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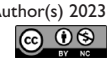

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Historiographies of science and labor: From past perspectives to future possibilities

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Abstract
This article offers suggestions for what a labor history of science might look like and what it might accomplish. It does so by first reviewing how historians of science have analyzed the history of both "science as labor" and "science and labor" since the 1930s. It then moves on to discuss recent historiographical developments in both the history of science and labor history that together provide an analytical frame for further research. The article ends by projecting into the future, considering how a labor history of science might help us grapple with connecting our understanding of the past with the challenges of today and tomorrow.

Keywords
history of science, labor history of science, historiography, labor history, science as work

The history of science and technology is redolent with ingenious plans to diminish or eradicate labor from the human condition. Think, for example, of the allure of automation and countless perpetual motion dreams and schemes. Insofar as labor has been

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understood as a problem, the ensuing solutions have promised unimaginable liberation but just as often delivered unthinkable immiseration for those whose toil would remain necessary. More modestly, "end of work" fantasies have typically resulted in labor's mere reallocation, a reshuffling of the burden both reflecting and producing the structures of inequality that have governed almost every human society. In the twentieth century, the emancipatory possibilities of both capitalism and state socialism relied upon new metrics for standardizing, measuring, valuing, and presumably "saving" labor, resulting in a scientification of work that continues to undergird breathless reporting on unemployment rates, the "surge pricing" of the gig economy, the surveillance regime of Amazon warehouses, and the disciplining discourses of "productivity" that govern the rhythms of workplaces across the globe. Academics have come to know this all too well, as universities recategorize research as knowledge production and subject humanists and scientists alike to mind-numbing reporting protocols to capture something called "output." Most recently, the ability of ChatGPT to generate a passable essay risks making some labor redundant and other labor invisible, even as it reawakens fantasies of abundant spare time and achievement of the mythical work–life balance.

These predicaments prompt this special issue of *History of Science* and this essay's investigation into the past, present, and future of a project we call a labor history of science. Our interest in a more robust exchange between historians of science and labor historians responds to developments both within and beyond the academy. It is difficult, for example, to ignore recent labor actions at universities in the United Kingdom, the United States, India, and elsewhere. Although academic laboratories comprise a fraction of the spaces where scientific work is undertaken, unionized graduate students, faculty, and technical employees have catapulted the university to the forefront of struggles over hours and pay. These campaigns reveal science's commonality with other forms of work for which the terms of remuneration are the basis of labor politics the world over. Similarly, it is difficult to overlook the attention given to labor in recent history of science scholarship, where the recovery of hidden and invisibilized work has transformed the histories of botany, chemistry, geology, medicine, and other disciplines. New research embraces a wide variety of workers, beyond conventionally scientific networks of credentialing, who "do" science in fields, mines, and kitchens. The labor turn afoot on our campuses and in our scholarship invites further exploration of the conjoined challenges we face as historians and citizens of a troubled world.

Initially, our goal was to foster new conversations between historians of science and labor historians, thinking that scholars in each field would benefit from greater familiarity with one another's historiographical touchstones and methodological tools – a potential that became immediately visible during the planning phases of the 2022 "Let's Get to Work: Bringing Labor History and the History of Science Together" conference. For six months before convening at the Science History Institute in Philadelphia for this iteration of the annual Gordon Cain conference, participants working in and across the two subdisciplines grappled over keywords, frameworks, and indispensable texts in search of common ground. The conference itself proved quite forward-looking, attentive to emerging research, new collaborations, and possible futures for those investigating the work of the past.

The three journal publications resulting from the conference seek to fulfill the ambition of a new conversation, but also to advance the agenda of a labor history of science further. An *Isis* Focus section functions primarily as a provocation to historians of science, calling for a self-reflective engagement with our own working conditions and myopia as we undertake research that is fundamentally geared toward recovering silenced voices and erased experiences that were "once known."[1] A special issue of *Labor: Studies in Working-Class History* serves to introduce a labor history audience to the scholarship that historians of science have undertaken on classic labor history topics like automation, deskilling, and coercion.[2]

And then there is this special issue. The contributions that follow serve our collective project's ambition to showcase scholarship at the intersection of history of science and labor history. This essay programmatically frames the issue and larger project of which it is a part. Following a brief discussion of key terms, it reviews the historiographical erasure of labor by historians of science since the 1930s and its more recent recovery. Recognizing the growing success of this recovery project, the essay then moves to highlight promising pathways for future research. If one set of possibilities rests upon a closer engagement with political economy and class struggle, another urges us to sit in the space before science is reified as knowledge, a space between practice and episteme where labor and work come into focus in surprising ways.

The work that words do: Reflections on terminology

Historians understand the importance of examining key terms, both to learn how our use of them frames current interpretations and how they have historically taken on different meanings and significance. Here we reflect on the words "work," "labor," and "science," hoping such a reflection will spur discussion of comparable terms in other languages that reveal and transcend the particularities of Anglophone usage. The historical connections and resonances between these three words usher us into a field of nuanced complexities covered by this special issue's theme. While the first two are often used interchangeably, placing them together reveals a constellation of approaches, historical insights, and key distinctions. And, while readers of *History of Science* will be familiar with the history of the word "science" as both an actor's category and ideologically charged rubric for interpreting the past, specifying its historical relation with "work" and "labor" helps root the discussion that follows.[3]

Contributors to this special issue largely use "work" and "labor" interchangeably for reasons of ease and style. They are, however, only partial synonyms, each with its own etymology and set of meanings. As a noun, work can refer simply to something that is or was done, often in judgmental contrast to leisure or idleness. But it can also infer cultural

1. Alexandra Hui, Lissa L. Roberts, and Seth Rockman, "Let's Get to Work: Bringing Labor History and the History of Science Together," *Isis* 114 (2023): 817–26.
2. Seth Rockman, Lissa L. Roberts, and Alexandra Hui, "Joining Forces: Labor History and the History of Science," *Labor: Studies in Working-Class History* 21 (forthcoming, 2024).
3. Jan Golinski, "Is it Time to Forget Science? Reflections on Singular Science and its History," *Osiris* 27 (2012): 19–36.

value, as in a "work of art," or moral status, as in "good works," performed out of a sense of social or faith-based responsibility. As a verb, it refers to the action of a person, animal, or contrivance, generally directed toward a function and/or purpose. Quite often it entails an assemblage in which humans act in concert with each other, animals, materials, tools, and/or machinery.[4]

Like work, labor denotes an interesting range of meanings: the physiological process whereby a mother gives birth; physical, mental, or emotional exertion; toil that merits remuneration or is subject to extraction; a historically emerging, collective socioeconomic or political entity, often with a capital "L". As Marx so potently analyzed, all these meanings consider labor as separated from its efforts' results and full value. By exploring the space of alienation that has come to exist between labor as the performance of work and the fruits of that exertion, we can recover what history and too many historians have rendered invisible and recognize labor's vast contributions. Importantly, historians have realized that these acts of recovery must extend beyond a traditional focus on the (industrial) working class and include attention to the fullest range of workers. The contributions to this special issue pursue this goal by focusing on a broad cast of characters: scholars, scribes, illustrators, translators, slaves, indentured servants, women armaments workers, oil drillers, "coolies," and farmers.

Of special interest is that Marx linked his analysis of labor exploitation to the exploitation of nature and that he did so by drawing on Justus von Liebig's conception of "metabolism" [*stoffweschel* – literally, "material exchange"]. In his work on agricultural chemistry, Liebig made crucial contributions to the understanding of soil's need for nutrients, the dangers of soil exhaustion, and the unsustainability of modern agriculture on a global scale without a system for managing fertility. Marx, in turn, defined labor as "a process by which man, through his own actions, mediates, regulates and controls the metabolism between himself and nature."[5] Under capitalism, however, "the circumstances surrounding that metabolism" had been destroyed, leading to the degradation of both labor and the environment.[6] We see here one more instance of the intimate connection between labor history and the history of science, as well as their confluence with environmental history.

The word "science" stems from the Latin *scientia* [knowledge] and *scire* [to know]. This root definition certainly held in the medieval West; scholastics understood *scientia* to denote absolute knowledge, opposed, for example, to faith or moral conviction – science versus conscience, if you will. We see its legacy today in talk of science as "knowledge production" and calls to place the history of science under the banner of the history

4. The concept of "workscapes," which recognizes the nigh impossibility of maintaining control over every component, captures this understanding. Thomas Andrews, *Killing for Coal: America's Deadliest Labor War* (Cambridge, MA: Harvard University Press, 2008), p.125.
5. Karl Marx, *Capital*, Vol. I (New York, NY: Vintage, 1976), pp.283, 290; cited in John Bellamy Foster, *Marx's Ecology: Materialism and Nature* (New York, NY: Monthly Review Press, 2000), p.157.
6. Marx, *Capital*, Vol. I, p.368 (note 5), cited in Foster, *Marx's Ecology*, p.156 (note 5). See also John Bellamy Foster, "Marx's Theory of Metabolic Rift: Classical Foundations for Environmental Sociology," *American Journal of Sociology* 105 (1999): 366–405, esp. 379; Jason Moore, *Capitalism and the Web of Life* (London: Verso, 2015).

of knowledge.[7] But privileging knowledge as the telos of science obscures the latter's historical relations with "work" and "labor," the recognition of which is necessary to appreciate how extensively "science in action" is affected by and implicated in the actualities of our world's past, present, and future. And this recognition is, in turn, necessary as a step toward recognizing the social responsibilities of both science and its historians.

