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RESEARCH ARTICLE

Crises and the history of science: a materialist rehabilitation

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Abstract

Over the past four decades, historians of science have come to discard crisis as a guiding heuristic in 'big-picture' narratives of scientific change. In this article, we argue that it can be rehabilitated without reintroducing the conceptual drawbacks of earlier historiographies. We suggest that analysing material crises as distinct episodes of knowledge-in-the-making focuses attention on the mangling of science and social order. We distinguish material crises from Kuhnian intellectual crises; the analysis of material crises begins with the interactive dynamics of actor practices and performances, emergent within concrete social orders, rather than from technical breakdowns within isolable theoretical paradigms. Drawing on Reinhart Koselleck's account of crisis, we characterize such events as patterned shifts in the *tempo* of actor behaviours, which are brought about by real-time processes of *realization*. In addition to the familiar, contemporary cases of climate change and COVID-19, we sketch out how three historical crises transformed knowledge production in disparate ways: the Ming–Qing transition in late imperial China, crises of labour precarity in seventeenth-century Istanbul and the 1960 Sharpeville massacre in South Africa.

> The present society is no solid crystal, but an organism capable of change, and is constantly changing.
>
> Karl Marx[1]

Towering before the Francis Crick Institute stands Conrad Shawcross's imposing construction, *Paradigm* (Figure 1). Unveiled in 2016, the sculpture models American philosopher of science Thomas Kuhn's theory of scientific change propounded in *The Structure of Scientific Revolutions*.[2] *Paradigm*'s explanatory plaque tells us that 'scientific advancement does not progress in a seamless linear fashion, but rather through massive shifts that lead to breakthroughs, which change the course of thought, comprehension and application'.[3] Kuhn's 'big-picture' account of scientific change continues to catch the imagination of prominent

1 Karl Marx, preface to the first German edition of *Capital*, 1867, at www.marxists.org/archive/marx/works/1867-c1/p1.htm (accessed 18 January 2024).

2 Thomas Kuhn, *The Structure of Scientific Revolutions*, Chicago: The University of Chicago Press, 1962.

3 'Paradigm', www.crick.ac.uk/about-us/our-history/our-building/paradigm (accessed 18 January 2024).

Figure 1. *Paradigm*, in front of the Francis Crick Institute, London. Copyright Fiona Hanson, the Francis Crick Institute (2016).

scientists – not least that of the Crick's director, Nobel laureate Paul Nurse, who proclaimed that the sculpture reminds scientists that new advances 'often occur when we are able to look at things from a different perspective'.[4]

Despite its continued invocation by scientists, Kuhn's theory has long since become unpopular with historians of science. As Mario Biagioli put it in 2012, '*Structure* no longer frames the research agenda'.[5] Over the past four decades, and not without good reason, historians of science have moved away from a focus on radical conjunctural transformations, and, in their place, attend to continuity and piecemeal changes.[6] This shift is perhaps best captured by the provocative opening line of Steven Shapin's *The Scientific Revolution* (1996): 'There was no such thing as the Scientific Revolution, and this is a book about it.'[7] This decentring of intellectual rupture has paid huge dividends, particularly in moving away from the idealist, teleological and Euro-exceptionalist histories of Herbert Butterfield and Alexandre Koyré.[8] However, our concern is that this shift has

4 'Paradigm: a new public art commission', 15 February 2016, at www.crick.ac.uk/news/2016-02-24-paradigm (accessed 18 January 2024).

5 Mario Biagioli, 'Productive illusion: Kuhn's *Structure* as a recruitment tool', *Historical Studies in the Natural Sciences* (2012) 42(5), pp. 479–84, 479.

6 For exemplar histories of gradual scientific change see Lorraine Daston and Peter Galison, *Objectivity*, Princeton, NJ: Princeton University Press, 2010; Lorraine Daston, 'The immortal archive: nineteenth-century science imagines the future', in Daston (ed.), *Science in the Archives: Pasts, Presents, Futures*, Chicago: The University of Chicago Press, 2017, pp. 159–82.

