8

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Cosmologies Materialized: History of Science and History of Ideas

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For most historians of science trained in the past thirty years, doing history of science has meant avoiding the history of ideas. Our teachers warned us against traditional intellectual history's neglect of practice, material culture, and complex, pluralistic contexts in favor of artificially tidied, abstract systems of thought. The distrust may have been mutual. Despite the innovations in Dominick LaCapra's *Rethinking Intellectual History* (1983), none of its chapters addressed natural science. Unfortunately, the standoff between these fields has hidden the close relationship they previously enjoyed. Many of the works that defined early twentieth-century history of ideas took natural science as a central topic, and for the scholars who set the history of science on its feet in the 1940s and 1950s the two fields were nearly inseparable. The gap that has opened between them has made it hard to see in what ways the new history of science resembles the old—and why that might be a good thing.[1]

The split occurred in the 1970s and 1980s with the appearance of sociologically informed studies of laboratories and scientific controversies in their detailed historical settings. Among academic historians of science, biographies celebrating isolated geniuses who transcended their time and place have gone out of vogue. Equally absent from our accounts—or at least in abeyance—are the normative preoccupations that had guided many earlier histories. Our case studies no longer aim to demonstrate the emergence of a universal rationality overcoming obstacles, or the progress of scientific thought toward certainty. As Steven Shapin, a scout of "the social turn," argues, historians' new focal points—the institutional basis and political economy of struggles between schools of thought, the precariousness of proof and replication, the historical variability of methods and standards of certainty, and the physical idiosyncrasies and frailty of researchers and their equipment—may be argument enough. These new interests have all contributed, however modestly, to "lowering the tone" in discussions of science, a goal he sees as a laudable realization of the historian's vocation: "to try to tell it as it really was in the past."[2]

Shapin offers an inclusive credo for today's historians of science: "[We] are telling stories—rich, detailed, and, we hope, accurate—about a tone-lowered, heterogeneous, historically situated, embodied, and thoroughly human set of practices."[3] Yet as suggested by a recent exchange over whether the affections of history of science ought to lie with sociologists or with philosophers, the split between history of science and history of ideas still rankles.[4] Some worry that the field has lost its critical edge by abandoning its role as epistemological tribunal; others fear a collapse into a morass of isolated case studies disconnected from broader narratives or explanatory aims.

This chapter insists, on the contrary, on the vitality of today's history of science. More counterintuitively, it suggests that some of its promise lies in its past: in its long-standing, underappreciated allegiance to the history of ideas. This alliance should be acknowledged and deepened. To this end, I undertake a review of the history of science's early, happy union with intellectual history—while making a distinction between Lovejoy's embracing, ecumenical approach and what I call the "neo-revolutionary" mode. I then present the developments that led to the apparent split between the fields, though the divorce was neither so thorough nor so final as we have been warned. Although the narrative of modern science has been decentered, tilting away from an assumed unity of method and doctrine whose roots go back to Newton, one key aspect of traditional history of ideas has remained central: its interest in cosmological ideas.[5]

In the new approaches, scientific ideas have been materialized, while "science" has been disaggregated into a multiplicity of methods, styles, disciplinary arrangements, and practices. What is now required, I suggest, is a principled reassembly of these fragmentary shards, especially in the light of major reorientations in understandings of the origins and consequences of modern science. With the growing recognition that "Western science" emerged along with European nation-states and movements of exploration, trade, and conquest, scholars increasingly consider science's contents as well as its sense of itself as a distinct tradition to be inseparable from both internal politics and myriad engagements with other cultures. Further, the outsized impact of the sciences in the age of industrial technology and global capitalism has vertiginously intensified historians' understanding of science's role in "the construction of nature": scientifically informed industry has altered and destabilized processes of planetary equilibrium.

Reframing the history of science as the comparative study of materialized cosmologies—ideas of the order of nature that are enacted, embodied, elaborated, and contested in concrete settings, institutions, representations, instruments, and practices—helps us grapple with science's culturally hybrid and stratified past, as well as with its profound and growing impact on the earth. These pressures make the history of science an exceptionally fruitful and necessary perspective from which to trace the roots of today's global condition.

Eclectic Lovejoy and the Neo-revolutionaries

From its first issues in the early 1940s, the *Journal of the History of Ideas* under Lovejoy's editorship displayed a persistent interest in scientific ideas and their connections to wider intellectual patterns. Readers encountered articles on Ficino's astrology, Darwin's effect on American theology, Boyle's alchemy, and Pascal's liberalism. It featured authors who demonstrated the variety and richness of Western knowledge traditions in studies of magic, the poetics of mountains and moon voyages, and the fate of evolutionary thought.[6]

The field's wide compass was nowhere more apparent than in Lovejoy's own highly readable—suspenseful, even!—*Great Chain of Being* (1936), which followed a single "unit-idea" through metaphysics, theology, astronomy, and natural history over twenty-three centuries.[7] Understandings of the Great Chain—a hierarchical continuum joining the lowliest of worldly entities up to God—shifted depending on whether it was allied with the notion of an otherworldly, self-sufficient deity, or with an overflowing creator expressing his perfection through incessant creation. Touching upon poetry, politics, and landscape gardening, Lovejoy followed the shifting combinations of three notions—gradation, continuity, and plenitude—with a range of "dialectical motives" and forms of "metaphysical pathos." According to Lovejoy, the fate of the Great Chain was tied up with the assumption of a rational and knowable plan of nature. Its ultimate failure—signaled by romanticism's embrace of irrationality and nationalism's championing of individual identity—prepared the impasse faced by Western thought at the start of World War II.[8]

The Great Chain revealed that Lovejoy's true obsession, despite his declared interest in "unit-ideas," was large-scale, synchronic ensembles of ideas—cosmologies or worldviews—and their modifications over time. This preoccupation ran through early twentieth-century history of ideas. Ernst Cassirer's philosophy of symbolic forms—forged in contemplation of Aby Warburg's collection of the products of the human mind—connected mythical, expressive systems of thought to empirical knowledge and mathematical methods from the Renaissance to relativity.[9] Under the influence of Hegel, Oxford philosopher R. G. Collingwood presented actors' ideas as historical driving forces: his *Idea of Nature*, posthumously published in 1945, concisely expounded a series of conceptions of the cosmos from the pre-Socratics to Henri Bergson, ending at the "modern" view of nature as an organic and historical process. Romanticism was also an inflection point for Alfred North Whitehead—one of Lovejoy's mentors—whose *Science and the Modern World* (1925) depicted "the romantic reaction" as a sane, holistic response to the seventeenth century's reduction of nature to primary qualities and mechanisms—a view he expanded in *Process and Reality* and *Adventures in Ideas* into his own organic cosmology.[10] These authors' engagement with organicism testifies to their debt to Bergson and romanticism.