The concept of "work" [*travail*] has long had a place within the history of physics, though insufficient attention has been given to the broader historical consequences of its particularly defined inclusion. "*Travail*" was introduced into the lexicon of physics with the 1829 publication of Gustave Coriolis, *Du calcul de l'effet des machines, ou Considérations sur l'emploi de moteurs et sur leur évaluation*, defined quantitatively as expended effort and traveled distance (*l'idée d'un effort exercé et d'un chemin parcouru simultanément*).[8] Initially applicable to the study of machines, the term found a new context and meaning with Helmholtz's work on the conservation and convertibility of energy, of which *arbeitskraft* (labor power) was one form. These developments collapsed the Cartesian dichotomy of human and nonhuman machines, situating human work and labor power within a unified system of scientific analysis.[9] Following the advent of the second law of thermodynamics, which aligned human fatigue with other forms of energy loss, the door was opened for the development of a science of work and its rationalized management on both the shop floor and throughout society.[10]

This history bears a certain irony. For as work became subject to scientific analysis, equating science with knowledge both camouflaged its practical essence and isolated it from the other sorts of labor with which it is actually entwined. Enunciating where scientific work is done, however, helps counteract this, given that the laboratory – literally "a place for labor" – is historically one of its most iconic locations. Identifying science as what is done in places of labor invites us to explore the expansive list of sites in which it takes place.[11] As those sites multiply, so does the range of people who can be said to "do" science, along with what that "doing" entails. In turn, this larger cast of characters and activities reveals the equally wide range of social relations that have mobilized scientific labor across time and place, whether under the patronage of princely courts, the violence of slave plantations, the salaried comfort of corporate research parks, the sweltering heat of kitchens, or the hallowed halls of universities. It might be pleasing to frame science narrowly as "discovery," its essence somehow independent of all the other relationships that organize the social world. But we know this to be untrue. Yet even as we start with science as not merely related to labor, but *as* labor, we must still confront our disciplines' tendencies to obscure this important realization.

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7. Lorraine Daston, "The History of Science and the History of Knowledge," *Know: A Journal on the Formation of Knowledge* 1 (2017): 131–54.
8. Gustave Coriolis, *Du calcul de l'effet des machines, ou Considérations sur l'emploi de moteurs et sur leur évaluation* (Paris: Carilian-Goeury, 1829), p.17.
9. Anson Rabinbach, *The Human Motor: Energy, Fatigue, and the Origins of Modernity* (New York, NY: Basic Books, 1990). For Engels' subordination of political economy to the "science of labor power," see p.82.
10. M. Norton Wise and Crosbie Smith, "Work and Waste: Political Economy and Natural Philosophy in Nineteenth-Century Britain (iii)," *History of Science* 28 (1990): 221–61.
11. Steven Shapin, "Invisible Science," *Hedgehog Review* (Fall 2016): pp. 34–46.

Tracing labor's historiographical erasure and reappearance in the history of science

As a discipline, the history of science is marked by its own history of drawing attention to and away from the entangled relations between science and labor. Reviewing that history is an important step toward recovering that which it has helped make invisible. An obvious place to start is with Boris Hessen's "The Social and Economic Roots of Newton's *Principia*," which he first presented at the Second International Congress of the History of Science and which was subsequently published with other Soviet contributions to the congress, in *Science at the Crossroads* (1931).[12] While often caricatured as a vulgar portrayal of Newton's physics, purportedly painting it as determined by the economic and technological needs of his time, the essay bears careful reading.[13] Far from a narrow determinist, Hessen viewed the scientific study of extant technologies as opening new possibilities rather than as entailing limiting constraints. In his telling, Newton was highly conversant with the economically harnessed technologies of his time, but reached far beyond such specificities in the *Principia*.

Hessen's genius was to reveal how Newton and his work served the reigning socioeconomic order in ways that went deeper than merely supporting and pursuing technical contrivances, including through their erasure of social relations. Rather than publicly acknowledge all those whose work provided him with needed data, Newton presented himself as a "boy playing [alone] on the seashore" or as "standing on the shoulders of giants."[14] Beyond projecting science as independent from the labor on which it actually rested, Newton argued for applying its seemingly autonomous authority to the world of work. Here, Hessen turned to Marx's insight regarding the fetishization of science. Observing both past and present projects, Hessen argued that reformers' application of science to improve production and the plight of workers was doomed by the ongoing erasure of "those social relations that exploit machinery in such a way as to turn the worker into a mere appendage to it."[15]

Hessen proved a divisive figure within the history of science community. Some felt compelled to refute what they unfairly painted him and similarly minded historians to be arguing. Alexandre Koyré, for example, famously quipped that "Galileo did not learn *his* business from people who toiled in the arsenals and shipyards of Venice. Quite the

12. Boris Hessen, "The Social and Economic Roots of Newton's *Principia*," in Gideon Freudenthal and Peter McLaughlin (eds.), *The Social and Economic Roots of the Scientific Revolution* (New York: Springer, 2009), pp.41–102, 57.
13. Gideon Freudenthal and Peter McLaughlin, "Classical Marxist Historiography of Science: The Hessen-Grossmann Thesis," in Freudenthal and McLaughlin (eds.), *The Social and Economic Roots*, pp.1–40 (note 12); Loren Graham, "The Socio-political Roots of Boris Hessen: Soviet Marxism and the History of Science," *Social Studies of Science* 15 (1985): 705–722; Simon Schaffer, "Newton at the Crossroads," *Radical Philosophy* (Summer 1984): 22–29.
14. Simon Schaffer, "Newton on the Beach: The Information Order of *Principia Mathematica*," *History of Science* 47 (2009): 243–76.
15. Hessen, "Social and Economic Roots," p.87 (note 12).

contrary: he taught them *theirs*."[16] More generally, historians interested in foregrounding theories and ideas as the core of scientific development tended to be reductionist in their assessment of Hessen. As Arnold Thackray explains, these were the historians of science (he mentions Marshall Clagett, I. B. Cohen, A. C. Crombie, Charles C. Gillispie, Henry Guerlac, A. Rupert Hall, Thomas Kuhn, and Richard Westfall) who spearheaded the field's professionalization in the 1950s. During a decade in which American academia barely tolerated even a whiff of Marxism, such scholars were careful to distinguish their approach from the "externalism" of Hessen and those who focused on the social relations of science.[17]

Two names stand out beside Hessen among those labeled "externalists": Edward Zilsel and Robert K. Merton. Unlike Hessen, they both accepted the separation of scientific content from the study of social relations, as they filtered their analyses through different perspectives. Zilsel's sociological inquiry into "the roots of science" was self-consciously Marxist, leading him to explore the world of work beyond the confines of fifteenth- and sixteenth-century scholarship.[18] Leaving the content of ideas and theories aside, he sought to explain how craftsmen's practices – experimentation, dissection, and quantitative measurement – crossed the social divide to be wed with the disciplined reason that he described as stock in trade for humanists and university scholars. The craftsmen of early capitalism were Zilsel's heroes; he portrayed them as innovative and

16. Alexandre Koyré, "Galileo and Plato," *Journal of the History of Ideas* 4 (1943): 400–28, 401. Emphasis in the original. Koyré did not actually cite Hessen in his article, but chose instead to reference Maxime Leroy, *Descartes Social* (Paris: Vrin, 1931); Franz Borkenau, *Der Übergang vom feudalen zum bügerlichen Weltbild* (Paris: Alcan, 1934); Henryk Grossman, "Die gesellschaftlichen Grundlagen der mechanistischen Philosophie und die Manufaktur," *Zeitschrift für Sozialforschung* 4 (1935): 161–231; Leo Olschki, *Galileo und seine Zeit* (Halle, Germany: Max Niemeyer, 1927); and Edgar Zilsel, "The Sociological Roots of Science," *The American Journal of Sociology* 47 (1942): 544–62. The first three considered Descartes and Cartesianism in relation to contemporary developments of manufacture; the last two focused on Galileo.

17. Arnold Thackray, "Science: Has its Present Past a Future?," in Jeffrey Sturchio and Bruce Lewenstein (eds.), *Science: Has its Present Past a Future?: Selected Essays by Arnold Thackray* (Ithaca, NY: Seavoss Associates, 2022), pp.152–75, 116–19. On the "externalism–internalism" debate, Steven Shapin, "Discipline and Bounding: The History and Sociology of Science as Seen through the Externalism-Internalism Debate," *History of Science* 30 (1992): 333–69. Readers will notice that this is told as an Anglo-American story – with the exception of the towering presence of Alexandre Koyré. It is worth noting that, as founder (1951) and first director of the *Centre de Recherches en Histoire des Sciences et des Techniques*, renamed the *Centre Koyré* after he stepped down, Koyré left a dominant legacy of internalism in the French history of science community, overseen especially by his successor René Taton into (at least) the 1980s. On the history (and sociology) of science in France, see Geof Bowker and Bruno Latour, "A Booming Discipline Short of Discipline: (Social) Studies of Science in France," *Social Studies of Science* 17 (1987): 715–48. The history of opposition to Koyré in France has yet to be written, but see Lucien Febvre, "De l'a peu près à la précision en passant par ouï-dire," *Annales. Histoire, Sciences Sociales* 5 (1950): 25–31; Henri Lefebvre, *Descartes* (Paris: Éditions Hier et aujourd'hui, 1948).

18. Zilsel, "Sociological Roots" (note 16).

anti-corporatist, relying on empirical observation, causal research, and experimentation. But they labored in silence, he averred, lacking the disciplined language and approach of logical thought and rational deduction. Taking advantage of the growing porosity of social boundaries brought on by capitalist development, certain "superior craftsmen" ("artist–engineers," surgeons, instrument makers, mapmakers, and the like) developed increasing literacy and interacted with their more learned, socially superior, and equally curious counterparts. Out of these interactions, he argued, came a convergence of methods that triggered modern science.