7 Steven Shapin, *The Scientific Revolution*, Chicago: The University of Chicago Press, 1996, p. 1.

8 Herbert Butterfield, *The Origins of Modern Sciences*, New York: The Free Press, 1965; Alexandre Koyré, *From the Closed World to the Infinite Universe*, Baltimore: Johns Hopkins University Press, 1957.

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been accompanied by an ungrounded dismissal of crises more broadly from 'big-picture' narratives in the history of science.

It appears timely to us to write this article now, amidst what Adam Tooze calls the era of the 'polycrisis'.[9] Repeated market crashes, wars, pandemics and the increasingly realized threats of climate devastation are returning attention to rupture and rapid transformation.[10] We have seen the vast mobilization of resources for the development of vaccines to contain COVID-19, in a remarkably short time frame.[11] By contrast, governments across the world remain criminally slow in taking sustained action towards preventing environmental collapse, engendering grass-roots movements for climate justice, whose demands typically entangle knowledge making, a sense of urgency and calls to action: 'tell the truth', 'act now', 'decide together' and 'follow the science'.[12] Our current predicament thus urges renewed examination of the role of material crises in the organization of scientific knowledge.[13] That said, Reinhart Koselleck's theory, on which we draw, characterizes crisis as 'a structural signature of modernity' – and perhaps, in this respect, our own appropriation of the categories of high modernity reveals the challenges of transcending a presentist perspective.[14]

As we argue, beyond entailing potential breakdowns or reinforcements of social orders, crises are marked by sudden shifts in tempo. As Koselleck expounds, crises are moments that require subjects to make quick decisions between starkly different futures, based on past experiences, and thus entail a complex intermingling of temporalities.[15] Such intense moments, which demand critique, judgement and decision making, are by definition political.[16] Crises offer actors with particular interests, be they reactionary or revolutionary, an opportunity to change their participation within a polity on an accelerated timescale.

It is important to note, however, that social change is by no means a necessary outcome of crises. Indeed, as Joseph Masco warns, crises can function as 'a counterrevolutionary idiom', allowing powerholders to stabilize and naturalize an existing status quo rather

9 Adam Tooze, 'Welcome to the world of the polycrisis', *Financial Times*, 28 October 2022, at www.ft.com/content/498398e7-11b1-494b-9cd3-6d669dc3de33 (accessed 18 January 2024); Nancy Fraser, *Cannibal Capitalism: How Our System Is Devouring Democracy, Care, and the Planet – and What We Can Do about It*, London: Verso, 2022; Andreas Malm, *Corona, Climate, Chronic Emergency: War Communism in the Twenty-First Century*, London: Verso, 2020.

10 See, for example, Geoff Eley, 'Historicizing the global, politicizing capital: giving the present a name', *History Workshop Journal* (2007) (63), pp. 154–88; Naomi Klein, *On Fire: The Burning Case for a Green New Deal*, London: Penguin, 2019; Dipesh Chakrabarty, *The Climate of History in a Planetary Age*, Chicago: The University of Chicago Press, 2021.

11 Philip Ball, 'The lightning-fast quest for COVID vaccines – and what it means for other diseases', *Nature* (2021) 589(7840), pp. 16–18.

12 See https://extinctionrebellion.uk/the-truth/demands (accessed 18 January 2024).

13 As we write this article, the spectre of crisis is increasingly haunting our discipline. To list a few examples, the Max Planck Institute for the History of Science's 2022–3 colloquium series was on Science Diplomacy and Science in Times of War (www.mpiwg-berlin.mpg.de/colloquium/science-diplomacy, accessed 18 January 2024); the opening plenary at the History of Science Society's 2023 meeting in Portland, Oregon, was titled 'Perpetual crisis? Problems and methodological questions'; the journal *Isis* recently had a focus section dedicated to 'Disasters, science, and history' (see Julia F. Irwin and Jenny Leigh Smith, 'Introduction: on disaster', *Isis* (2020) 111(1), pp. 98–103); and the Department of History and Philosophy of Science at the University of Cambridge recently reorganized their introductory undergraduate survey course in the history of science, which now concludes with three lectures on 'Science and crisis, 1989 to the present'.

