science at the University of Cambridge. He received his degrees from Caltech and Stanford and has taught at University College London. He is the author of *Is Water H2O? Evidence, Realism and Pluralism* (2012), and *Inventing Temperature: Measurement and Scientific Progress* (2004). He is a co-founder of the Society for Philosophy of Science in Practice (SPSP) and the Committee for Integrated History and Philosophy of Science.

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Deivide Garcia is an Adjunct Professor at the Federal University of Recôncavo da Bahia, where he completed his Master's and PhD in Teaching, Philosophy and History of Sciences. He did his Post-doctorate at York University. He also holds a Master's degree in Logic and Philosophy of Science from the Universidad de Valladolid. His research focuses on scientific pluralism and scientific experience in Feyerabend's philosophy, which often gives support to his other interests, such as history and philosophy in evolutionary theory, Galileo's methodology, and science education.

Patrick Fraser is a graduate student in the Department of Philosophy at the University of Toronto. His research interests include logic, philosophy of physics, inter-theory relations (such as emergence and reduction), and the foundations of quantum mechanics and quantum gravity. In particular, he is interested in understanding how scientific representation and formal theorizing together yield coherent descriptions of physical reality across distinct regimes. He also studies inter-subjective and relational approaches to interpreting physical theories.

Tsung-Ren Huang is currently an Associate Professor in the Department of Psychology at National Taiwan University, Taiwan. His research interest lies at the intersection of psychology, neuroscience, and computer science. Specifically, he applies machine learning and AI techniques to discover regular patterns in the human brain, mind, and behavior, such as finding elements of attracted faces. He is also the current director of the Modeling and Informatics Laboratory at National Taiwan University.

Kye Palider has been a part of the scientonomy community since 2018 and is currently a graduate student at the University of Toronto. He has introduced epistemic reasons to the scientonomic ontology and has participated in the creation, development, and application of a diagrammatic notation for visualizing belief systems. His general interests lie in the philosophy of logic, formal epistemology, probability, pragmatism, and integrated history and philosophy of science.

Paul Patton holds a doctorate in neuroscience from the University of Chicago and has published research in perceptual neurobiology. Paul is currently a Research Fellow at Victoria College and a doctoral candidate at the Institute for History and Philosophy of Science and Technology, University of Toronto. His philosophical specialties are in the philosophy of perception, and in the philosophy of neuroscience, cognitive science, and biology, as well as in integrated HPS and scientific change. Paul is the co-editor in-chief of the online Encyclopedia of Scientonomy and an editor of Scientonomy journal.

Gregory Rupik is a doctoral candidate at the Institute for the History & Philosophy of Science and Technology at the University of Toronto. His academic research encompasses the history and philosophy of biology, exploring the remarkable similarity between the understanding of the organism which emerged from German biology at the turn of the 19^{th} century, and the understanding of the organism central to "Situated Darwinism" in contemporary philosophy of biology. Gregory is a founding member of the Scientonomy Community and is an editor of the journal *Scientonomy*.

William Rawleigh is a graduate student at the University of Toronto's Faculty of Information. His past research has focused on the logic and semantics of science, with a particular focus on the semantic ontology inherent in the theory and practice of science as a whole enterprise. While he is still dedicated to the study of semantic ontologies, his present studies examine the intersection of semantic ontology and the social study of information with a particular eye towards how different semantic infrastructure influences the information practices of individual scientists. His own information practices are regularly disrupted by the urge to pet every dog he sees.

Ameer Sarwar is a graduate student in Neuroscience at the University of Oxford and completed his Honors BA and MA in Philosophy, both at the University of Toronto. He is interested in the intersection between biological sciences, especially neuroscience, development, and genetics, and philosophy, with a particular focus on empirical ("wet lab") research and philosophical reflection on its findings. He is also intrigued by attempts to formally model scientific phenomena and generate testable predictions.

Jamie Shaw is a SSHRC-sponsored postdoctoral fellow at the University of Toronto. He completed his PhD in 2018, under the supervision of Kathleen Okruhlik at the University of Western Ontario, with the dissertation entitled "A Pluralism Worth Having: Feyerabend's Well-Ordered Science". His primary research focuses on science funding policy and its relationship to debates on scientific rationality. This often borrows from his research on Feyerabend and pluralism. He is the editor of a collected volume on Feyerabend, entitled *Interpreting Feyerabend: Critical Essays*, and is an editor of Scientonomy journal.