Zilsel's "The Sociological Roots of Science" was published in 1942. Merton's PhD dissertation, "Science, Technology, and Society in Seventeenth-Century England," appeared four years before, its self-announced externalism bracketed by Merton's disavowal of "materialist" (read: Marxist) causality.[19] As part of his thesis, Merton depicted the rise of capitalism in seventeenth-century England, manifested in the division of labor and expanding markets that accompanied growth in industrial, manufacturing, transportation, and military sectors. But he would say only that "the requirements of industrial technology which derive from economic development exert a powerful, though not exclusive, influence on the direction of scientific activity."[20] Scientists contributed to solving problems raised by economic and technological development, but either directly by individuals seeking profit and prestige or indirectly through the diffuse influence that society and the state had on science as a "collectivity."[21]

It was this move of describing scientists (certainly an anachronism for the seventeenth century) as belonging to a collectivity that profoundly marked Merton's oeuvre and its impact. In the same year that his dissertation appeared in the journal *Osiris* (1938), Merton published an article entitled "Science and the Social Order" that, together with one published in the midst of World War Two, laid out what he took to be the norms governing scientists and their work, carried out within the communal bounds of science.[22] Again, this was not an inquiry into the specific methods or content of science, but a social analysis of what marked scientists and their work as distinct from other communities of practitioners and society at large.[23] True "men of science" absorb a particular ethos from the start of their training, he wrote, leading them to: practice and defend scientific universalism over ethnocentrism and the interests of the state; consider scientific findings as their community's communal property; be disinterestedly honest about the results of their work; and practice organized skepticism. Such are the norms that protect the independence of scientific work and that scientists must shield from external intrusions, he claimed. If scientists

19. Robert K. Merton, "Science, Technology, and Society in Seventeenth-Century England," *Osiris* 4 (1938): 360–632. See Steven Shapin, "Understanding the Merton Thesis," *Isis* 79 (1988): 594–605.
20. Merton, "Science, Technology, and Society," p. 515 (note 19).
21. Ibid., pp. 517–18.
22. Robert K. Merton, "Science and the Social Order," *Philosophy of Science* 5 (1938): 321–37; Robert K. Merton, "Science and Technology in a Democratic Order," *Journal of Legal and Political Sociology* 1 (1942): 115–26.
23. Science, according to Merton, should be "in society but not of it." Merton, "Science and Technology," p. 116 (note 22).

had to defend their nascent community and work in the seventeenth century in terms of "economic utility and the glorification of God," he argued, in 1942 they had to defend their community's independence against both (totalitarian) governments that sought to pervert scientific findings to support their purposes *and* labor leaders and their followers who charged science with working to extend automation to their detriment.[24]

Merton's sociological depiction of science as constituted by a unique community of practitioners, bounded by an institutionalized set of norms, fit well with the view that the content of science was equally unique, bounded by criteria of objectivity and truth. Together these norms and criteria set (the historical and sociological study of) science apart from society. The gap this separation reified could then be bridged on one side by the application of science to social and technical problems, and on the other by either society's support for or constraints on science and its practitioners.

As widely noted, cracks began to appear in the walls guarding this perceived autonomy by the 1960s and 70s. Critics drew attention to science's ambivalent legacy: its entanglement with the threats of nuclear holocaust and environmental disaster; the politics of eugenics; and the profits of, for example, tobacco companies. But we can identify at least two sources from within the historical study of science, both of which might be seen as re-opening the door to recognizing the place of work/labor in the history of science. Thomas Kuhn's *Structure of Scientific Revolutions* anchored scientific development in an examination of scientific communities, raising the specter of similarities between them and communities of nonscientific practitioners.[25] And the history of chemistry accentuated the multisited character of scientific work.[26]

Following the publication of his epochal book, Kuhn was criticized for using the term "paradigm" in twenty-one different ways, which opened the book to various interpretations – not all of which Kuhn liked.[27] We therefore take license to consider it in our own way. Kuhn argued that scientific communities are held together by specific methods, standards, and techniques, some of which cannot be formally articulated, but are passed

24. Ibid.

25. Thomas Kuhn, *The Structure of Scientific Revolutions* (Chicago, IL: University of Chicago Press, 1962). Kuhn argued against interpreting his book as undergirding the social construction of scientific knowledge and arguments from interest, which would indeed make scientific communities and practices essentially similar to other communities. Thomas Kuhn, "The Trouble with the Historical Philosophy of Science," in James Conant and John Haugeland (eds.), *The Road Since Structure: Philosophical Essays, 1970–1993, with an Autobiographical Interview* (Chicago, IL: University of Chicago Press, 2000), pp.105–20.

26. One might also refer to historians of the field sciences, which also directed attention beyond the laboratory. Henrika Kuklick and Robert E. Kohler (eds.), *Science in the Field*, vol. XI of *Osiris* (Chicago, IL: University of Chicago Press, 1996); Robert Kohler and Jeremy Vetter, "The Field," in Bernard Lightman (ed.), *A Companion to the History of Science* (New York, NY: John Wiley and Sons, 2016), pp.282–95. We focus on the history of chemistry not only because its study was recognized as a field of study earlier, but also because it revealed chemistry and chemically based activities as present across a huge range of material- and knowledge-producing endeavors (often in ways that demonstrate the hybridity of material and knowledge production), making it harder to ignore the interactions between science and labor.

27. Margaret Masterman, "The Nature of a Paradigm," in Imre Lakatos and Alan Musgrave (eds.), *Criticism and the Growth of Knowledge* (Cambridge: Cambridge University Press, 1970), pp.59–90. For Kuhn's response, see his "Reflections on my Critics," in Imre Lakatos

on through training. Science, from this perspective, is revealed as constituted by organized work practices, some of which must be learned on the job and most of which are subject to internal management and discipline. Once understood as a community at work, the distance between scientific and other working communities is greatly reduced.

While Kuhn's discussion situates science in clearly identifiable research- and teaching-oriented locations, separated from the quotidian worlds of making and the market, historians of chemistry have contended with a much broader array of worksites. From the early twentieth century until at least the 1970s, this challenge was largely met by accepting a separation between theory and application, assigning them to distinct sites, sets of historical actors, and studies. As such, the chemical revolution of the late eighteenth century took on a schizophrenic character. Usually examined in terms of a break in theory – a "postponed" scientific revolution, it was occasionally studied in terms of the application of chemical knowledge to industry as part of the broader Industrial Revolution.[28] The first was situated in libraries, laboratories, and scientific societies; the second focused on sites of material extraction and chemical manufacture.[29] But what about intermediary figures, practices, and sites that didn't fit with this sharp division of labor: apothecaries, mining managers, innovative dye and porcelain manufacturers, brewers, and distillers? At some point it became impossible to view them as nothing more than "sooty empirics," as some among their ranks went to university, belonged to scientific societies, and published in scientific journals.[30] And what of the activities carried out by the scientific heroes of the chemical revolution? The biographies of Lavoisier, Guyton de Morveau, Chaptal, and numerous others are filled with crossover details that highlight the practical entanglements of material, knowledge, and political production.

Chemistry historically required the coordinated manipulation of hands, instruments, minds, and material substances, whatever the immediate goal.[31] As such, it entailed work. Did that work entail a division of labor? Certainly, but not in a way that maps

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and Alan Musgrave (eds.), *Criticism and the Growth of Knowledge* (Cambridge: Cambridge University Press, 1970), pp. 231–78.

28. Herbert Butterfield, *The Origins of Modern Science* (London: Bell and Sons, 1957), chapter 11.
29. For the first, Hélène Metzger, *La philosophie de la matière chez Lavoisier* (Paris: Hermann et cie, 1935). For the second, Archibald Clow and Nan Clow, *The Chemical Revolution: A Contribution to Social Technology* (London: Batchworth Press, 1952). For the chemical revolution as a "postponed" revolution, Butterfield, *The Origins*, chapter 11 (note 28).
30. Ursula Klein, "Hybrid Experts," in M. Valleriani (ed.), *The Structures of Practical Knowledge* (Dordrecht, Netherlands: Springer, 2017), pp.287–306.
31. Ursula Klein, "Technoscience *avant la lettre*," *Perspectives on Science* 13 (2005): 226–66. A "new history of alchemy" has emphasized practice and its associated labor. See Marcos Martinón-Torres, "Some Recent Developments in the Historiography of Alchemy," *Ambix* 58 (2011): 215–37; Margaret Garber, "Untwisting the Greene Lyon's Tale," *Historical Studies in the Natural Sciences* 39 (2009): 491–500; Tara Nummedal, *Alchemy and Authority in the Holy Roman Empire* (Chicago, IL: University of Chicago Press, 2009); George Starkey, *Alchemical Laboratory Notebooks and Correspondence*, edited by William Newman and Lawrence Principe (Chicago, IL: University of Chicago Press, 2004).

easily onto the distinction between mind and hand or theory and application.[32] History and historiography, however, are filled with attempts to make it seem as if this was so.[33] What is more, as captured by Steven Shapin's term "invisible technicians," the often essential work performed by laborers and assistants of various sorts was effaced by historical authorities and historians alike.[34] Focusing on Robert Boyle's private laboratory, Shapin demonstrates that numerous assistants were actively engaged there. Though they rarely appear in the written record, Boyle depended on their experimental work. Within the laboratory, his managerial oversight led him to demand that experiments with unclear outcomes be repeated. In the public arena, he carefully managed his assistants' (in)visibility, augmenting his own credit when things succeeded and shifting responsibility to underlings when they went wrong.[35]

Shapin's call to recover the role played by "invisible technicians" has met with widespread response.[36] But the recovery work done by others also stimulated attention, such as that previously done in the field of sociology to make women's work visible.[37] Among historians of science, Margaret Rossiter sought to counter the "Matilda effect" by recounting the too-often ignored achievements of American women scientists.[38] Others went beyond the narrow confines of official sites of scientific work and drew attention to the crucial role played by women in domestic settings. This underscored both women's involvement in scientific work and the fact that much of that history is situated in nonconventional scientific settings.[39] Among other things, attention to women's domestic