Those influences were largely undetectable among the scholars responsible for establishing the discipline of history of science in the United States and England at the end of World War II in the form of professorships, departments, journals, degrees, and a canon. These scholars invented the synthetic narrative of "the Scientific Revolution": the breakdown of geocentric cosmology and the virtues and appetites of Aristotle's natural philosophy, the rise of mathematical idealization and mechanical explanations, the move from thought experiment to actual experiment, and the coronation of Newton as the synthesizer and founder of the new "scientific worldview." These "neo-revolutionaries" held that all fields of physical science underwent the same transformation at roughly the same time (even if chemistry's "revolution" was deferred until the late eighteenth century), replacing one worldview—traditional, scholastic, and dependent on theology—with another that was forward-looking, empirical, mechanical, and free-thinking.[11]

British neo-revolutionaries included Cambridge historian Herbert Butterfield, author of the *Origins of Modern Science* (1949), who coined the expression "the Whig interpretation of history," or the tendency to see events in the past leading inevitably toward the most valued aspects of the present. Butterfield argued that a specialist profession of history of science—one conducted not by scientists but by historians, leaving aside the political valences or uses of science—could avoid this pitfall.[12] His Cambridge colleagues Rupert Hall and Mary Boas Hall joined him in isolating the intellectual changes of the seventeenth century as the field's center of gravity.[13] In the United States the discipline's emergence was embroiled with postwar pedagogy. As president of Harvard, former physicist and federal administrator James Bryant Conant created a humanities-based general education program in which science and liberal democracy were presented as crowning achievements of Western civilization.[14] Conant was patron to both George Sarton, the Belgian-born historian who launched the journal *Isis*, and I. Bernard Cohen, the first American Ph.D. in history of science. In Paris and Princeton, Russian émigré Alexandre Koyré honed the study of science's unfolding conceptual structures to a fine edge; his works cast a potent influence on subsequent neo-revolutionaries, including Richard Westfall and Charles Gillispie, whose 1960 epic, *The Edge of Objectivity*, was subtitled *An Essay in the History of Scientific Ideas*.[15]

The works of this first generation of professional historians of science carried a normative insistence on the unity of scientific method, science's internal consistency, and its epistemological, political, and ethical value. They often presented the scientific revolution as shorthand for all that was best in the modern worldview as a whole.[16] In contrast to Lovejoy's model of history of ideas—eclectic, cosmological, attuned to aesthetics, ethics, and politics—for the neo-revolutionaries, the seventeenth century's empiricism and mechanism were the hallmarks of rationality and progress. Ironically, their view that science transcended politics and economics often went hand in hand with an interpretation of science as an outgrowth and reinforcement of democracy and capitalism; the central role they gave Newton and Galileo reinforced the preeminence of physics in the military-industrial order of the early Cold War.[17]

From this perspective, Koyré, who had studied with Bergson and Husserl, and presented Galilean physics as a peculiar, alienating form of idealization, might have less in common with his neo-revolutionary successors than with Whitehead, Collingwood, Cassirer, and Lovejoy (whose *Great Chain* shared many topics with Koyré's *Closed World*). Though the philosopher-historians working in Lovejoy's mode did not refuse normative judgments, their evaluations of cosmological conceptions placed greater weight on ideas' ethical, aesthetic, and existential implications than on their epistemological validity.[18]

Ideas in situ, in vivo, in Action

Despite their distinctive slant, the neo-revolutionaries often wrote for the *JHI*, nesting comfortably within the broader terrain prepared by Lovejoy. The field was united by a concern with worldviews (even if the neo-revolutionaries focused on a single, "scientific" worldview) and with intellectual change over time; it also tended to relegate ideas' social origins and political provocations to asides and footnotes.[19] By the late 1960s—as Quentin Skinner took aim at Lovejoy's neglect of ideas' settings and prompts—new approaches appeared, defining themselves against decontextualized and "internalist" histories of science.[20]

A turning point was Kuhn's *Structure of Scientific Revolutions* (note the plural), which spelled out the sociological dimensions of scientific communities, including journals, meetings, and institutional hierarchies, as well as training programs, textbooks, and, crucially, *exemplars*—problems that teach students to see certain situations as like others.[21] Those who adhered to different paradigms, he claimed, inhabited "different worlds," and successive paradigms did not imply increasing truth or improved fit to nature. If anything set science apart, Kuhn argued, it was not its certainty, but rather the quotidian activity of "normal science," defined, deflatingly, by routine work "solving puzzles." Regardless of his own much-debated intentions, Kuhn was enshrined as the pioneer of a politically and sociologically informed study of science, one that left behind internalist history and resonated with Vietnam-era critiques of science and rationalism as weapons of militarism, capitalism, and patriarchy.[22]

Kuhn was seen as an ally by historians of the 1970s who sought to reinvigorate earlier traditions of sociology of knowledge.[23] Those who launched the sociology of scientific knowledge (SSK) in Edinburgh and England in the mid-1970s claimed Kuhn as a founder. SSK used case studies to argue that scientific knowledge relied on trust, testimony, and the acceptance of assumptions that could never be irrefutably confirmed; revisiting Wittgenstein and Durkheim, they insisted on the practical and social grounding of epistemic conventions and on the link between scientific and political authority.[24] Kuhn's emphasis on the unspoken rules behind scientific concepts also harmonized with Michel Foucault's work. Though *epistemes* were vaster than paradigms, and Foucault's later "genealogies" gave power relations a primacy absent from Kuhn, Foucault's analyses of bodily discipline, the normative force of classifications, and the "breaks" between internally coherent discursive formations helped align *Structure*'s tacit knowledge, conceptual schemes, and incommensurability with critical reflection on enlightenment and modernity. Further, Foucault's excoriation of "magical" concepts such as influence, the author, and the "mentality" or "spirit" of the age also strengthened the notion that the traditional history of ideas was an obstacle to a politically attuned history of science.[25]

Foucault, Kuhn, and SSK were staples of the smorgasbord that came to be known in the 1980s as science studies or science and technology studies (STS). They joined philosophers who argued against the notion of a single scientific method and ethnographers who showed how the frontiers between society and nature, humans and nonhumans, truth and falsity dissolved and recrystallized in practice both inside and beyond the lab.[26] Historians also contributed to and made use of STS. Influentially, Shapin and Schaffer's *Leviathan and the*

Air-Pump demonstrated that the controversy between the founders of the Royal Society and Thomas Hobbes was waged not just with words but with presses and pictures, air pumps and barometers, rules of sociability and rituals—what the authors called literary, material, and social technologies.[27] Under the sign of "technologies" and "forms of life," *Leviathan* set contrasting ideas about the vacuum, the nature of matter, God's action in the world, and the proper methods of proof within their practical, theological, and political contexts.