David J. Stump is an Emeritus Professor of philosophy at the University of San Francisco. Educated at the University of California and Northwestern University, he is the author of *Conceptual Change and the Philosophy of Science* and co-translator of a new version of Henri Poincaré's *Science and Hypothesis*. He is also co-editor, with Peter Galison, of *The Disunity of Science*, and is author of numerous journal articles on Poincaré, Duhem, the history and philosophy of mathematics, and general philosophy of science. He is president of HOPOS, the International Society for the History of the Philosophy of Science.

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Introduction

Gregory Rupik, Hakob Barseghyan, Paul Patton, & Jamie Shaw

University of Toronto

Over the last half-century, the contributions of historians, philosophers, sociologists, and anthropologists have produced a richer, more complex portrait of science, its past, and its transformations than was once appreciated. This more comprehensive understanding of science and its dynamics has thrown the inadequacies of past theories of scientific change, like those proposed by Fleck, Kuhn, Lakatos, and Laudan, and earlier by the logical positivists, into stark relief. Many of these theories aimed not only to account for scientific change across diverse contexts, but – by clarifying the mechanism of this change – to illuminate how science *ought* to change. While the classic theories of the logical positivists envisaged a mechanism of scientific change driven by a transhistorical scientific method, the richer portrait of science emerging from subsequent and ongoing work evinces that no single method exists. Rather, there seem to be myriad methods employed across the sciences and their histories. This presents an intimidating challenge facing anyone who attempts to construct a comprehensive theory of scientific change today: to account for the diversity and change of scientific theories as well as the diversity and change of these scientific methods.

The challenges facing any prospective theoretician of scientific change do not stop at the dynamic and diverse methods of sciences. For instance, if the means by which scientific communities assess rival scientific theories are diverse and change through time, it becomes less straightforward how the descriptive project of understanding science's changes can inform a normative project of how science *ought* to change, or if it should at all (Rupik 2019). Our growing appreciation for science's variety, social nature, and transformations task theoreticians to confront a number of claims. These include the claim that there may be nothing stable and common among the sciences or scientific changes, that there may be nothing that distinguishes scientific changes from other types of change in society, or that attempts to construct a theory of scientific change are doomed given the track-record of previous attempts (Barseghyan 2015, 81-97). Indeed, the same historical, sociological, and anthropological research that has empirically enriched our image of science can be used to render the very category of “science” so capacious as to be meaningless.

For a growing number of scholars, however, these challenges are not insuperable ones. They see an opportunity to construct a more nuanced theory of scientific change that draws lessons from the failures of past attempts, and fundamentally embraces today’s empirically enriched portrait of science (Barseghyan, 2015; Scholl & Räz, 2016; Rupik, 2019). There is a commitment to integrate the history and philosophy of science in this endeavor (Integrated HPS, iHPS, &HPS; see Herring et al. (Eds.), 2019), enacting a more “naturalistic turn” wherein “*matters of fact* are as relevant to philosophical theory as they are relevant in science” (Callebaut, 1993, p. 1). It was only by considering the wealth of information now available about science’s history and practice, for instance, that members of the Scientonomy Community recognized regular patterns in the change of theories, methods, and questions that would form the basis of their own theorization. While this volume will not recapitulate these historical developments here, they were a crucial impetus towards taking the idea of a general theory of scientific change seriously again.

The Scientonomy Community formed in Toronto in 2015 with the goal of refining and further developing a theory of scientific change first proposed in Hakob Barseghyan’s *The Laws of Scientific Change* (2015). By setting their sights on the transformations of epistemic agents’ theories, questions, and *methods*, they claim to have identified law-like patterns that appear to be common across time periods and fields of inquiry. The precise content and scope of these patterns is constantly in flux as conjectures about the laws of scientific change are evaluated on the basis of historical data and theoretical considerations. The theory aims to be descriptive, not normative, articulating the *nomic* regularities that emerge when researchers consider mosaics as their objects of study. Considering scientonomy a “science of science” has allowed the community to articulate how it has embraced the “naturalistic turn” in philosophy of science: the inseparability of theory and observation in the sciences drives the community’s commitment to explicitly weave the history and philosophy of science together as observational and theoretical scientonomy, respectively (Rupik 2019).