32. Lissa Roberts, Simon Schaffer, and Peter Dear (eds.), *The Mindful Hand: Inquiry and Invention from the Late Renaissance to Early Industrialism* (Amsterdam, Netherlands: Royal Netherlands Academy of Arts and Sciences, 2007).
33. Simon Schaffer, "Enlightened Automata," in Simon Schaffer, William Clark, and Jan Golinski (eds.), *The Sciences in Enlightened Europe* (Chicago, IL: University of Chicago Press, 1999), pp.126–65.
34. Steven Shapin, "The Invisible Technician," *American Scientist* 77 (1989): 554–63.
35. Ibid., p. 558.
36. Lydia Barnett, "Showing and Hiding: The Flickering Visibility of Earth Workers in the Archives of Earth Science," *History of Science* 58 (2020): 245–74; Jenny Bangham, Xan Chacko, and Judith Kaplan, *Invisible Labour in Modern Science* (Lanham, MD: Rowman and Littlefield, 2022); Patrick Anthony et al., "(Un)making Labor Invisible: A Syllabus," *History of Science* 61 (2023): xx–xx.
37. Arlene Kaplan Daniels, "Invisible Work," *Social Problems* 34 (1987): 403–15.
38. Margaret Rossiter, *Women Scientists in America: Struggles and Strategies to 1940* (Baltimore, MD: Johns Hopkins University Press, 1982); Margaret Rossiter, *Women Scientists in America: Before Affirmative Action, 1940–1972* (Baltimore, MD: Johns Hopkins University Press, 1998); Margaret Rossiter, "The Matthew Matilda Effect in Science," *Social Studies of Science* 23 (1993): 325–41. See also Evelyn Fox Keller, "Feminism and Science," *Signs: Journal of Women in Culture and Society* 7 (1982): 589–602.
39. Alisha Rankin, *Panaceia's Daughters: Noblewomen as Healers in Early Modern Germany* (Chicago, IL: University of Chicago Press, 2013); Paula Findlen, "Listening to the Archives: In Search of the Eighteenth-Century Women of Science," in Paola Govoni and Zelda Alice Franceschi (eds.), *Writing about Lives in Science: (Auto)biography, Gender and Genre* (Göttingen, Germany: V&R, 2013), pp.87–115; Nina Rattner Gelbart, *Minerva's French Sisters: Women of Science in Enlightenment France* (New Haven, CT: Yale University Press,

work has given the lie to common claims that science and technology invariably lead to a reduction of labor.[40]

Another influential avenue for making unconventional scientific work visible has involved a focus on the African diaspora and the valuable contributions of enslaved peoples' labor.[41] A standard Cold War trope argues that science is directional, spreading from the West to the rest of the world as a vehicle of progress.[42] Contrarywise, as Judith Carney recounts in the introduction to *Black Rice*, innovative research in the early 1970s began to reveal the impact of enslaved Africans and the expertise they brought with them on American agriculture.[43] Some reviewers of her book dug their heels in, criticizing her thesis because written and statistical traces of these claimed contributions could not be found in the archives. Without evidence, the standards for which (as Duygu Yildirim argues in her contribution to this special issue) tend to replicate the hegemony of Western culture and its calculus of (in)visibility, the traditional geography of scientific "diffusion" would continue to stand.[44] Recovery, in other words, has faced – and continues to face – both the disciplinary biases of historians and the silence of conventional archives in which they apply their interpretive standards.

2021); Tara Nummedal, *Anna Zieglerin and the Lion's Blood: Alchemy and End Time in Reformation Germany* (Philadelphia, PA: University of Pennsylvania Press, 2019); Catherine McNeur, *Mischievous Figures: The Forgotten Sisters who Transformed Early American Science* (New York, NY: Basic Books, 2023).

40. Ruth Schwartz Cowan, *More Work for Mother: The Ironies of Household Technology from the Open Hearth to the Microwave* (New York, NY: Basic Books, 1983); Trish Kahle, "Electric Discipline: Gendering Power and Defining Work in Electric Power Systems," *Labor: Studies in Working-Class History* 21 (forthcoming, 2024).
41. Mary E. Hicks, "Blood and Hair: Barbers, Sangradores and the West African Corporeal Imagination in Salvador da Bahia, 1770–1870," in Sean Morey Smith and Christopher Willoughby (eds.), *Medicine and Healing in the Age of Slavery* (Baton Rouge, LA: Louisiana State University Press, 2021), pp.61–80; Kathleen S. Murphy, "Translating the Vernacular: Indigenous and African Knowledge in the Eighteenth-Century British Atlantic," *Atlantic Studies* 8 (2011): 29–48; Pablo F. Gomez, *The Experiential Caribbean: Creating Knowledge and Healing in the Early Modern Atlantic* (Chapel Hill, NC: University of North Carolina Press, 2017); Susan Scott Parish, "Diasporic African Sources of Enlightenment Knowledge," in James Delbourgo and Nicholas Dew (eds.), *Science and Empire in the Atlantic World* (New York, NY: Routledge, 2007), pp.281–310.
42. Walt Whitman Rostow, *The Stages of Economic Growth, a Non-Communist Manifesto* (Cambridge: Cambridge University Press, 1960); George Basalla, "The Spread of Western Science," *Science* 156 (1967): 611–22.
43. Judith Carney, *Black Rice: The African Origins of Rice Cultivation in the Americas* (Cambridge, MA: Harvard University Press, 2001); Peter Wood, *Black Majority: Negroes in Colonial South Carolina, from 1670 through the Stono Rebellion* (New York, NY: Alfred A. Knopf, 1974).
44. Case Watkins and Judith Carney, "Amplifying the Archive: Methodological Plurality and Geographies of the Black Atlantic," *Antipode* 54 (2022): 1297–319; Duygu Yildirim, "Ottoman Plants, Nature Studies, and the Attentiveness of Translational Labor," *History of Science* 61 (2023): 497–521.

The growth of what is loosely called the "global history of science" provides a repository of strategies for overcoming this double-layered challenge, as it moves beyond the history of imperialism's binary view of "Western science" as either a force of progress or repression.[45] Some call for decentering science as only one of many systems of natural knowledge, others for uncovering go-betweens who worked as intermediaries between different parties, their interests, and cultures.[46,47] Still others advocate reading between the lines of local encounters and charting how the work of indigenous practitioners was transformatively appropriated through its export to Western metropolitan centers.[48] And still others encourage focusing on work, itineraries, and exchanges whose geographies bypass the Global North.[49]

Whatever historiographical strategy one chooses, the recovery project should entail asking how, why, and by whom such stories were rendered invisible. How have we come to forget? What are the consequences of this learned ignorance? Robert Proctor and Londa Schiebinger provide initial answers, but they need to be reinforced and amplified.[50] Beyond the innocent ignorance that can actually spur curiosity, Proctor and Schiebinger distinguish two other types. The first is born of the choice to look in one direction, which inevitably entails ignoring or denigrating what is going on elsewhere. Influential historians of science such as Koyré, as we've shown, emphasized the philosophical underpinnings and theoretical character of science – at best considering what went on outside the minds and laboratory-bound activities of a select few as "external factors" that "enable or constrain." This has had a long-lasting impact on the field,

45. Lissa Roberts, "Situating Science in Global History: Local Exchanges and Networks of Circulation," *Itinerario* 33 (2009): 9–30; Sujit Sivasundaram, "Global Histories of Science," *Isis* 101 (2010): 95–158; Fa-ti Fan, "The Global Turn in the History of Science," *East Asian Science, Technology and Society* 6 (2012): 249–58. Fan's critique of the term "trading zone" (pp. 254–5) is especially valuable.
46. Helen Watson-Verran, David Turnbull, and Sheila Jasanoff, "Science and Other Indigenous Knowledge Systems," in Nico Stehr and Reiner Grundmann (eds.), *Knowledge: Critical Concepts* (London: Routledge, 2005), pp.345–69.
47. Simon Schaffer et al. (eds.), *The Brokered World: Go-Betweens and Global Intelligence, 1770–1820* (Sagamore Beach, MA: Science History Publications, 2009).
48. Kapil Raj, "Circulation and the Emergence of Modern Mapping: Great Britain and Early Colonial India, 1764–1820," in Claude Markovits, Jacques Pouchepadass, and Sanjay Subrahmanyam (eds.), *Society and Circulation: Mobile People and Itinerant Cultures in South Asia 1750–1950* (New Delhi, India: Permanent Black, 2002), pp.23–54; Simon Werrett, "William Congreve's Rational Rockets," *Notes and Records of the Royal Society* 63 (2009): 35–56.
49. Dana Leibsohn and Meha Priyadarshini, "Transpacific: Beyond Silk and Silver," *Colonial Latin American Review* 25 (2016): 1–15; Clapperton Mavhunga (ed.), *What Do Science, Technology, and Innovation Mean from Africa?* (Cambridge, MA: The MIT Press, 2017).
50. Robert Proctor and Londa Schiebinger (eds.), *Agnotology: The Making and Unmaking of Ignorance* (Palo Alto, CA: Stanford University Press, 2008); Peter Galison and Robert Proctor, "Agnotology in Action: A Dialogue," in Janet Kourany and Martin Carrier (eds.), *Science and the Production of Ignorance: When the Quest for Knowledge is Thwarted* (Cambridge, MA: MIT Press, 2020), pp.27–54.

ranging from histories that consciously support a vision of science and democracy as the twin motors of progress to those written from the stance of the history of ideas.[51] Even Marxist historians of science offered little resistance since the 1950s in that they too largely sought the historical foundations of science through the study of concepts.[52] But the approach was also naturalized by succeeding generations of historians, some of whom had imbibed the myth of "pure" science while working on science degrees, others of whom came to the history of science as intellectual or cultural historians with little or no experience of what actual scientific practice entails to help them counterbalance such a limiting view. As history attests, this sort of learned ignorance is hard to unlearn.[53]

The second type of ignorance is consciously produced and defended by (historical) actors, often with the witting or unwitting complicity of science and scientists. Recent examples include cases involving the tobacco, chemical, and fossil fuel industries, in which scientists were recruited to obscure or counter evidence of negative effects on public health and the environment.[54] Exposés of these practices rightly raise public outrage. But we are interested here in a more pervasive and longer-term process that has been intrinsic to the coupled construction and maintenance of knowledge and social order since at least the seventeenth century. No one has done more to what this entailed than Simon Schaffer. In an impressive series of articles, Schaffer analyzes the work that went into re-presenting workers who were most closely and practically engaged with material production as needing the guiding discipline of externally situated science.[55] His analyses range from the dockyards on which nations' naval and commercial might