14 Reinhart Koselleck, 'Crisis', *Journal of the History of Ideas* (2006) 67(2), pp. 357–400, 372. See also Harry Collins, 'Actors' and analysts' categories in the social analysis of science', in Peter Meusburger, Michael Welker and Edgar Wunder (eds.), *Clashes of Knowledge: Orthodoxies and Heterodoxies in Science and Religion*, Dordrecht: Springer, 2008, pp. 101–10.

15 Koselleck, op. cit. (14), pp. 361, 372.

16 Koselleck, op. cit. (14), pp. 361.

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than 'reenergizing a collective imaginary that can engage alternative modes of living'.[17] Similarly, Janet Roitman shows that the declaration of particular moments as crises can serve to foreclose possibilities – something with substantial consequences for knowledge production.[18] Thus, as Masco concludes, 'crisis talk without the commitment to revolution becomes counterrevolutionary'.[19] However, whether a crisis results in a radical or conservative reorganization of social order, such accelerated moments of activity have the potential to bring about sudden transformations in regimes of knowledge production.

By returning attention to crisis, we by no means wish to rehabilitate Butterfieldian narratives of scientific revolutions, which presuppose a Eurocentric genealogy of 'Science' and afford intellectual transformations explanatory priority over their social-historical conditions. Nor do we seek to rehabilitate the teleological historiographies of science typical of early twentieth-century Marxists such as Boris Hessen. Hessen contended that '[t]he progressive development of productive forces gave rise to progressive science', and that the transition between dominant modes of production was 'historically inevitable'.[20] Conversely, while maintaining that social crises and radical conjunctural changes in knowledge production *do* happen, we emphasize that they are neither inevitable, isotropic, perfectly predictable, nor unidirectional.

As analysts, we neither celebrate nor make *a priori* value judgements about the cultures of knowledge engendered by crises.[21] Writing at a time when, as Naomi Klein cautions, neoliberalism propagates itself through the exploitation and reproduction of crises, we are compelled to stress that the new knowledges emerging from such junctures need not be 'better' than their antecedents.[22] Rather, and as far as we are concerned, they are simply different, due to the diverse material conditions, interests and paces of activity of their producers. Indeed, as we later recount, ventriloquizing Harun Küçük, the academic precarity borne of material crises in seventeenth-century Istanbul produced a new 'unphilosophical' practical naturalism, pervaded by 'intellectual mediocrity', which replaced far richer, theory-heavy Islamic traditions of natural philosophy.[23] Our focus on changes in cultures of knowledge brought about by crises thus resonates with Lorraine Daston's observation of our discipline's metamorphosis into the history of knowledge, which 'allows historians to follow practices wherever they may lead, however remote these may be from anything resembling latter-day science'.[24] Welcoming this shift, we suggest that attention to material crises can enrich and complement current continuity-oriented big pictures of the history of science.

A basic insight for our analysis is that scientists who find themselves in critical situations (be it as a direct result of their own performances, or through interactions with so-called 'external' actors) will be motivated to behave in different and perhaps surprising ways, at least compared with the conditions of so-called 'normal' research. When human

17 Joseph Masco, 'The crisis in crisis', *Current Anthropology* (2017) 58(S15), pp. S65–S76, S65, S75.

18 Janet Roitman, *Anti-crisis*, Durham, NC: Duke University Press, 2014, p. 10.

19 Masco, op. cit. (17), p. S73.

20 Boris Hessen, 'The social and economic roots of Newton's "Principia"', in Nikolai Bukharin *et al.*, *Science at the Cross Roads*, London: Frank Cass, 1971, pp. 147–212, 205, 204. For a re-evaluation of Hessen's work see Simon Schaffer, 'Newton at the crossroads', *Radical Philosophy* (1984) (37), pp. 23–8.