In addition to facing the challenges peculiar to constructing a theory *of scientific change*, the Scientonomy Community has also been confronted with the more generic challenges of constructing and refining *an empirical theory*. Confronted by diverse scientific practices across time and space, scientonomers have been compelled to adjust and expand their beliefs concerning the ontology of epistemic agents, elements, and stances, modify some of the key tenets of their theory, and thus undergo their own process of scientific change. To successfully do so, the Scientonomy Community has adopted strategies similar to those used in the natural sciences: it rebooted the project of constructing a general theory of scientific change by implementing a new digital workflow. This iterative, communal workflow publicly tracks developments in scientonomy and helps to guarantee cumulative knowledge production and progress. Two pieces of this workflow worth highlighting here are its online wiki-styled *Encyclopedia*, which documents the current state of scientonomic knowledge, and its online journal *Scientonomy*, whose peer-reviewed submissions make concrete suggestions for how current scientonomic theory can be modified. One motivation for establishing this iterative workflow was the realization that any theory of scientific change is as fallible as any other empirical theory and the best strategy – implemented differently by different sciences – is to work collectively on *piecemeal* and *transparent* advancement of our communal knowledge on scientific change. Implicit in this workflow is openness to new historical evidence concerning the dynamics of theories, questions, and methods and deep respect for critique. The community's workflow has already refined scientonomic theory's ontology and taxonomy, which may serve as the foundation for a future database of epistemic communities, their mosaics, and their historical transformations – provisionally named the *Tree of Knowledge Project*. These undertakings have revealed new challenges and opportunities for a science of science.

In this communal spirit, the Scientonomy Community convoked a conference entitled *The Challenges of Constructing a Theory of Scientific Change* in 2019. Ironically, despite the fact that the ultimate ambition of the Scientonomy community is an empirically adequate general theory of scientific change, the conference did not focus directly on assessing historical episodes. Although this would obviously be essential for any viable theory of scientific change, the primary concern of the papers presented was more theoretical – that is, discerning what promises and perils belie any attempt to construct a theory of scientific change. And while the program included explicit engagements with scientonomic theory, it importantly ranged well beyond uniquely scientonomic concerns. This volume collects the proceedings of this generative, collegial gathering.

Hasok Chang's contribution notes the importance of an ontology for empirical investigations of the process of scientific change, particularly those involving the analysis of large databases. He focuses on an area of the scientonomic ontology that has so far been neglected – the ontology of scientific practice. He notes that historians of science have often offered only an imprecise analysis of the scientific activities and offers some pointers toward a rigorous analysis of the activities that epistemic agents undertake during the production of knowledge.

Kye Palider tackles the thorny issue of the nature of integrated history and philosophy of science. He summarizes the extant literature as containing two approaches: the top-down approach, where philosophy informs history, and the bottom-up approach where history informs philosophy. Palider contends that neither of these approaches can survive on their own and must be synthesized into a broader account. Palider goes on the provide a way forward which integrates and corrects the top-down and bottom-up approaches into a coherent approach based on the notion of epistemic iterations.

Hakob Barseghyan and Jamie Shaw's paper discerns ways in which normative philosophical claims about science can benefit from history. The primary worry here has been that deriving philosophical *oughts* from historical facts would commit the naturalistic fallacy. They claim that by taking the descriptive findings of scientonomy and coupling them with additional normative premises, philosophers of science can draw normative methodological conclusions which can guide future scientific practices. The paper outlines a viable path for integrated history and philosophy of science that does not relinquish normativity and avoids the problem of cherry-picking which has plagued general accounts of science.

Karen Yan, Meng-Li Tsai, and Tsung-Ren Huang's contribution explores the relationship between scientonomy and scientometrics. The authors argue that given the vast volume of scientific literature currently being produced each year, the quantitative methods of scientometric analysis are needed to test hypotheses about the process of scientific change posited by scientonomy. As a test case, they offer an analysis of the literature concerning a physiological phenomenon called heart-rate variability.

Will Rawleigh's contribution critiques the current understanding of the scientific mosaic and its constituent theories. He notes the many problems of the syntactical view of theories as sets of propositions, which is currently held within scientonomy and introduces an alternative model-theoretic view. Based on this new view, he proposes a new formulation of the third law of scientific change.

Patrick Fraser's paper is part of a bold attempt to provide a formal framework to represent scientonomic claims about theory change. Specifically, Fraser models the mosaics of scientific communities as actual instantiations of possible worlds by using a semantic approach inspired by Kripke. This provides a way forward to a possible formalization of scientonomic knowledge.