Subsequent works have likewise aimed to disaggregate the neo-revolutionaries' "unity of science" into particular cases and components.[28] Science historians no longer see it as their job to separate the wheat of "real science" from the chaff of error and superstition; instead, they detail how "universal" concepts such as truth, proof, and objectivity, as well as science's double aims of doing and knowing, have been applied and transformed in various specific settings.[29] If a "revolution" is said to occur, they examine through what arguments and routes of persuasion is it recognized—when, where, and by whom.[30] Of course, scientific concepts and "themata" continue to capture historians' attention—life, matter, energy, probability, relativity, descent, proof, norms, mechanism, universality, the economy, or time, to name just a few.[31] But such ideas are relentlessly shown to be woven into skillful practice with things: scientific instruments, collections and displays of objects and facts, and methods and media of inscription, analysis, accounting, and transmission. The focus on objects has a tripled valence. First, historians of science insist (against both scientific idealism and a thoroughgoing "constructivism" that exists primarily as a straw man) on the reality of material entities, their capacities, and the constraints they impose. Further, inspired by the history of technology, science itself is examined as a "technological system": facts and theories extend only as far as the concrete networks or infrastructures that carry them. Finally, specimens, instruments, or artificially and naturally encountered phenomena are also considered as semiotic supports and embodiments of epistemological and cosmological commitments.[32]

Alongside scientific concepts and objects, historians have also isolated "ideas" of different sorts. Instead of a single "scientific method" they recognize a range of "styles of reasoning" and "ways of knowing." They also follow shifting disciplinary boundaries, discursive formations, and "forms of positivity" that have organized research, tracing the limits of, for instance, natural philosophy, mixed mathematics, and natural history. Another element they have identified is ideas of practice—implicit or explicit theories about the right way to get to grips with the material world, as well as the ethical codes that organize knowledge practices. Scholars have, for instance, examined the "artisanal epistemology" of early modern alchemists and natural philosophers, the division of labor between public virtuosi and "invisible technicians" behind the scenes in the early Royal Society, and the "moral economy" allotting credit and encouraging exchange of *drosophila* samples in T. H. Morgan's laboratory.[33] Along these lines, Daston and Galison's *Objectivity* matched successive articulations of its titular concept to historically favored modes of representation and epistemic ideals, such as the delicate paintings of idealized plants in the era of "truth to nature" and the gritty, particular photographs of "mechanical objectivity."[34]

In the self-understandings and "epistemic virtues" of scientists, *Objectivity* also isolated a further dimension of science. Eighteenth-century empiricists experienced the self as a sensitive tablet on which fragmentary external impressions were written, arriving at general ideas only after long observation, while post-Kantian experimentalists fretted that the desires of an excessive will had to be kept in check by machines. Such analyses resonate with arguments of feminist epistemologists who have shown how gender norms shape and reflect scientific values. These norms also bear upon ethics and the emotions, or affect, as Tracie Matysik explores in this collection.[35] Even if the pursuit of truth has been presented as a struggle against the passions, suppressed emotion remains an emotional state—one as significant for the history of science as it is for histories of Western subjectivity.[36]

The new historians have revealed that "science" contains a multitude of elements, each with its own types and variations. Further, replacing the single line that the neo-revolutionaries drew between the seventeenth century and the technocratic arrangements of the Cold War, alternative historical trajectories are now drawn: laterally to other domains of culture (politics, arts, technology), and transversally to other historical predecessors and cultures.

Concrete and Fragmentary Wholes

These new cartographies of knowledge have not gone unchallenged. Notions of linear progress and unity still dominate mainstream understandings of science; internalist, idealist histories are still written and taught. A reaction flared up in the 1990s with the "Science Wars" and the "Sokal Hoax," when a disgruntled physicist wrote an article peppered with exaggerations and jargon that interpreted his own field in the light of critical theory; at its publication, he declared his article a joke that should have been recognized as such.[37] The ensuing fracas—along with the discovery that STS arguments were being used to promote Intelligent Design and to undermine scientific consensus on global warming—contributed to a dampening of theoretical agitation. This quietism fit well with the sense that in the 2000s the humanities were entering a "post-theory" era.[38]

As a result, some within the field have critiqued what they perceive as narrowed horizons and a dulled critical edge.[39] Even if the polemical volume has dropped, however, philosophical questions remain, though on new ground. Many authors now serve a constructivist cake that can be realistically eaten. Donna Haraway's "semiotechnologies" and Andrew Pickering's "mangle of practice" present entities of biology, chemistry, physics, or engineering—quarks, human bodies, bespoke mice, and electronic brains—as both intellectual and material, as constructs with concrete effects; likewise, Bruno Latour insists that he has always been a realist, though now in the characteristically gonzo form of "multinaturalism."[40] Further, one of the preferred genres of STS and history of science—the detailed case study—can itself be read as an epistemological argument: by showing scientific ideas and objects bound up with historically specific and variable systems of practice, reasoning, and technique, case studies offer support for pluralist epistemologies and ontologies.[41]

Yet this virtue matches a vice. Disconnected from the unities of the neo-revolutionaries, case studies risk closing in on themselves, in a celebration of the singular recalling early modern cabinets of curiosity.[42] To arrive at more general perspectives, one solution might be to heed the invitation to return to the *longue durée* emphases of earlier history of ideas.[43] Various components of "science" may be linked, compared, and contrasted across time and location, replacing the neo-revolutionaries' grand narrative with new "serial contextualizations." *Objectivity* points in this direction; following suit, others may isolate general topics to guide transhistorical investigations.