21 We thus seek to uphold the methodological relativism of the strong programme of the sociology of scientific knowledge. See David Bloor, *Knowledge and Social Imagery*, Chicago: The University of Chicago Press, 1976, pp. 158–9.

22 Naomi Klein, *The Shock Doctrine: The Rise of Disaster Capitalism*, London: Penguin, 2008. See also Masco, op. cit. (17) and Fraser, op. cit. (9).

23 Harun Küçük, *Science without Leisure: Practical Naturalism in Istanbul, 1660–1732*, Pittsburgh: University of Pittsburgh Press, 2020, p. 48.

24 Lorraine Daston, 'The history of science and the history of knowledge', *KNOW: A Journal on the Formation of Knowledge* (2017) 1(1), pp. 131–54, 143.

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actors or machines behave in dramatically unexpected ways, the pace of scientists' activity typically changes, and similarly dramatically. For instance, when a nuclear reactor shows signs of a meltdown, actors in an extended technoscientific network must make quicker-than-usual decisions about how to respond, in the interests of damage control.[25] When fascists seize power in a nation's government, those scientists who are at risk of persecution must decide whether to suspend their activity altogether and seek asylum elsewhere.[26] Such events engender unexpected but patterned changes in scientists' activity, and radically alter the pace of their interactions, in some cases interrupting them altogether. Thus the cornerstone of our analysis is the temporal dimension of scientific activity, of tempo.

In the next section, we offer a historiographical overview of crisis in the history of science, contextualizing our intervention. Subsequently, we outline our theoretical account of crisis, understood as shifts in social tempo, which are co-produced with temporally emergent processes of realization. Finally, we offer three episodes of crisis to illustrate our theory: the collapse of the Ming dynasty in China, academic precarity in seventeenth-century Istanbul and the 1960 Sharpeville massacre in South Africa.

Crisis in historiographies of science

Unlike today, crisis once occupied a central place in the historiography of the sciences.[27] For substantial spells of the twentieth century, Marxist, liberal and conservative historians of science alike deployed crisis (typically alongside 'revolution') as a tool with which to study scientific change, albeit in dissimilar ways.[28] On the eve of the Second World War, the Irish communist crystallographer J.D. Bernal prophetically observed that 'the greatest changes in theory and general outlook' in the sciences in the past three centuries arose with 'the Great War, the Russian revolution, the economic crisis, the rise of Fascism, and the preparation for newer and more terrible wars'.[29] Despite this, Bernal never developed a fleshed-out theory of scientific change based on crisis.[30] Nevertheless, throughout his career he continued to make broad-brush and equivocal claims about the role of crises in engendering new, 'revolutionary' sciences.[31] In *Science in History* (1952), noting that the 'progress of science has been anything but uniform in

25 Serhii Plohky, *Chernobyl: History of a Tragedy*, London: Penguin, 2018.

26 Herbert A. Strauss, *Die Emigration der Wissenschaften nach 1933: Disziplingeschichtliche Studien*, Munich: K.G. Saur, 1991.

27 Of course, crises and revolutions continue to be mobilized in popular accounts of the history of science, which often retell the pathologically Eurocentric histories that most academic historians have discarded.

28 For instance, both Butterfield and Koyré, the idealist historians of science par excellence, drew on the work of the French intellectual historian Paul Hazard and the Austrian German phenomenologist Edmund Husserl, and pointed to the contemporaneity of social, religious and intellectual crises in Europe and the seventeenth-century scientific revolution. Unlike the Marxist historians, however, both contended that intellectual transformation preceded social transformation. See Butterfield, op. cit. (8), p. 194; Koyré, op. cit. (8), p. vii; Paul Hazard, *La crise de la conscience européenne (1680–1715)*, Paris: Boivine & Cie, 1935; Edmund Husserl, *Die Krisis der Europäischen Wissenschaften und die transzendentale Phänomenologie: Ein Einleitung in die phänomenologische Philosophie*, The Hague: Martinus Nijhoff, 1954 (first published 1936).