51. For the first, Charles Coulton Gillispie, *The Edge of Objectivity: An Essay in the History of Scientific Ideas* (Princeton, NJ: Princeton University Press, 1960). For the second, Amos Funkenstein, *Theology and the Scientific Imagination from the Middle Ages to the Seventeenth Century* (Princeton, NJ: Princeton University Press, 1986).
52. James Secord, "Revolutions in the Head: Darwin, Malthus and Robert M. Young," *British Journal for the History of Science* 54 (2021): 41–59, 45.
53. Jean-Paul Gaudillière and Ilana Löwy tell an all-too-typical story of work in a scientific laboratory, which they describe as, on one hand, "[d]eeply concerned with the manipulation of industrial commodities and the use of industrial models of work organization" and, on the other, managed by a scientist who is convinced that they are exclusively involved in "the production and diffusion of scientific knowledge." The links to industrial labor remain "invisible unless something goes wrong." Jean-Paul Gaudillière and Ilana Löwy (eds.), *The Invisible Industrialist: Manufacture and the Construction of Scientific Knowledge* (London: Palgrave Macmillan, 1998), pp.3–4.
54. Robert Proctor, *Cancer Wars: How Politics Shapes What We Know and Don't Know about Cancer* (New York, NY: Basic Books, 1995); Naomi Oreskes and Erik M. Conway, *Merchants of Doubt: How a Handful of Scientists Obscured the Truth on Issues from Tobacco Smoke to Global Warming* (New York, NY: Bloomsbury Press, 2010); Gerald Markowitz and David Rosner, *Deceit and Denial: The Deadly Politics of Industrial Pollution* (Berkeley, CA: University of California Press, 2002); David Michaels, *Manufactured Uncertainty: Contested Science and the Protection of the Public's Health and Environment* (New York, NY: Oxford University Press, 2007); Kourany and Carrier (eds.), *Science and the Production of Ignorance* (note 50).
55. Schaffer, "Newton at the Crossroads" (note 13); Simon Schaffer, "Astronomers Mark Time: Discipline and the Personal Equation," *Science in Context* 2 (1988): 115–45; Simon Schaffer,

depended, to the automated silk manufactories discussed in the *Encyclopédie*, and the workshops where automatic machines – the very machines intended to replace human intelligence – were produced.[56] Together, they underscore how the mindful contributions of those who worked with their hands were challenged, subdued, silenced, and co-opted in the name of enlightened, scientific reason. While historical examples of clichéd rhetoric abound regarding the need to discipline workers for the sake of material and moral progress, Schaffer delineates how science-laden processes such as rearranging the spatial architecture of workplaces, gaining a manipulative monopoly over paper tools, and establishing regimes of standardization contributed to the reconstitution of workers as "appendages of the machine."

Nothing symbolizes this transition better, perhaps, than the industrial chemist Andrew Ure's cruel title *The Philosophy of Manufactures*, by which he celebrated the modern factory system's management of "scientific, moral, and commercial economy" as dependent on wresting initiative and control from workers. "Manufacture," he proclaimed, had come by 1835 to mean "machinofacture."[57] This returns us to questions regarding the relations between science, labor, and the worlds they inhabit. The challenge now is to enunciate these questions and provide answers that are explicit about the matters of social, cultural, epistemological, and environmental justice they entail.

The political economy of science as/and labor

A robust project of recovery has been underway for three decades now to rectify the erasures of labor in the history of science. Committed to a more socially inclusive and globally expansive history, recent scholarship has repopulated the scientific past with workers "once known."[58] Re-visibilizing labor (alongside naming erasure as a deliberate and violent exertion of power) is a flourishing and essential element of a history of science responsive to the political and moral claims of the present. This project benefits from a deeper engagement with labor history as a mode of inquiry with its own sensibilities, preoccupations, and historiography.[59] Beyond undergirding further scholarship of

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"Babbage's Intelligence: Calculating Engines and the Factory System," *Critical Inquiry* 21 (1994): 203–27; Simon Schaffer, "Experimenters' Techniques, Dyers' Hands, and the Electric Planetarium," *Isis* 88 (1997): 456–83; Schaffer, "Enlightened Automata" (note 33); Simon Schaffer, "'The Charter'd Thames': Naval Architecture and Experimental Spaces in Georgian Britain," Roberts et al., *The Mindful Hand*, pp.279–305 (note 32); Schaffer, "Newton on the Beach" (note 14).

56. For a twentieth-century case that parallels this final setting, David Noble, "Social Choice in Machine Design: The Case of Automatically Controlled Machine Tools, and a Challenge for Labor," *Politics and Society* 8 (1978): 313–47.
57. Andrew Ure, *The Philosophy of Manufactures: An Exposition of the Scientific, Moral, and Commercial Economy of the Factory System* (London: Charles Knight, 1835).
58. Gabriela Soto Laveaga, "Worker Once Known: Thinking with Disposable, Discarded, and Precariously Employed Laborers in History of Science," *Isis* 114, no. 1 (2023): 834–40.
59. See also Hui et al., "Let's Get to Work" (note 1).

recovery, we hope this engagement will increase appreciation of science itself as labor and as always entangled with other forms of labor.

Consider scholars' longstanding interest in scientific practice's spatial dimensions. If modern science has sought universals that render location irrelevant, historians have shown that space and place still establish the terms of scientific authority and enable knowledge claims to travel, achieve reproducibility, and become facts.[60] At the micro- and macro- scales, the characteristics of a given location structure the labor of investigation and discovery. Cubicles, glass office doors, elevator speakers, and other design elements shape interactions and collaborations in scientific workspaces, but so does whether the state provides universal healthcare, respects women's reproductive freedom, issues visas easily to foreign nationals, or recognizes the right to collective bargaining. The bucolic landscaping of corporate research campuses promotes collaborative interactions and facilitates quiet thinking, while ample parking or proximity to "good" public schools might determine who is present to work on a project.[61]

Equally important are the impacts of terrain, temperature, altitude, and other climatic conditions on scientific labor. Practices of collection and observation reflect the particularities of place: the length of time a person can work on the seafloor, the garb necessary to conduct Arctic research, or the techniques required to preserve data during monsoon season.[62] Attention to space and place highlights the somatic and material experiences of scientific labor while gathering environment, political economy, and quotidian social relations together into "workscapes." For Thomas Andrews, who introduced the concept to write the natural world into his history of a deadly, early-twentieth-century Colorado coal strike, "workscapes" foreground the "constellation of unruly and ever-unfolding relationships" between human and nonhuman actors (and nonhuman actors with one another) in the performance of work.[63] Latourian echoes, as well as elements of a "new materialist" thinking that redistributes agency and calls for *more-than-human* histories,

60. David N. Livingstone, *Putting Science in its Place: Geographies of Scientific Knowledge* (Chicago, IL: University of Chicago Press, 2003); Diarmid A. Finnegan, "The Spatial Turn: Geographical Approaches in the History of Science," *Journal of the History of Biology* 41 (2008): 369–88.

61. William H. Rankin, "The Epistemology of the Suburbs: Knowledge, Production, and Corporate Laboratory Design," *Critical Inquiry* 36 (2010): 771–806; Alex Sayf Cummings, *Brain Magnet: Research Triangle Park and the Idea of an Idea Economy* (New York, NY: Columbia University Press, 2020); Robin Wolfe Scheffler, "David Clem: Building Genetown," *The Metropole: The Official Blog of the Urban History Association*, March 28, 2023, <https://themetropole.blog/2023/03/28/david-clem-building-genetown/> (accessed 8 September 2023).

62. Kimberley Peters, Philip Steinberg, and Elaine Strathford (eds.), *Territory beyond Terra* (Lantham, MD: Rowman and Littlefield, 2018); David Aubin, Charlotte Bigg, and H. Otto Sibum (eds.), *Heavens on Earth: Observatories and Astronomy in Nineteenth-Century Science and Culture* (Durham, NC: Duke University Press, 2010); Hester Blum, *The News at the Ends of the Earth: The Print Culture of Polar Exploration* (Durham, NC: Duke University Press, 2019).

63. Andrews, *Killing for Coal*, p.125 (note 4). For importing this frame to the history of science, see Patrick Anthony, "Introduction to 'Working at the Margins: Labor and the Politics of Participation in Natural History, 1700–1830,'" *Berichte zur Wissenschaftsgeschichte* 44 (2021): 121–5.

are evident here.[64] Among scholars modeling this approach, Tamara Fernando writes a "below the waterline" account of an Indian Ocean pearl fishery in which Gulf of Mannar divers and British colonial mapmakers constructed competing seafloor cartographies in conjunction with oceanic currents, sharks, parasitic tapeworms, and bivalves.[65]

This spatial shift decenters laboratories, salons, and universities as the emblematic sites of science, taking us instead to sites like the ocean floor and making it easier to see scientific work mobilized across the widest spectrum of conditions: by freely made contract and violent extraction, with and without remuneration, through the market and within the household. The diversity of labor relations that science entails reflects the diversity of the spaces where it is practiced. Predictable wages, year-long salaries, and employee benefits have never characterized most scientific labor, any more than has the ability of most scientific workers to choose their own employers or seek better pay in a competitive market. Princely court, colonial research stations, artisan workshops, and university biology labs all mobilize labor under their own logics, often producing internal stratifications that distinguish, for example, the "principal investigator" who has gained summer salary through a grant, their graduate students and lab techs working on terms established by a union contract, and a janitorial staff earning hourly wages from a company to which the university has outsourced its building maintenance.

Hand-in-hand with the history of science's global turn, attention to the geographical distribution of scientific work accentuates the multiplicity of labor forms it mobilizes; the natural philosopher reliant on courtly patronage and the enslaved specimen-gatherer toiling under compulsion slide into the same narrative frame.[66] Recognizing the simultaneity *and* compatibility of presumptively antagonistic modes of production encompassed by science aligns with the impulses of a global labor history to emphasize capitalism's capacity to coordinate commodity production across space under disparate, discrete, and dispersed regimes of governance.[67] "Core" and "periphery" – whether the factory and the plantation, or the laboratory and the "field" – have relied on radically different terms of

64. Emily O'Gorman and Andrea Gaynor, "More-Than-Human Histories," *Environmental History* 25 (2020): 711–35.

65. Tamara Fernando, "Mapping Oysters and Making Oceans in the Northern Indian Ocean, 1880–1906," *Comparative Studies in Science and History* 65 (2023): 53–80; Tamara Fernando, "Seeing Like the Sea: A Multispecies History of the Ceylon Pearl Fishery 1800–1925," *Past & Present* 254 (2022): 127–60.