Yet the methodological innovations of the past thirty years of history of science have raised the stakes for contextualization. If transhistorical genealogies are to be more than annotated N-grams, it is worth reflecting on the ways in which scholars reassemble the material fragments into which "science" has been broken. How should we consider the diachronically separate conjunctures—the "cases"—that "serial contextualizations" would connect? Here, once more, we might draw upon the salutary resources of traditional history of ideas. Despite the variety of their topics, Lovejoy and his fellow travelers were driven by a fascination for ideas about the composition, extent, and structure of the universe, and the place of humans within it. Like cultural anthropologists (and inspired by similar post-Kantian impulses), they undertook comparative studies of cosmology. Even the neo-revolutionaries, though privileging a single "scientific" cosmology, shared this vocation.

The cosmological impulse surreptitiously remains at work in the newer histories of science. Yet this continuity is rarely acknowledged, much less celebrated.

In jettisoning the normative unities of the neo-revolutionaries, historians of science encouraged a renunciation of the history of ideas as a whole. Further, their chosen allies—Wittgenstein, poststructuralism, cultural anthropology—all contributed arguments that could be applied not just against "grand narratives" and "scientific absolutism," but against generalizing concepts of all kinds. Any notion that claimed to convey a shared system of thought—worldview, cosmology, mentality, *episteme*, culture, *Zeitgeist*, conceptual scheme, even Kuhn's "paradigm"—provoked suspicion.[44]

There were and are excellent reasons for such skepticism. Worldviews float everywhere and nowhere, operating through spooky action at a distance when not enclosed in skulls. Cosmologies have often been presented as uniform, coherent, and widely shared, rather than in the motley, variable, idiosyncratic forms through which they are lived and practiced. Philosophers have asked whether there is even such a thing as a conceptual scheme; others claim that formalized systems of thought are invented by researchers out of partial, discordant observations; others pronounce the notion of a "subject" experiencing "objects" through "representations" as just one possible mode for the disclosure of being.

Despite endorsing many of these very critiques, the new historians of science have maintained the study of cosmology as a central organizing principle. This is precisely what was at stake in many of the exemplary works of the past thirty years: those that examined conceptualizations of wondrous particulars and natural laws, reconstructed the natural philosophical detours of Newton's successors, stalked computationally masterable chance from astronomy to sociology and statistical mechanics, detailed the contributions of geologists, Jacobin journalists, and Goethe to the different shadings of "evolution," or perused the railway schedules that grounded Einstein's relativity. Like the earlier historians of ideas, the new historians of science study the ways in which facts, concepts, and arguments form a world, a nature, a cosmos. Yet the cosmologies they study are materialized—not "reduced to" or "determined by" a material base, but instantiated in concrete actions, texts, and institutions, even when (as is often the case) the very definition of matter and "materiality" is what is at stake. Cosmological ideas take on realist force when they are anchored, housed, and transmitted in objects, technical networks, routine practices, and social institutions. Acknowledging this connection with the older history of ideas allows us to reclaim a rich heritage that adds depth and perspective to local situations and particular cases.

Yet this affirmation has to incorporate not just the materializing turn but the skepticism toward totalizing concepts and seamless holism mentioned above. Materialized cosmologies involve potentially incompatible elements;

they are riddled with gaps and counterpoints. The challenge, then, is to follow the elements that make a cosmos as they arise from and feed back into concrete activities, settings, and objects. While studying the habitual, entraining, mutually constraining relationships among humans and other beings, we must also attend to the openness, changeability, and contradictions of the conceptual, practical, and cosmological orders that may arise, hold, or dissolve through their interactions.

To this end historians can continue to learn from anthropology's attention to the meshing (and the splitting) of the quotidian and the cosmological and to the embodiment of natural and social hierarchies in practice and ritual, as well as from its insistence on the dialogical, perspectivally shifting, contested nature of public life. Systems of knowledge are riven with divisions, such as those among disciplines, research programs, and roles. Furthermore, actors may spend time in labs, offices, or lecture halls, while involved in religious, governmental, or artistic activities, all of which are underwritten by distinct concepts and principles of value. To reckon with the tensions between the phenomenological and pragmatic worlds of complex societies—what Weber called "the struggle that the gods of the various orders and values are engaged in"—sociologists have developed many helpful frameworks.[45] STS has contributed the notion of "boundary work," efforts to mark divisions between disciplines, groups, and metaphysical domains. Thomas Gieryn, for instance, showed the Victorian physicist John Tyndall using lectures and popular writings to raise the status of science by distinguishing it both from religion (emphasizing its empiricism and utility) and from mechanics (emphasizing its abstraction and freedom from utility). Similarly, we can study the ways, whether internally consistent or not, in which actors try to make plain the overall arrangement of the entities they recognize by making and using concrete representations of the universe, or cosmograms; such objects—maps, diagrams, buildings, calendars, poems, encyclopedias—are not transparent, uncontested encapsulations of a bounded world, but performative assertions, entries into debates, points of reference for further elaboration. Paying attention to the locally situated acts and objects through which historical actors divide and connect parts of the universe keeps us at the level of observable, material practices, while showing how they assemble and situate themselves within greater wholes—however incomplete or fragmented these may be.[46]

In short, doing history of science means contributing to the comparative study of materialized cosmologies. It means undertaking the description, narration, and analysis of embodied, concrete, totalizing but unavoidably incomplete and equivocal systems of natural and social order. This modest reframing of our field picks out a level from which to think comparatively and genetically about the diverse case studies assembled in the past thirty years. It reconnects us to the wider field of intellectual history, both ancestors and contemporaries—a renewed alliance encouraged by Antoine Lilti and Suzanne Marchand in this book. It also encourages a robust engagement with history of religions, archaeology, area studies, and anthropology, whose interest in comparative cosmology has recently been reaffirmed.[47]

When Material Cosmologies Collide

Defining our field as the study of materialized cosmologies may also help address some of the most pressing questions historians of science currently face. I conclude with a glance at three closely connected sites of inquiry: modern scientific cosmologies and their complexities, the global origins and settings of Western knowledge, and science's environmental impacts. Arising out of concerns of the present, these topics exert a reorienting pressure on understandings of the past and future.