29 John Desmond Bernal, *The Social Function of Science*, London: George Routledge & Sons, 1939, p. 2. For an overview of Bernal's philosophy of science see Helena Sheehan, *Marxism and the Philosophy of Science: A Critical History*, London: Verso, 2017, pp. 309–16.

30 However, the pace and scale of scientific change, contextualized in social, economic and military conditions, long remained a pressing concern for Bernal. See Anna-K. Mayer, 'Setting up a discipline, II: British history of science and the "end of ideology", 1931–1948', *Studies in History and Philosophy of Science Part A* (2004) 35(1), pp. 41–72, 53.

31 John Desmond Bernal, *Science in History*, vol. 1: *The Emergence of Science*, Cambridge, MA: MIT Press, 1965, p. 4.

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time and place', Bernal identified four key instances of 'rapid advance': the sixteenth-century Italian Renaissance, the seventeenth-century Western European 'scientific revolution', the British industrial and French political revolutions, and the many global crises of the mid-twentieth century.[32] He suggested that 'each of these great periods of science corresponds to one of social and economic change'.[33] Bernal's instinctive, undertheorized association of crises with transformations in the sciences speaks to the uncontroversial importance attributed to such critical moments by early to mid-twentieth-century Marxist historians of science.

A more robust, though far briefer and underappreciated, account of the connection between crises and the sciences was elaborated in 1939 by the Scottish Jewish Marxist mathematician Hyman Levy.[34] In his introduction to the British communist Christopher Caudwell's posthumously published *The Crisis in Physics*, Levy propounded a materialist, social-constructionist theory of scientific change.[35] He argued that 'images and concepts of fundamentally social origin represent an aspect of the prevailing ideology. Its form depends on the socio-economic structure'.[36] Levy suggested that as

> economic instability sets in, the ideology of that social phase moves from unconscious acceptance to conscious criticism. Just as soon as the categories of social life begin themselves to shift, as in the present, so also, therefore, will a movement of a similar nature be reflected within the inner structure of theoretical science.[37]

Levy prefigured Koselleck's association of objective crisis with subjective critique, realizing that such moments urged actors to make choices and exercise judgement, leading to new ways of organizing knowledge across the sciences. As he summarized, 'A deep-seated social crisis involves in its turn a corresponding unsettlement in every developed branch of science.'[38] Levy's theorization re-presented classical Marxist accounts of crisis and their impact on reconfigurations of social order to explain change in the sciences. His account echoed Marx's observation in *The Class Struggles in France* that '[a] new revolution is only a consequence of a new crisis'.[39] Thus, much as Engels viewed crises as moments that catalyse 'mankind's leap from the realm of necessity … to the realm of freedom', Levy conceptualized crises as times in which 'new [scientific] outlooks [are] engendered'.[40]

Levy's social theory of scientific change resonated strongly with his own era: the crisis-laden 1930s. Unsurprisingly, he viewed his present as nothing short of an 'international nightmare'.[41] More striking, however, is Levy's claim that crisis-oriented accounts of scientific change had 'at last come to be widely recognized'.[42] As he elaborated, the 'mutual conditioning of science and society has become itself an accepted

32 Bernal, op. cit. (31), p. 3.

33 Bernal, op. cit. (31), p. 4.

34 We are very grateful to Simon Schaffer for pointing us to Levy's life and work. On Levy's philosophy of science see Sheehan, op. cit. (29), pp. 353–4.

35 Christopher St John Sprigg, alias Caudwell (1907–37), was a Marxist writer and communist revolutionary, who fought in the Spanish Civil War and was killed by Franco's Nationalists.