66. Daniel Rood, "Toward a Global Labor History of Science," in Patrick Manning and Daniel Rood (eds.), *Global Scientific Practice in an Age of Revolutions, 1750–1850* (Pittsburgh, PA: University of Pittsburgh Press, 2016), pp.255–74; Lissa Roberts, "Exploring Global History through the Lens of Chemistry: Materials, Identities, and Governance," *History of Science* 54 (2016): 335–61; James Delbourgo, "The Knowing World: A New Global History of Science," *History of Science* 57 (2019): 373–99; Fa-ti Fan, "The Global Turn in the History of Science," *East Asian Science, Technology and Society: An International Journal* 6 (2012): 249–58.

67. Marcel van der Linden, "The Promise and Challenges of Global Labor History," *International Labor and Working-Class History* 82 (2012): 57–76; Christian G. De Vito, Juliane Schiel, and Matthias Van Rossum, "From Bondage to Precariousness? New Perspectives on Labor and Social History," *Journal of Social History* 54 (2020): 644–62; Sven Beckert, "The Labor of Capitalism: Industrial Revolution and the Transformation of the Global Cotton-Growing

labor, but one could scarcely conceptualize a history of industrialization or, say, botany without both elements in the picture.[68]

The ubiquity and persistence of coerced labor have proven animating concerns both for labor historians and historians of science, directing their attention to plantation refineries, subterranean silver mines, and exploratory expeditions in the service of cartography, oceanography, and geology. The embeddedness of Western science in the exploitative relations of colonialism and plantation slavery is well-established in the scholarship, with space often functioning to produce race when some bodies are deemed more suited than others to labor under "hostile" environmental conditions. Opportunities remain to explore other spaces of unfreedom, including penal colonies, poor relief institutions, and military barracks, which have played their own roles in the production of difference.[69] To the extent that confinement and conscription have generated bodies for testing and experimentation, it is worth thinking further about forms of "clinical" or "biological" labor that, even when consensual, often defy straightforward forms of compensation.[70] Scientific labor under state socialism suggests yet other varieties of coercion that have

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Countryside," in Leon Fink, Joseph A. McCartin, and Joan Sangster (eds.), *Workers in Hard Times: A Long View of Economic Crises* (Urbana, IL: University of Illinois Press, 2014), pp.83–98.

68. Emblematic work might include Prakash Kumar, "Plantation Science: Improving Natural Indigo in Colonial India, 1860–1913," *British Journal of the History of Science* 40 (2007): 537–65; Londa Schiebinger, *Plants and Empire: Colonial Bioprospecting in the Atlantic World* (Cambridge, MA: Harvard University Press, 2007); Michael Boyden, "Introduction to Special Issue: The New Natural History," *Early American Literature* 54 (2019): 633–41.
69. Daniel Rood, "Plantation Laboratories: Industrial Experiments in the Cuban Sugar Mill, 1830–1860," in Dale W. Tomich (ed.), *New Frontiers of Slavery* (Albany, NY: SUNY Press, 2016), pp.157–84; Eric Otremba, "Enlightened Institutions: Science, Plantations, and Slavery in the English Atlantic, 1626–1700" (PhD dissertation, University of Minnesota, Minneapolis, MN, 2012); Renée Raphael, "In Pursuit of 'Useful' Knowledge: Documenting Technical Innovation in Sixteenth-Century Potosí," *Journal for the History of Knowledge* 1 (2020): 1–14, 11; Londa Schiebinger, *The Secret Cures of Slaves: People, Plants, and Medicine in the Eighteenth-Century Atlantic World* (Stanford, CA: Stanford University Press, 2017); Gregg Mitman and Paul Erickson, "Latex and Blood: Science, Markets, and American Empire," *Radical History Review* 107 (2010): 45–73; Patrick Anthony, "The View from the *Wachtberg*: Surveying a Mineral Empire in Central Asian Borderlands," in Tobias Kraft and Florian Schnee (eds.), *Die Tagebücher der Russisch-Sibirischen Reise* (Berlin: Akademie der Wissenschaften, 2023); Elena Serrano, *Ladies of Honor and Merit: Gender, Useful Knowledge, and Politics in Enlightened Spain* (Pittsburgh, PA: University of Pittsburgh Press, 2022); Anya Zilberstein, "Bastard Breadfruit and Other Cheap Provisions: Early Food Science for the Welfare of the Lower Orders," *Early Science and Medicine* 21 (2016): 492–508.
70. Melinda Cooper and Catherine Waldby, *Clinical Labor: Human Research Subjects and Tissue Donors in the Global Bioeconomy* (Durham, NC: Duke University Press, 2014); Rebecca Herzig and Banu Subramaniam, "Labor in the Age of 'Bio-Everything,'" *Radical History Review* 127 (2017): 103–24; Kean Birch, "Knowledge, Place, and Power: Geographies of Value in the Bioeconomy," *New Genetics & Society* 31 (2012): 183–201; Deirdre Cooper Owens, *Medical Bondage: Race, Gender, and the Origins of American Gynecology* (Athens, GA: University of Georgia Press, 2017); Wendy Kline, *Building a Better Race: Gender, Sexuality, and Eugenics from the Turn of the Century to the Baby Boom* (Los Angeles, CA: University of California Press, 2001).

functioned not only to mobilize workers en masse, but also to discipline the creative and mental work of highly educated researchers.[71]

Historians of science must also further interrogate the non-marketized labor of social reproduction: the emotional care, maintenance of useful kin networks, childrearing, and cooking and cleaning that have (for our purposes) historically "freed" male scientists to lose themselves in their work. To acknowledge the family as science's private infrastructure is not exclusively a matter of recovering the invisibilized labor of the devoted spouse or spinster sister, nor does it require delving into the interpersonal dynamics that might characterize some familial relationships as loving and others abusive. Of interest, rather, are the structural "background conditions of possibility" that, in the case of scientific labor, consolidated the requisite financial and social capital for leisure time, educational access, patronage, and the pretense of existing outside the crass demands of the market.[72]

By no means must a labor history of science originate in spatial terms, but it should be clear that the longstanding oppositions of home/work, laboratory/field, periphery/center, mobility/fixity, and presence/absence guide attention to the fundamental issue of who performs labor, under what conditions, and to whose benefit. As science is increasingly pursued in fictive spaces – "knowledge districts," "innovation hubs," and "opportunity zones" – these labor questions will be framed by public policy choices regarding tax breaks for entrepreneurs, the enforcement of safety and environmental regulations, and the educational and social welfare options for a future workforce. Likewise, in the most indispensable yet ungraspable space of the present moment – cyberspace or "the internet" – the appropriation of mental and creative labor animates anxious debates over AI and the capacity of some people to profit from – or else, to wholly de-commodify – other people's intellectual property.[73] Similarly, "citizen science" might convey a different set of political-economic

71. Karl Hall, "'The Realm of Cognition Grew out of the Realm of Labor'? Scientific Discipline, Worker Inventiveness, and Intellectual Property in the Early Soviet Union," and Yang Li, "From Bourgeois Intellectual to Replaceable Laborer: The Nationalization of Scientific Expertise as Capital in Early Socialist China, 1949–1966," projects discussed at the "Let's Get to Work: Bringing Labor History and History of Science Together" conference, Science History Institute, Philadelphia, June 2022.
72. Nancy Fraser, "Behind Marx's Hidden Abode: For an Expanded Conception of Capitalism," *New Left Review* 86 (2014): 55–72, 57; Alix Cooper, "Natural History as a Family Enterprise: Kinship and Inheritance in Eighteenth-Century Science," *Berichte zur Wissenschaftsgeschichte* 44 (2021): 211–27; Joan L. Richards, *Generations of Reason: A Family's Search for Meaning in Post-Newtonian England* (New Haven, CT: Yale University Press, 2021); Ann Fabian, "The Long Life of William Blanding: Doctor, Apothecary, Naturalist," *Journal of the Early Republic* 36 (2016): 5–36.
73. Brian L. Frye and ChatGPT, "Should Using an AI Text Generator to Produce Academic Writing Be Plagiarism?" *Fordham Intellectual Property, Media & Entertainment Law Journal* 33 (2023): 947–69.
74. Bruno J. Strasser et al., "'Citizen Science'? Rethinking Science and Public Participation," *Science & Technology Studies* 32 (2022): 51–76; Dana Mahr and Sascha Dickel, "Citizen Science beyond Invited Participation: Nineteenth Century Amateur Naturalists, Epistemic Autonomy, and Big Data Approaches avant la lettre," *History and Philosophy of the Life Sciences* 41 (2019): 41.

ambitions, but yet also bump up against the likelihood of an unequal division of labor and unequal access to the marketplace's rewards for knowledge-as-commodity.[74]

Across diverse sites of scientific labor, distinct modes of knowing both reflect and serve competing political-economy visions for making sense – and use – of the material world. The resulting frictions run along numerous axes, including class conflict. The intersectional understandings of class that predominate in labor history see economic power/powerlessness as something more than the result of a person's or group's relationship to the means of production, but rather as the product of the numerous kinds of social difference that organize a given society.[75] The tendency to presume crucial intellectual competencies as belonging exclusively to European-descended men, for example, has historically structured the scientific labor market, and the multigenerational struggle for access could readily be understood as a contest over the means of scientific production – albeit one not easily assimilated into standard accounts of class conflict.[76] At the same time, the phenomenon of capital flight (more colloquially called "globalization") has relocated portions of scientific labor to places where workers may have fewer legal protections or where the state can be better trusted to defend multinational capital.[77] Similarly, lab techs, graduate workers, and other workers within the ecosystems of research universities have formed unions and waged strikes over issues such as hourly wages and guaranteed cost-of-living increases.[78] A labor history of science that attends to the various solidarities and antagonisms that organize work and society reciprocally must also recognize that the competing interests of capital and labor are as operative in the realm of science as in other sectors of economic activity.