One challenge is to make sense of the cosmological complexities of the industrial past and postindustrial present. For historians of the medieval and early modern periods, consideration of large-scale cosmological frameworks connecting science, religion, commerce, politics, and the arts has been a matter of course.[48] In studies of the period after 1800, however, the question of a general natural order is often swiftly glossed with notions such as secularization, standardization, disenchantment, mechanization, normalization, or discipline. Yet the material turn pushes us to ask: in what diverse practices, settings, and objects do these general tendencies reside? What sort of world do they gather together? How do they incorporate or exclude other possibilities? Indeed, such questions can lead to the realization that the uniformity of the modern world has been greatly exaggerated. Throughout the nineteenth century, even as many administrators, scientists, and entrepreneurs worked on various fronts to standardize entities and sites including schools, industries, and markets, wildly variable theological, metaphysical, and epistemological conceptions proliferated. Alternative modernities, often grounded in heterodox sciences and challenges to existing social hierarchies, flourished within Europe as well as in those regions forced into new global routes of labor, production, and trade; these cosmologies need to be shown materially, dialectically, and critically engaging with more familiar "modern" patterns of action and thought.[49]

Further, the more we learn about the knowledge practices that administered the nineteenth-century global order, the more we realize the necessity of following their transformations forward into the scientific orders consolidated in the North Atlantic and worldwide after World War II. Mining the archives of the "Strangelovian sciences" has begun to reveal Cold War rationality not as a self-evident unity, but a varied set of calculating practices, organizational logics, and attitudes toward nature, the state, the public, "the enemy," and "the Third World" that demands further excavation.[50] The perspective of material cosmologies also leads to questions not just about the theoretical complexity of twentieth-century sciences but about their experiential complexity and the ways they have been implemented. How were fields as disparate as post-Copenhagen physics, molecular biology, or neuropsychology linked by personnel, research, and funding institutions, computational techniques and metaphors, and conceptions of knowledge, self, and nature? How did scientific explanations align or clash with the views of "humanity's place in the universe" inculcated by advertising, entertainment, economics, government propaganda, mainstream religions, or new-age philosophies? Such questions guide recent works that show how cosmological ideas from physics, information science, business, and the 1960s counterculture were assembled, more or less comfortably, into new forms of life.[51] Comparable questions can be raised about the cosmologies juxtaposed and synthesized in Western science's postwar transfers and frequent hybridizations with "local" knowledge traditions; they resonate with interest in the theory and practice of "development" as a novel, quasi-imperial mode of coordinating states, populations, and natural resources.[52]

Positioning natural knowledge within stratified global political economies is a challenge being taken up by scholars not just of the recent past but of all periods. As a result, the contours of "Western science" have begun to shift. In 1931 Boris Hessen demonstrated the connections between the "pure science" of Newton's age and the rise of commercial and professional classes, European states' military and administrative apparatus, and the extension of empires.[53] Much of today's most interesting scholarship arguably continues Hessen's work, showing the entanglement of natural knowledge with trade networks, state formation, class conflicts, and imperial ambitions. Renaissance collections housed curiosities of art and nature while cementing exchange relations among courts, merchants, and explorers. Newton's *Principia*, created in a furious correspondence with traders, plantation owners, natural philosophers, and sailors from the Americas to Japan and the Gulf of Tonkin, was a node in the British Empire's emerging information order. In the eighteenth and nineteenth centuries, natural history flourished on board survey, trade, and military expeditions, while new social sciences steered interventions in declining populations, dangerous urban classes, and defiant colonial subjects. Physicists instituted a cosmos of energy and ethers and prophesied the heat-death of the sun, while building networks to streamline productive forces at home and abroad.[54]

In all of these cases, material cosmologies set the stage for cultural contacts. Western science was not a neutral "tool of empire," using value-free facts to accomplish utilitarian ends; it carried culturally specific values (not least accuracy, efficiency, commensuration) and sought to redraw the map of the world, both metaphysically and geographically. Further, many of its orientations emerged in confrontation with other traditions. Increasing attention has been paid to the elusive and mercurial "go-betweens" who served as ambassadors, translators, negotiators, procurers, and enablers in the distributed administration of empires.[55] The knowledge of indigenous experts was incorporated into "universal" science in various ways, as in maps of New Spain that inscribed native views of landscape, flora and fauna; Serge Gruzinski's arguments about the "mestizo" knowledge in the Americas can extend to "hybrid" knowledge formations in Asia and Africa.[56] As Marwa Elshakry has argued, the very notion of a distinct "Western science" was only consolidated around 1900, through the historiographical construction of past "Golden Ages" (in Greece, India, and Islam) and the modernizing efforts of pedagogues outside the West.[57]

Rewriting another chapter of the origin story of Western science, Bernal's *Black Athena* set the knowledge traditions of Egypt, Mesopotamia, and India—recrafted as Greek—within the imperial intersections of the ancient world, while George Saliba has helped reconstruct the role of Islam in the European Renaissance. To re-imagine other points of transmission and reconstitution of diverse knowledge traditions requires deep familiarity with diverse learned practices, local and imperial formations, and the variable diagrams that connect commerce, statecraft, and religion—in short, it demands a grasp of multiple materialized cosmologies.[58] From this perspective, the comparative history of civilizations urged by George Sarton and Joseph Needham in the early twentieth century might appear strikingly avant-garde, suggesting multiple starting points from which to trace our own moment's "globalization."[59]

A final challenge for the history of science set by the present is to help make sense of the impact of ideas of nature on the natural world itself. The idea that nature is not a different kind of being "out there," but rather a given that accompanies, constitutes, and yet can be transformed by human activity has a long, varied history. Some of its turns were tracked by Georges Canguilhem in his genealogy of the concept of "milieu," or the nutritive envelope surrounding organisms, an idea central for Alexander von Humboldt's biogeography, and through him, for Darwin and those who study "the environment." A further elaboration came with the ethologist Jacob von Uexkull's concept of *Umwelt*: the world inhabited by different species depends on the configuration of their senses.[60]