Guillaume Dechauffour positions scientonomy within a broader scientific framework of evolutionary epistemology by linking the evolution of science with evolution in general and the evolution of philosophical systems. By doing so, he aims to dissolve the problem of scientific progress in favor of much less problematic idea of scientific evolution. The paper also highlights the role of evolutionary epistemology in understanding the initial conditions of scientific change.

Paul Patton's paper explores the entities and relations within the sociotechnical domain, i.e., between epistemic agents and their tools. By reviewing the current body of scientonomic literature, Patton offers a robust new alternative to the networks of practitioners view. The paper delineates the role of individual and communal epistemic agents and epistemic tools and posits two types of relationships: the relationship of authority delegation between epistemic agents, and the relationship of tool reliance between epistemic agents and epistemic tools.

Ameer Sarwar's paper argues that the intended object of study of scientonomy lacks specificity and outlines a general conception that can help with distinguishing the object of study from background noise. It differentiates between various perspectives, types of explanations, and levels of analysis when dealing with the object of study. The paper also notes that incorporating the technical apparatus of the general system theory into scientonomy can potentially offer us a radically different way of thinking about scientific change.

Deivide Garcia's essay opens a pandora's box by discussing the many ways in which pluralism may appear or present a challenge to the currently accepted theory of scientific change within the Scientonomy Community. Garcia seeks to answer two questions in particular. First, is the current theory of scientific change necessarily exclusive, or is it possible and/or desirable to have multiple theories of scientific change? Second, is the zeroth law, which states that at a given point of time all elements of a mosaic are mutually compatible, compatible with the history of science?

In their contribution, Jamie Shaw and Justin Donhauser argue that the current scientonomic ontology doesn't quite conform with historical advances in theoretical ecology and suggests a few revisions to the scientonomic ontology. By analyzing the development of Lotka-Volterra models, broken stick models, and exergy models, they refine the scientonomic category of use by drawing a distinction between two distinct types of *use* – *epistemic* and *practical* and provide additional support for the accepted definition of *theory acceptance*.

In David J. Stump's contribution, he tackles the historically dominant issue of radical theory change. Building off of the work of others, Stump defends a conception of the relative a priori where conceptual changes can be all-encompassing. Against some, though, Stump contends these changes can be rational. While Scientonomy is traditionally neutral with regards to whether changes between theories and methods are 'rational', Stump's chapter penetrates thorny issues about the historical rationales during episodes of radical theory change.

These contributions represent an invaluable set of first steps towards fully understanding the possibility of reigniting the bold historical pictures of science of the past. That being said, there are many limitations and many other sources – both historical and philosophical – that may be fruitfully used in future discussions. For example, further engagements with recent work on cognitive attitudes, philosophy of action, or with historically oriented philosophers of science from continental traditions, Indo-China, and Latin American scholars (to name a few) will surely increase the scope of issues to be brought to bear on the topics in these pages.

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Chapter 1

The Ontology of Scientific Practice

Hasok Chang

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Abstract: Any database project needs to be based on an ontology that is suitable for its subject matter. For the scientonomy project, it is important to conceive a good ontology of the human actions that constitute scientific practice, which allows rigorously conceived activity-based analyses of science. Mainstream philosophers of science have offered very precise analyses of scientific knowledge, but only in terms of beliefs and their assessments. Recent historians of science have been more attentive to the activities undertaken by scientists, but only offered imprecise analyses of them. Scientonomers have a chance to get the ontology right from this early stage of their enterprise. In this paper, I make some programmatic proposals on the ontology of scientific work, in terms of epistemic activities and systems of practice. I also offer a framework for conceptualizing epistemic agents, and some clues on the ontology of the processes of inquiry. Scientonomy as the general "science of science" should not have an overly limited ontology. In particular, I suggest that the "scientific mosaic" should include a diverse array of elements and consider other aspects of methodology in addition to theory assessment.