36 Hyman Levy, 'Introduction', in Christopher Caudwell, *The Crisis in Physics*, London: Verso, 2017, pp. v–xiii, ix.

37 Levy, op. cit. (36), p. ix.

38 Levy, op. cit. (36), p. ix.

39 Karl Marx, *The Class Struggles in France, 1848 to 1850*, Marxists Internet Archive, at www.marxists.org/archive/marx/works/1850/class-struggles-france/ch04.htm (accessed 18 January 2024). See also Trent Schroyer, 'Marx's Theory of Crisis', *Telos* (1972) 14, pp. 106–25. See also Hyman Levy, 'Marx as scientist', *Centennial Review of Arts & Science* (1959) 3(4), pp. 407–22.

40 Levy, op. cit. (36), p. vii.

41 Levy, op. cit. (36), p. v.

42 Levy, op. cit. (36), p. ix.

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category, but this has not happened until the nature of the relationship is rapidly changing'.[43] Levy reflexively applied his account to the contemporary social sciences, viewing the global crisis of capitalism (and its spawning of fascisms) as a moment for social theorists to radically rethink their big-picture narratives of scientific change.

The 1930s and 1940s were decades of significant institutional shifts within the emerging discipline of the history of science. For instance, the Cambridge History of Science Committee, established in 1936 and first run by scientists, including Bernal, the Marxist biochemist Joseph Needham and the conservative physician Walter Pagel, was taken over in 1945 by liberal historians helmed by Herbert Butterfield.[44] The postwar institutional domination of the history of science by trained historians rather than scientists tethered the emergent discipline to the shifting scholarly standards of academic history.[45] For at least around a decade, professional historians such as Butterfield and his protégé A. Rupert Hall continued to describe scientific change as an intellectual revolution.[46] However, by the later twentieth century, academic historians came to reject such narratives, shifting their focus towards epistemic continuities, often by examining localized case studies.[47]

In the mid-twentieth century, anglophone historians continued to treat crises as valuable resources with which to study social – and occasionally scientific – change.[48] Most famously, the Marxist scholar Eric Hobsbawm wrote about the role played by various crises in transforming world history. In 1954, he argued that the European economy experienced a 'general crisis' in the seventeenth century, which 'resulted in a considerable concentration of economic power' – a necessary precondition 'to make industrial revolution possible'.[49] Hobsbawm's bold argument attracted engagement from across the political spectrum in Britain, with the conservative historian Hugh Trevor-Roper asserting that the 'general crisis' had been spurred by collapsing social and political norms and values rather than by economic transformation.[50] The following decade, Hobsbawm published his best-selling *The Age of Revolution* (1962). The work examined how the 'dual revolution' (the French Revolution and the British Industrial Revolution) ushered in bourgeois–liberal capitalism and, with it, modern terms and concepts, including 'scientist', 'engineer', '(economic) crisis', 'statistics' and 'sociology'.[51] Hobsbawm maintained – despite his disclaimer that 'the world of thought is to some extent autonomous' – that changes in the natural and social sciences between 1789 and 1848 'reflected the impact of the dual

43 Levy, op. cit. (36), p. ix.

44 Anna-K. Mayer, 'Setting up a discipline: conflicting agendas of the Cambridge History of Science Committee, 1936–1950', *Studies in History and Philosophy of Science Part A* (2000) 31(4), pp. 665–89; Mayer, op. cit. (30).

45 Mayer, op. cit. (30); Mayer, op. cit. (44).

46 Butterfield, op. cit. (8); A. Rupert Hall, *The Scientific Revolution, 1500–1800: The Formation of the Modern Scientific Attitude*, London: Longmans, 1954.

47 Peter Galison, 'Ten problems in history and philosophy of science', *Isis* (2008) 99(1), pp. 111–24, 119–21. On the late twentieth-century rejection of metanarratives see Jean-François Lyotard, *The Postmodern Condition: A Report on Knowledge*, Minneapolis: University of Minnesota Press, 1984 (first published 1979).