In the earth sciences, the notion that humans construct their worlds has recently moved from pragmatic metaphor and phenomenological speculation to quantified fact. With discussions of the "Anthropocene," the proposed geological era defined by industry's impact on the planet, we are forced to acknowledge "ideas of nature" as instruments for permanent modifications of "external" and "objective" nature itself.[61] Accordingly, history of science joins forces with environmental history. There is considerable interest in the history of the earth sciences, climatology, and space sciences: their extreme settings and aesthetic motivations as well as the role various fields (geology, agronomy, chemistry) have played in shaping landscapes, from uranium mines and oil fields to hill stations and urban research centers. A further tendency, one with outstanding precursors in the history of ideas, addresses the aesthetic and moral valences of ideas about nature—as garden, wasteland, wilderness, standing reserve—and how these have directed practical engagements with the landscape. Following the convolutions of such ideas as they shape the material conditions of our existence in the hands not only of "thinkers" but of engineers, politicians, corporate managers, farmers, citizens, consumers, and activists, the history of science can help ground our understanding of the most pressing challenges of today.[62]

To come to grips with the disorientingly plural, technologically modified, politically and environmentally precarious worlds we now inhabit, the new history of science examines ideas of nature in their complex and concrete ecologies, tracing their roots, movements, and mergers as they have coordinated actions and interventions, defining the contours of the real. The study of materialized cosmologies goes beyond the neo-revolutionaries' insistence on a single method and idealized scientific worldview. Yet in an important sense it lands us back where we began: in productive dialogue about concepts of natural order with our neglected ally, the history of ideas.

Notes

1. This paper began in conversation and collaboration with Graham Burnett, whose suggestions and encouragement were indispensable. Thanks also to Darrin McMahon, Samuel Moyn, the conference participants, Robert Kohler, and especially James Delbourgo for helpful comments.

2. Steven Shapin, "Lowering the Tone in the History of Science: A Noble Calling," in *Never Pure: Historical Studies of Science as If It Was Produced by People with Bodies, Situated in Time, Space, Culture, and Society, and Struggling for Credibility and Authority* (Chicago: University of Chicago Press, 2010), 13.

3. Shapin, "Lowering the Tone," 14.

4. In "Science Studies and the History of Science" (*Critical Inquiry* 35 [2009]: 798–813), Lorraine Daston argues that the partnership in the 1980s between the

history of science and science studies has run its course, concluding with a sporting invitation: "Philosophy, anyone?" In reply, Peter Dear and Sheila Jasanoff ("Dismantling Boundaries in Science and Technology Studies," *Isis* 101 [2010]: 759–74) point to a tradition of sociologically informed histories, rejecting Daston's interpretation of a splintering.

5. According to Andrew Cunningham and Perry Williams, "Historians are ceasing to believe in a single scientific method which makes all knowledge like the physical sciences, or that science is synonymous with free intellectual enquiry and material prosperity, or that science is what all humans throughout time and space have been doing as competently as they were able." "De-Centring the 'Big Picture': 'The Origins of Modern Science' and the Modern Origins of Science," *British Journal for the History of Science* 26 (1993): 407–32.

6. Lynn Thorndike, *The Place of Magic in the Intellectual History of Europe* (New York: AMS Press, 1967); Marjorie Hope Nicolson, *Mountain Gloom and Mountain Glory: The Development of the Aesthetics of the Infinite* (New York: Norton, 1959); John C. Greene, *The Death of Adam: Evolution and Its Impact on Western Thought* (Ames: Iowa State University Press, 1959). Greene's work intersects with classics such as Carl Becker's *Heavenly City of the Eighteenth Century Philosophers* (New Haven, CT: Yale University Press, 1932) and Karl Löwith's *Meaning in History* (Chicago: University of Chicago Press, 1949).

7. Arthur Lovejoy, *The Great Chain of Being: A Study of the History of an Idea* (1936; Cambridge, MA: Harvard University Press, 1976).

8. Daniel J. Wilson, "Lovejoy's The Great Chain of Being after Fifty Years," *Journal of the History of Ideas* 48 (1987): 187–206; Isaiah Berlin, *The Roots of Romanticism* (Princeton, NJ: Princeton University Press, 1999).

9. Ernst Cassirer, *The Individual and the Cosmos in Renaissance Philosophy* (Chicago: University of Chicago Press, 1963); see Peter Gordon, *Continental Divide: Heidegger, Cassirer, Davos* (Cambridge, MA: Harvard University Press, 2010).

10. Arthur Lovejoy, "The Meaning of Romanticism for the Historian of Ideas," *Journal of the History of Ideas* 2 (1941): 257–78; R. G. Collingwood, *The Idea of Nature* (Oxford: Clarendon Press, 1945); Alfred North Whitehead, *Science and the Modern World* (New York: Macmillan, 1925).

11. Michael Dennis, "Historiography of Science: An American Perspective," in *Companion to Science in the Twentieth Century*, ed. John Krige and Dominique Pestre (New York: Routledge, 2003), 1–26; I. B. Cohen, *The Birth of a New Physics* (New York: Doubleday, 1960); Richard Westfall, *The Construction of Modern Science: Mechanism and Mechanics* (Cambridge: Cambridge University Press, 1977).

12. The first informal group of Cambridge historians of science led by Joseph Needham included scientists who favored "leftish" historical and sociological approaches; Butterfield encouraged a far less contextual approach. Anna-K. Mayer, "British History of Science and 'the End of Ideology,' 1931–1948," *Studies in History and Philosophy of Science Part A* 35 (2004): 41–72.

13. Herbert Butterfield, *The Origins of Modern Science, 1300–1800* (London: Bell, 1950); A. Rupert Hall, *The Scientific Revolution, 1500–1800: The Formation of the Modern*

Scientific Attitude (London: Longmans, Green, 1954); Mary Boas Hall, *The Mechanical Philosophy* (New York: Arno, 1981).

14. *General Education in a Free Society: Report of the Harvard Committee* (Cambridge, MA: Harvard University Press, 1945); John Rudolph, "Epistemology for the Masses: The Origins of 'The Scientific Method' in American Schools," *History of Education Quarterly* 45 (2005): 341–76.

15. Alexandre Koyré , *From the Closed World to the Infinite Universe* (Baltimore: Johns Hopkins Press, 1957); Charles Coulston Gillispie, *The Edge of Objectivity: An Essay in the History of Scientific Ideas* (Princeton, NJ: Princeton University Press, 1960).

16. See Butterfield, *Origins of Modern Science*, chap. 10, for jaw-droppingly ethnocentric expressions of this view.

17. See Karl Popper, *The Open Society and Its Enemies* (Princeton, NJ: Princeton University Press, 1966); David Hollinger, "Science as a Weapon in Kulturkampfe in the United States during and after World War II," *Isis* 86 (1995): 440–54.