Keywords: scientific practice; pragmatism; epistemic activities; inquiry; knowing-how

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1. Initial Motivations

Any database requires an ontology, and *the Tree of Knowledge* project ("a comprehensive online database of intellectual history that will trace the evolution of human knowledge") proposed in scientonomy is no exception.[1]

[1] https://www.scientowiki.com/Tree_of_Knowledge_Project

The Tree is important, because without the historical database, the scientonomic laws of scientific change will remain untested conjectures (or even function as tautologies), which would mean that scientonomy cannot be a truly empirical discipline (see the papers in this collection by Deivide Garcia and Kye Palider for indications of the empirical nature of scientonomic work). Curiously, this practical need for ontology is not often appreciated by philosophers. I remember being delighted some years ago to meet a computer scientist whose business card declared that he was the "Chief Ontologist" for his company – I doubt that any metaphysicians carry such a job title! The scientonomy community has been keenly aware of the need for an ontology (Barseghyan, 2018).[2] And the push for diagrammatic representation of worldviews will also make visible the necessity to have the right kinds of ontological "boxes" to use (Barseghyan, Patton, & Shaw, in press).

My own appreciation of the need for ontology comes from the philosophy of scientific practice. Analytic philosophers have mostly worked with inadequate ontologies of knowledge, the knowing agents, and their experiences. A significant part of my work in the philosophy of science is an attempt to pay more attention to scientific practices, and for this task I need to craft an ontology of activities and agents, going well beyond the familiar ontology of propositions in epistemology and the philosophy of science. In this paper, I will give some indication of that ongoing work, highlighting aspects of it that are most relevant to scientonomy. In this enterprise, it is essential to maintain connections with work in the history of science, and there is a great need for conceptual discipline there. As Hakob Barseghyan and Jamie Shaw (2022, in this collection) have argued persuasively, much work in the history of science is still framed in quotidian common-sense terms, and most philosophy of science making reference to history fails to question these terms. These terms are undisciplined – ill-defined, and more vague and ambiguous than they need to be. Again, we need a good ontology with which to understand the goings-on in scientific work.

In relation to scientonomy, what I want to offer in this paper is a friendly critique, from the perspective of someone who has been trying to think carefully about the nature of the scientific practice. My main point is that scientonomy as the general "science of science" should not have an overly limited ontology. I think the "scientific mosaic" should include aspects other than theory and methodology. And methodology should address more than assessment. Also, stable configurations deserve as much attention as change.

[2] https://www.scientowiki.com/Ontology_of_Scientific_Change

2. Activity-Based Analysis

A serious study of scientific practice must be concerned with what it is that we actually do in scientific work (this spirit is exemplified in Yan, Tsai, & Huang, 2022, in this collection). This requires a change of focus from propositions to activities. Percy Bridgman, the American experimental physicist who became the unwitting originator of the philosophical doctrine of "operationalism", can serve as a useful initial inspiration (see Chang, 2019, for all quotations from Bridgman and the original citations). Bridgman advocated "an attitude or point of view generated by continued practice of operational analysis. So far as any dogma is involved here at all, it is merely the conviction that it is better, because it takes us further, to analyze into doings or happenings rather than into objects or entities". And an operational analysis was only "a particular case of an analysis in terms of activities – doings or happenings", instead of analysis "in terms of objects or static abstractions", or "in terms of things or static elements". So let us begin with the recognition that all scientific work, including pure theorizing, consists of actions – physical, mental, and "paper-and-pencil" operations, to put it in Bridgman's terms. Of course, all verbal descriptions we make of scientific work must be put into propositions, but we must avoid the mistake of only paying attention to the propositional aspects of the scientific actions. That is a sure path to disconnection from practice, and it is precisely the path that analytic philosophers on the whole have taken. What I am complaining about is our habit of focusing on descriptive statements that are either products or presuppositions of scientific work, and our commitment to solving problems by investigating the logical relationships between these statements.

This way of thinking recommends an analysis of scientific practice in terms of epistemic activities (in Chang, 2011a, with further elaborations in Chang, 2014). I will state more carefully below what exactly I mean by "epistemic activity", but I begin here with an intuitive presentation. The easiest first step we can take in moving toward the habit of activity-based analysis is a grammatical one: bring back the verbs into our descriptions. Try a simple linguistic trick of taking a common noun designating a standard philosophical topic and thinking about the verb form instead. So, take "representation" and think of it as "representing", as Hacking (1983) does; take "causation" and think of it as "causing", or "making things happen" as James Woodward (2003) does, or in terms of "hunting" and "using" causes as Nancy Cartwright (2007) does. Consider how different that feels already, with fresh philosophical questions bubbling up as a result of that simple change of viewpoint. When our thinking is structured around the active verbs, a whole range of questions regarding actions emerge naturally, almost without any effort: who is doing what, why, how, and in what context?

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