Science, of course, has also played a crucial role in what is traditionally understood as class conflict precisely through its contributions to management strategies for extracting greater qualities of labor from workers. From the medicalization of West Africans to legitimate their enslavement to Taylorist fantasies of docile workers toiling robot-like (and slave-like) along a factory assembly line, labor has constituted an object of study in

75. Seth Rockman, "Class and the History of Working People in the Early Republic," *Journal of the Early Republic* 25 (2005): 527–35; Julie Greene, "Rethinking the Boundaries of Class: Labor History and Theories of Class and Capitalism," *Labor: Studies in Working-Class History* 18 (2021): 92–112.

76. Mar Hicks, *Programmed Inequality: How Britain Discarded Women Technologists and Lost its Edge in Computing* (Cambridge, MA: MIT Press, 2017).

77. Colette Perold, "IBM's World Citizens: Valentim Bouças and the Politics of IT Expansion in Authoritarian Brazil," *IEEE Annals of the History of Computing* 42 (2020): 38–52; Jefferson Cowie, *Capital Moves: RCA's Seventy-Year Quest for Cheap Labor* (New York, NY: New Press, 2001).

78. Elizabeth Tandy Shermer, "What's Really New about the Neoliberal University? The Business of American Education Has Always Been Business," *Labor: Studies in Working-Class History* 18 (2021): 62–86; Gabriel Winant, *The Next Shift: The Fall of Industry and the Rise of Health Care in Rust Belt America* (Cambridge, MA: Harvard University Press, 2021).

79. Bill Cooke, "The Denial of Slavery in Management Studies," *Journal of Management Studies* 40 (2003): 1895–918; Bernard Burnes and Bill Cooke, "The Tavistock's 1945 Invention of Organization Development: Early British Business and Management Applications of Social Psychiatry," *Business History* 55 (2013): 768–89; Maarten Derksen, "Turning Men into

the behavioral, biological, and social sciences.[79] The disciplinary regimes of management and business administration have subjected laboring bodies to measurement and manipulation in the service of efficiency, ergonomics, and "industrial relations." The metrics that have assigned value to labor and laborers also merit historicizing, particularly as they have facilitated the transformation of skill, strength, and expertise into "human resources" and "human capital."[80] To the extent that state legitimacy often hinges on the perception of a successful stewardship of society's collective labor, government statistics regarding workforce participation and unemployment rates might be better understood as political claims in the service of class rule than as objective measures of reality. Scientific modes of measuring and representing work in the aggregate constitute crucial sites of political contestation, most recently exemplified by the combined efforts of the International Labor Organization and allied NGOs to measure the informal sector and count its contribution toward such weighty "facts" as gross domestic product.[81]

Long before Taylorism became a synonym for the regimentation of human labor to meet the rhythms of industrial machinery, "scientific management" had been mobilized in the service of productivity gains on plantations, in subterranean mines, and in craft workshops. The subdivision of artisanal labor processes into discrete components – made famous by Adam Smith's account of an eighteenth-century pin factory and known as "deskilling" by labor organizers and labor historians – was concurrent with efforts to codify workers' tacit knowledge, organize productive enterprises along bureaucratic structures, and employ new modes of recordkeeping on the premise that data regarding

Machines? Scientific Management, Industrial Psychology, and the 'Human Factor,'" *Journal of the History of the Behavioral Sciences* 50 (2014): 148–65; Edward Jones-Imhotep, "The Ghost Factories: Histories of Automata and Artificial Life," *History and Technology* 36 (2020): 3–29; Jason Resnikoff, "The Myth of Black Obsolescence," *International Labor and Working-Class History* 102 (2022): 124–45.

80. Loren Baritz, *The Servants of Power: A History of the Use of Social Science in American Industry* (Middletown, CT: Wesleyan University Press, 1960), pp.130–1; Eli Cook, "The Pricing of Everyday Life," *Raritan* 32 (2013): 109–21.

81. John Wallach Scott, *Gender and the Politics of History* (New York, NY: Columbia University Press, 1988), chapter 6; Oz Frankel, *States of Inquiry: Social Investigation and Print Culture in Nineteenth-Century Britain and the United States* (Baltimore, MD: Johns Hopkins University Press, 2006); Sibylle Marti, "The ILO, the Politics of Statistics, and Changing Perceptions of Informal Work, 1970–Present," *Labor: Studies in Working-Class History* 21 (forthcoming, 2024).

82. Jaap Harskamp, "In Praise of Pins: From Tool to Metaphor," *History Workshop Journal* 70 (2010): 47–66; James D. Fisher, *The Enclosure of Knowledge: Books, Power, and Agrarian Capitalism in Britain, 1660–1800* (New York, NY: Cambridge University Press, 2022); Ursula Klein, "Depersonalizing the Arcanum," *Technology & Culture* 55 (2014): 591–621; Sebastian Felton, "The History of Science and the History of Bureaucratic Knowledge: Saxon Mining, circa 1770," *History of Science* 56 (2018): 403–31; Justin Roberts, *Slavery and the Enlightenment in the British Atlantic, 1750–1807* (New York, NY: Cambridge University Press, 2013); Caitlin Rosenthal, *Accounting for Slavery: Masters and Management* (Cambridge, MA: Harvard University Press, 2018).

the past might fruitfully inform future endeavors.[82] Nor was this an exclusively Western phenomenon tied to the emergence of modern capitalism. As Francesca Bray argues, "imperial Chinese agriculture was a science in its own right," a convergence of "knowledge, practice, and power" at the intersection of the state's imperatives of governance and the planting methods of a dispersed peasantry. Collected and disseminated, agronomic knowledge aligned "science, technique, and technology" to feed a growing populace and legitimate a growing state.[83]

The notion of "embedded science" conveys the presence of science in locations that look nothing like laboratories, whether a blacksmith's workshop, a village rice field, or, in Steven Shapin's memorable example, a present-day McDonald's fast-food restaurant where "practically everything that goes on there is saturated with science." From locating individual franchises and sourcing ingredients to designing packaging and operating the touchscreen ordering station, "huge amounts of scientific and technological expertise" infuse a location often derided for its "low-skill," low-wage workforce.[84] To be sure, fry-cooks are not scientists, but the science that infuses this commercial kitchen is easily overlooked precisely because it is so "embedded." As such, it obscures the relationship of science and work that exists virtually wherever labor takes place.

Those entanglements are never far from the surface, if one looks for them. Certainly, workers, unions, and advocates of economic justice have a longstanding antagonism toward technologies that seek to measure, regulate, and intensify effort: plantation scales, time clocks, and moving assembly lines, for example. Aggression directed against industrial machinery has historically been a tactic of workers seeking to retain shopfloor authority, protect workplace prerogatives, and defend the labor theory of value.[85] What is hailed as "labor-saving technology" has often brought factory workers declining pay and layoffs, not lives of leisure and a greater share of the profits. As Salem Elzway and Jason Resnikoff argue, automation is not an inevitable function of scientific progress, but a set of strategies for capital to maximize its power vis-à-vis its workforce.[86] Similarly, the gig economy's siren song and promises of "being one's own boss" have brought with them a chilling intensification of labor discipline; smartphones facilitate geolocation, dynamic pricing, and instantaneous customer reviews for drivers contracting with app-based ride services, but not living wages. The order fulfillment warehouses of online retailers are among the most scientized contemporary workplaces, but with little benefit

83. Francesca Bray, "Science, Technique, Technology: Passages between Matter and Knowledge in Imperial Chinese Agriculture," *British Journal for the History of Science* 41 (2008): 319–44.
84. Shapin, "Invisible Science," 36, 37 (note 11).
85. Edward Baptist, *The Half Has Never Been Told: Slavery and the Making of American Capitalism* (New York, NY: Basic Books, 2014), pp.131–44; E. P. Thompson, "Time, Work-Discipline, and Industrial Capitalism," *Past & Present* 38 (1967): 56–97; Gavin Mueller, *Breaking Things at Work: The Luddites Were Right about Why You Hate Your Job* (London: Verso, 2021).
86. Salem Elzway and Jason Resnikoff, "Whence Automation? The History (and Possible Futures) of a Concept," *Labor: Studies in Working-Class History* 21 (forthcoming, 2024).

to workers outfitted with surveillance monitors, denied bathroom breaks, and subjected to time-consuming, off-the-clock security procedures at the end of each shift.[87]

Ultimately, very little work in the premodern or modern world has been conducted without some effort to rationalize and systematize it or to produce knowledge about it that might be deployed to sustain other social, cultural, and political projects. Such an observation provokes a consideration of plantations, factories, prisons, and laboratories as entangled enterprises at the heart of modernity. If science has underwritten extractive relationships to the natural world, accelerated the rhythms of mass production and consumption, and legitimated forms of governmentality that impose compulsion or confinement upon "surplus" populations, those same endeavors have fed back into a science primarily undertaken for commercial gain within private firms or universities under the auspices of "sponsored research": long reliant on the exploited labor of the Global South to produce raw materials and dependent on human subjects for testing and for producing vast quantities of commodifiable data that feed the intensification of these processes. It's not that science is a tarnished enterprise; it is simply unexceptional.

As the history of science comes to recognize science as labor and omnipresent in other forms of labor, it will reckon with science as having a political economy, as a site for class formation, and an arena for contestation over the organization of the material world. Doing so will not derail the ongoing scholarly project to recover the invisibilized and erased, but it will alter the political stakes and allow for different kinds of claims to be made on our readers, on one another, and on our world more generally.

What is to be done?

Worker consciousness did not spontaneously generate. Nor did the historian of science's consciousness of workers. As we have shown, reflecting the broader Cold War context and ascendancy of US science and engineering, historians of science pursued, with some deliberateness, a narrative that predominantly highlighted the intellectual labors of white male elites from the Global North. In turn, with even more deliberateness, until the last few decades, historians of science obfuscated the binds that tied infrastructural labor to scholarly networks of dissemination, supply chains of bodies and parts, bureaucracies of institutions, translation of language and culture, and so on. "Invisible technicians" and their ecosystems have only recently become apparent . . . because we have begun to look for them.