18. The distance between the neo-revolutionaries and the warier, humanistic approach associated with Lovejoy is made plain by comparing many of the contributions to Gerald Holton, ed., *Science and the Modem Mind: A Symposium* (Boston: Beacon, 1958), with Jacques Barzun, *Science: The Glorious Entertainment* (New York: Harper and Row, 1964).

19. Literally in Koyré's *Closed World*, where the notes provide detailed contextualization of the ideas of the text.

20. Quentin Skinner, "Meaning and Understanding in the History of Ideas," *History and Theory* 8 (1969); for discussion see Donald R. Kelley, *The Descent of Ideas: The History of Intellectual History* (Aldershot: Ashgate, 2002).

21. Thomas S. Kuhn, *The Structure of Scientific Revolutions* (Chicago: University of Chicago Press, 1970).

22. Against the canonization of Kuhn as a radical, Steve Fuller aligns his aims with Conant's, who saw a science independent of external review as critical for postwar national security. *Thomas Kuhn: A Philosophical History for Our Times* (Chicago: University of Chicago Press, 2000), 179–226.

23. Arnold Thackray and Robert K. Merton, "On Discipline Building: The Paradoxes of George Sarton," *Isis* 63, no. 4 (1972): 473–95.

24. Barry Barnes, *T. S. Kuhn and Social Science* (New York: Columbia University Press, 1982); David Bloor, *Knowledge and Social Imagery* (London: Routledge, 1976).

25. Michel Foucault, *The Archaeology of Knowledge* (New York: Pantheon, 1972), 3–20.

26. Andrew Pickering, ed., *Science as Practice and Culture* (Chicago: University of Chicago Press, 1992); Mario Biagioli, ed., *The Science Studies Reader* (New York: Routledge, 1999).

27. Steven Shapin and Simon Schaffer, *Leviathan and the Air-Pump: Hobbes, Boyle and the Experimental Life* (Princeton, NJ: Princeton University Press, 1985).

28. Rudolf Carnap, *The Unity of Science* (London: Kegan Paul, 1934).

29. See Cunningham, "De-Centring the 'Big Picture'"; Peter Dear, *The Intelligibility of Nature: How Science Makes Sense of the World* (Chicago: University of Chicago, 2006).

30. Adrian Johns, *The Nature of the Book: Print and Knowledge in the Making* (Chicago: University of Chicago Press, 2000).

31. Gerald Holton, "On the Role of Themata in Scientific Thought," *Science* 188 (1975): 328–34.

32. Lorraine Daston, ed., *Things That Talk: Object Lessons from Art and Science* (New York: Zone, 2004); Joseph O'Connell, "Metrology: The Creation of Universality by the Circulation of Particulars," *Social Studies of Science* 23 (1993): 129–73; Crosbie Smith and M. Norton Wise, *Energy and Empire: A Biographical Study of Lord Kelvin* (Cambridge: Cambridge University Press, 1989); focus section on "Thick Things," ed. Ken Alder, *Isis* 98 (2007): 80–142.

33. Steven Shapin, "The Invisible Technician," *American Scientist* 77 (1989): 554–63; Pamela Smith, *The Body of the Artisan: Art and Experience in the Scientific Revolution* (Chicago: University of Chicago Press, 2006); Robert Kohler, *Lords of the Fly: Drosophila Genetics and the Experimental Life* (Chicago: University of Chicago Press, 1994).

34. Lorraine Daston and Peter Galison, *Objectivity* (New York: Zone, 2007).

35. Helen Longino, "Taking Gender Seriously in Philosophy of Science," *Proceedings of the Biennial Meetings of the Philosophy of Science Association* 2 (1992): 333–40; Sandra Harding, *Sciences from below: Feminisms, Postcolonialities, and Modernities* (Durham, NC: Duke University Press, 2008).

36. Matthew Jones, *The Good Life in the Scientific Revolution: Descartes, Pascal, Leibniz, and the Cultivation of Virtue* (Chicago: University of Chicago Press, 2006).

37. Keith Ashman and Philip Baringer, eds., *After the Science Wars* (New York: Routledge, 2001).

38. W. J. T. Mitchell, "Medium Theory: Preface to the 2003 *Critical Inquiry* Symposium," *Critical Inquiry* 30 (2004): 324–36; Bruno Latour, "Why Has Critique Run Out of Steam?," *Critical Inquiry* 30 (2004): 238–39.

39. Steve Fuller, "CSI: Kuhn and Latour," *Social Studies of Science* 42 (2012): 429–34.

40. Bruno Latour, *Politics of Nature: How to Bring the Sciences into Democracy* (Cambridge, MA: Harvard University Press, 2004); Andrew Pickering, *The Mangle of Practice: Time, Agency, and Science* (Chicago: University of Chicago Press, 1995); Donna Haraway, *Simians, Cyborgs and Women: The Reinvention of Nature* (New York: Routledge, 1991); Ian Hacking, *The Social Construction of What?* (Cambridge, MA: Harvard University Press, 1999).

41. Daston, "Science Studies," 812–13; Ian Hacking, *Historical Ontology* (Cambridge, MA: Harvard University Press, 2002).

42. Peter Galison asks, "If case studies are the paving stones, where does the path lead?," in "Ten Problems in History and Philosophy of Science," *Isis* 99 (2008): 120. In the blog of Will Thomas (http://etherwave.wordpress.com), the disciplinary reflex of case studies is a recurrent *bête noire.*

43. See David Armitage, "What's the Big Idea? Intellectual History and the *Longue Durée*," *History of European Ideas* 38 (2012): 493–507, and Darrin McMahon's chapter in this volume.

44. Jean-François Lyotard, *The Postmodern Condition: A Report on Knowledge*, vol. 10, *Theory and History of Literature* (Minneapolis: University of Minnesota Press, 1984); Harold Garfinkel, *Studies in Ethnomethodology* (Englewood Cliffs, NJ: Prentice-Hall, 1967); Johannes Fabian, *Time and the Other: How Anthropology Makes Its Object* (New York: Columbia University Press, 1983); Peter Galison, "Computer Simulations and the Trading Zone," in *The Disunity of Science: Boundaries, Contexts, and Power*, ed. Peter Galison and David Strump (Stanford, CA: Stanford University Press, 1996), 118–57. For a discussion and rehabilitation of anthropological uses of cosmology, see Eduardo Viveiros de Castro, "Cosmologies: Perspectivism," *Hau Master Class Series*, vol. 1 (2012).

45. Max Weber, "Science as a Vocation," *Daedalus* 87 (1958): 111–34; Andrew Abbott, *Chaos of Disciplines* (Chicago: University of Chicago Press, 2001); Howard Becker, *Art Worlds* (Berkeley: University of California Press, 1982); Pierre Bourdieu, *Practical Reason: On the Theory of Action* (Stanford, CA: Stanford University Press, 1998); Luc Boltanski and Laurent Thévenot, *On Justification: Economies of Worth* (Princeton, NJ: Princeton University Press, 2006); Latour proposes a new grounding for modernity's pluralist values in *An Inquiry into Modes of Existence* (Cambridge, MA: Harvard University Press, 2013).

46. Thomas Gieryn, *Cultural Boundaries of Science: Credibility on the Line* (Chicago: University of Chicago Press, 1999); John Tresch, "Technological World-Pictures: Cosmic Things, Cosmograms," *Isis* 98 (2007): 84–99.

47. Philippe Descola, *Par-delà nature et culture* (Paris: Gallimard, 2005).

48. William Ashworth, "Natural History and the Emblematic World View," in *Reappraisals of the Scientific Revolution*, ed. David C. Lindberg and Robert S. Westman (New York: Cambridge University Press, 1990), 303–32.

49. See for instance Timothy Mitchell, ed., *Questions of Modernity* (Minneapolis: University of Minnesota Press, 2000); Alex Owen, *The Place of Enchantment: British Occultism and the Culture of the Modern* (Chicago: University of Chicago Press, 2004); John Tresch, *The Romantic Machine: Utopian Science and Technology after Napoleon* (Chicago: University of Chicago Press, 2012).

50. See Focus Section: "New Perspectives on Science and the Cold War," ed. Hunter Heyck and David Kaiser, *Isis* 101 (2010).

51. Fred Turner, *From Counterculture to Cyberculture: Stewart Brand, the Whole Earth Network, and the Rise of Digital Utopianism* (Chicago: University of Chicago Press, 2006); David Kaiser, *How the Hippies Saved Physics: Science, Counterculture, and the Quantum Revival* (New York: Norton, 2011).

52. Fa-ti Fan, "Redrawing the Map: Science in Twentieth-Century China," *Isis* 98 (2007): 524–38; Timothy Mitchell, *Carbon Democracy: Political Power in the Age of Oil* (New York: Verso, 2011).

53. Boris Hessen, "The Social and Economic Roots of Newton's Principia," in *Science at the Crossroads*, ed. Nicolai Bukharin (New York: Howard Ferting, 1974).

54. See for instance Simon Schaffer, *The Information Order of Isaac Newton's* Principia Mathematica (Uppsala: Office for History of Science, Uppsala University, 2008); N. Jardine, J. A. Secord, and E. Spary, *Cultures of Natural History* (Cambridge:

Cambridge University Press, 1996); the Focus Section on "Global Histories of Science," ed. Sujit Sivasundaram, *Isis* 101 (2010); James Delbourgo and Nicholas Dew, eds., *Science and Empire in the Atlantic World* (New York: Routledge, 2008); Londa Schiebinger and Claudia Swan, eds., *Colonial Botany: Science, Commerce and Politics in the Early Modern World* (Philadelphia: University of Pennsylvania Press, 2005); D. Graham Burnett, *Masters of All They Surveyed: Exploration, Geography, and a British El Dorado* (Chicago: University of Chicago Press, 2000); Suman Seth, "Putting Knowledge in Its Place: Science, Colonialism, and the Postcolonial," *Postcolonial Studies* 12 (2009): 373–88.

55. Marie-Noëlle Bourguet, Christian Licoppe, and H. Otto Sibum, eds., *Instruments, Travel and Science: Itineraries of Precision from the Seventeenth to Twentieth Century* (London: Routledge, 2002); Simon Schaffer, Kapil Raj, Lissa Roberts, and James Delbourgo, eds., *The Brokered World: Go-Betweens and Global Intelligence, 1770–1820* (Sagamore Beach, MA: Science History Publications, 2009).

56. Serge Gruzinski, *The Mestizo Mind: The Intellectual Dynamics of Colonization and Globalization* (New York: Routledge, 2002); Christopher Bayly, *The Birth of the Modern World, 1780–1914* (London: Blackwell, 2003).

57. Marwa Elshakry, "When Did Science Become Western?," *Isis* 101 (2010): 146–58.

58. Martin Bernal, *Black Athena: The Afroasiatic Roots of Classical Civilization* (New Brunswick, NJ: Rutgers University Press, 1987); George Saliba, *Islamic Science and the Making of the European Renaissance* (New York: MIT Press, 2007); Sheldon Pollack, ed., *Literary Cultures in History: Reconstructions from South Asia* (Berkeley: University of California Press, 2003).

59. Joseph Needham, *Science and Civilisation in China* (Cambridge: Cambridge University Press, 1954); George Sarton, *An Introduction to the History of Science*, 3 vols. (Baltimore: William and Wilkins, 1927–1948); Nathan Sivin and Geoffrey Lloyd, *The Way and the Word: Science and Medicine in Early China and Greece* (New Haven, CT: Yale University Press, 2005).

60. In Georges Canguilhem, *Knowledge of Life* (New York: Fordham University Press, 2008), 98–120.

61. Dipesh Chakrabarty, "The Climate of History: Four Theses," *Critical Inquiry* 35 (2009): 197–222; for a longer history of the "climatic paradigm," see Fabien Locher and Jean-Baptiste Fressoz, "Modernity's Frail Climate: A Climate History of Environmental Reflexivity," *Critical Inquiry* 38 (2012): 579–98.

62. James Fleming and Vladimir Jankovic, eds., "*Klima*," *Osiris* 26 (2011); Carolyn Merchant, *The Death of Nature: Women, Ecology, and the Scientific Revolution* (San Francisco: Harper and Row, 1980); Karl Appuhn, *A Forest on the Sea: Environmental Expertise in Renaissance Venice* (Baltimore: Johns Hopkins University Press, 2009); William Cronon, "The Trouble with Wilderness; or, Getting Back to the Wrong Nature," *Environmental History* 1 (1996): 7–28.