This sounds flippant but is worth stating baldly as we set a future course. Again, as Gabriela Soto Laveaga reminds us, the forgotten identities, lives, and experiences of past workers were known to their communities and to themselves.[88] Similarly, Laurel

87. Sam Adler-Bell and Michelle Miller, "The Datafication of Employment: How Surveillance and Capitalism are Shaping Workers' Futures without Their Knowledge," Century Foundation Report, December 19, 2018, <https://tcf.org/content/report/datafication-employment-surveillance-capitalism-shaping-workers-futures-without-knowledge> (accessed 8 September 2023); Adler-Bell, "Surviving Amazon," *Logic(s)* 8 (2018): 189–206; Shoshana Zuboff, *Surveillance Capitalism: The Fight for a Human Future at the New Frontier of Power* (New York, NY: Polity Press, 2020).

88. Soto Laveaga, "Worker Once Known" (note 58).

Thatcher Ulrich has shown that, while typicality conferred invisibility, the "vertuous" women of New England were hardly invisible to themselves.[89] As historians embark on recovery operations, then, they should also consider who did the losing to begin with and why and how. We need to disengage from the agnotological obfuscation of our profession's past. But while the discipline of history is littered with commitments to tell more and tell better, we are not simply calling for more thorough and earnest spadework to uncover untold stories.

Indeed, scholars of subalterity already critique recovery scholarship as its own end. They argue that the "ophthalmic relationship" between Global North consumers and ghost workers of the North and South can't be resolved by mere revelation; a decade of doing so for tech workers, for example, has resulted in minimal pro-labor reforms in the Global South.[90] Noopur Raval advocates shifting to a non-universalist approach that recognizes relative value and dignity, along with particularity and layered contexts, from local to national to global. Historians are well-suited to charting such complex, shifting, and relativistic systems that sprawl and scale over time and space. But where to begin?

Historians of science – like historians more generally – can start by reckoning with our discipline's own historicity, with the power structures of the past that invisibilized and the power structures of the present that continue to do so, albeit in new and different ways. We must continue asking where the thresholds and responsibilities for ignorance lie. Uncomfortable histories that took far too long to surface are in danger of being hidden again. In 2014, the Japanese Foreign Ministry pressured the textbook publishers McGraw Hill to eliminate several paragraphs describing the Japanese military's involvement in the creation of war-front "comfort stations" populated by coerced Asian (mostly Korean) women during World War II. Today, local and state governments in the United States are actively working to eliminate narratives addressing race, gender, sexuality, and anthropogenic climate change from primary and secondary education curricula. The effort to produce ignorance, which will impact generations of future citizens, has marched forward regardless of historians' efforts to "fact-check" these agnotological projects. Many scholars feel powerless as they confront the diminishing ability of empirical evidence to win arguments in the public sphere. But if "despair is analytical failure," how can historians move forward?[91]

One research area that offers clues for how to answer this urgent question is the history of resource extraction and its infrastructures. This history continues up to the present in discussions about the human and environmental costs of mining high-demand substances such as lithium, cobalt, and manganese, which are crucial for producing the storage batteries that run our laptops, mobile phones, and electric vehicles, and are enmeshed

89. Laurel Thatcher Ulrich, "Vertuous Women Found: New England Ministerial Literature, 1668–1735," *American Quarterly* 28, no. 1 (1976): 20–40.
90. Noopur Raval, "Interrupting Invisibility in a Global World," *Interactions* 28, no. 4 (2021): 27–31.
91. Emily Pawley, "Despair is Analytical Failure," in Alexandra Hui and Emily Pawley (eds.), *A Historian's Handbook to Save the World* (in process).

in geopolitical contests of global scale and consequence.[92] The impact of such supply chain systems is planetary, sweeping up humans, plants, animals, and the non-living in its churn, especially as the lucrative market for presumptively sustainable electric vehicles has intensified a worldwide scramble for mineral resources. Most historians of science, meanwhile, have focused on a differently delineated EV – rolling discussions of "episteme vehicles" that embody scientific knowledge, *techne*, and practice off the academic factory line. Is it time for a history of science that transcends historical epistemology? For those who want to stay focused on epistemic supply chains, let's at least include all that actually goes into making scientific knowledge. What and whose labor are involved? And what of the lives and labor that are never legitimated as scientific?

Beyond that, what if we heed Raval's call to move beyond recovery and revelation? We can push our inquiries to the individual subjective experiences of work and focus our analytical apertures on experiences of the tactile, of accelerations, the itching, the choking on airs, or the vibrating roars of the workscapes in which science is either embedded or itself the arena of production. Can workers' sensory perceptual experiences tell us something new about the constitution of labor and the role science has played in its configuration and management? Consider this example: In the 1940s, the Muzak Corporation used worker response cards to refine their music programming, both to make their existing music channels (one for the physical labor of the factory floor and one for white-collar work that required concentration) more effective and to develop a new music channel for distracting workers from tedious tasks. The sounds the workers did or did not hear, their bodily experiences (refreshed by music!), and their opinions articulated in the feedback surveys hint at their sensory perceptual experiences of not just receiving the applied sounds, but contributing to the defining and refining of their labor (for themselves, for management, for the corporate scientists and sound engineers). The phenomenological feedback loop generated by mid-twentieth-century technoscientific infrastructures of background music *preceded* and informed both the epistemological (industrial psychology) and material (industrial-scale production).

Beyond the level of individual experience, we can aim analytically to link the micro-, meso-, and macro-scales in which these workscapes are situated, thereby linking historians of science's prized "episteme vehicles" to the broader dynamics of global history – and future. How is (the episteme vehicle of) scientific work embedded in the complex networks that, for example, link R&D aimed at innovations in electric vehicle production – sold to the public as key to combating climate change – with the (largely inadequate) governance of sourcing materials and component parts in mines, refining plants, and manufacturing centers around the globe – locations rife with precarious and unfree labor practices, environmental devastation, and knowledge production and application? And how are these linked to the geopolitical strategies, policies, and activities – themselves

92. See, for example, Rachel Chason and Chloe Charrock, "On Frontier of New 'Glod Rusch,' Quest for Coveted EV Metals Yields Misery," *Washington Post*, April 27, 2023; Rachel Chason and Ilan Godfrey, "In Scramble for EV Metals, Health Threat to Workers Often Goes Unaddressed," *Washington Post*, June 8, 2023; Evan Halper, "EV Makers' Use of Chinese Suppliers Raises Concerns about Forced Labor," *Washington Post*, September 18, 2023.

saturated with scientific work – involved in attaining, maintaining, and challenging control over supplies of crucial metals and component parts?

Recognizing that the claimed distinctions between science and work have historically been carefully policed invites us to explore the contours of the "and" that links the two. But as the previous paragraph suggests, we need to add more "ands." Thinking about science *and* work prompts us to think about science and work *and* the environment, about science and work *and* the military, about science and work *and* waste, about science and work *and* farmed horseshoe crabs, and so on.[93]

This special issue also asks us to consider science *as* work. Its introduction describes the structures that organize work and science in time and place.[94] How do they create the conditions that make the supply chains of modern scientific thought, practice, and products possible? What would the history of the phenomenology of science as work look like? Several of the contributions to this special issue hint at possibilities, from laborers' sensoria to the in-betweenness of skills to the experience of science as drudgery.

In the two years since we initiated a discussion at the intersection of labor history and the history of science, splashy new technologies have drawn public and scholarly attention to the social impacts of artificial intelligence. The effects of reducing creative and intellectual work to replaceable parts is playing out in the present. Technologies that periodically replace our voices have already infiltrated academia. Consider automated email "away" messages. With varied tone, the latter immediately respond to efforts to engage with some combination of apology, explanation, and recrimination. Whatever the reason for absence (work-related travel, vacation, labor stoppage, dependent care, and so on), correspondence work carries on. This hints at a science-fictioney future in which we just point our laptops at each other and they chat while we get on with our projects. But what would these projects be? Would brainwork collapse into domestic labor into leisure? As Gadi Algazi shows, the binary of labor versus leisure has long been troubled.[95] And as various scholars have demonstrated, work is never eliminated from the system; it is reallocated to unseen others. Artificial intelligence will not liberate. Somebody must always mind the machines. A future without labor is fiction, not science.

By considering science as ordinary, we are doubling down on the disenchantment of the world. Are there any spaces in which science is still sublime? What does the past, present, or future look like when the production of scientific knowledge, objects, technologies, tests, processes, authority, power, and so on is seen as (ordinary) work? Does it neutralize contemporary perversions of the social construction of knowledge responsible for overwhelming the public with "alternative facts" and misinformation? Maybe the better question is *who* should understand science as (ordinary) work. One suspects that many historians of science, labor historians, and scientists already do – even if they simultaneously default to the familiar trope of "pure" science.[96]

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93. For farmed horseshoe crabs, see Freda Kreier, "An End to Horseshoe Crab Bleeds?," *Science* 381 (2023): 932–3.
94. Lissa Roberts, Seth Rockman, and Alexandra Hui, "Science and/as Work: An Introduction to This Special Issue," *History of Science* 61, no. 4 (2023): 448–47.
95. Gadi Algazi, "Kepler's Labors: Figurations of Scholarly Work," *History of Science* 61, no. 4 (2023): 475.
96. Gaudillière and Löwy (eds.), *The Invisible Industrialist*, pp.3–4 (note 53).

So why not say so forthrightly? It is our hope that future labor histories of science will reflect upon both the field's own labor practices and its own histories, acknowledging when it has been expedient to narrow the definition of "science" and "scientist" in order to exceptionalize science. What is more, we look forward to (collaborative) studies that embed science *as* work into analyses of science *and* work, framing them as truly planetary global histories. This strikes us as the most potent way to embed the history of science in discussions of the challenges of today and tomorrow, just as science is embedded in their constitution and potential resolution.

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