48 See, for example, Christopher Hill, *Change and Continuity in Seventeenth-Century England*, Cambridge, MA: Harvard University Press, 1975.

49 Eric Hobsbawm, 'The general crisis of the European economy in the 17th century', *Past & Present* (1954) 5(1), pp. 33–53; Hobsbawm, 'The crisis of the 17th Century – II', *Past & Present* (1954) 6(1), pp. 44–65, quotes at 46, 44.

50 Hugh Trevor-Roper, 'The general crisis of the seventeenth century', *Past & Present* (1959) 16(1), pp. 31–64. The theme of the 'general crisis of the seventeenth century' has more recently been addressed by Geoffrey Parker, who linked the era's transformational events to the Little Ice Age. See Geoffrey Parker, *Global Crisis: War, Climate Change & Catastrophe in the Seventeenth Century*, New Haven, CT: Yale University Press, 2013.

51 Eric Hobsbawm, *The Age of Revolution: 1789–1848*, London: Abacus, 2003, p. 13.

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revolution, which left no aspect of human life unchanged'.[52] Thus Hobsbawm's big-picture narrative of the emergence of the modern world and (albeit more peripherally) the modern sciences revolved largely around material crises and social revolutions. His work and its far-reaching influence underline the striking extent to which crisis was viewed as a legitimate and, indeed, valuable tool for historians in the mid-twentieth century.

In the same year as the appearance of Hobsbawm's book, Kuhn published *Structure*. Like his Marxist contemporaries, Kuhn viewed crisis as a key feature of scientific revolutions that led to paradigm shifts.[53] Unlike them, however, Kuhn privileged intellectual crises in his analysis. He contended that scientific crises arose from successive failures of dominant paradigms to offer the (intellectual) resources necessary to solve puzzles endogenous to research programmes.[54] *Structure* has been credited with opening the door to the sociology of scientific knowledge by focusing attention on the role of scientific communities in the assessment of epistemic claims.[55] Astonished by sociologists' embrace of his study, Kuhn maintained that he 'thought of [*Structure*] as exclusively internalist', and that 'considerations of the social setting of science had … no place' in the book.[56] Nevertheless, the key element of Kuhn's work that vanished from its subsequent reinterpretations was its emphasis on crises and revolutionary paradigm shifts in transforming the sciences.

In the 1980s, the history of science largely discarded crisis and revolution from its big picture. The decade saw the consolidation of historical sociology informed by the sociology of scientific knowledge, best represented by Steven Shapin and Simon Schaffer's *Leviathan and the Air-Pump* (1985).[57] As a methodological approach, historical sociology rejected the essentialism of earlier historiographies concerned with the epochal categories of 'modernity' or 'the Scientific Revolution', pointing instead to the all-important place of contestation and heterogeneity as features of science-in-the-making.[58] Drawing on histories from below, the new historiography crucially replaced inertial social models, which supposed that 'normality' need not be sociologically explained, revealing the constant struggle required to maintain a social and epistemic status quo.[59] Another aspect of historical sociology that borrowed heavily from British social history (as well as Italian *microstoria*) was its focus on small-scale, localized sites of knowledge production.[60] Given that crises have often been associated with necessarily large-scale events and

52 Hobsbawm, op. cit. (51), pp. 354, 357.

53 Kuhn's privileging of crises and revolutions arose largely from his engagement with one group of theoretical physicists associated with Niels Bohr's institute in Copenhagen, who employed crisis talk to generate interest in their work. Suman Seth, 'Crisis and the construction of modern theoretical physics', *BJHS* (2007) 40(1), pp. 25–51.

54 Kuhn, op. cit. (2), pp. 69–70.

55 Barry Barnes, *T.S. Kuhn and Social Science*, London: Macmillan, 1982. The sociological aspects of Kuhn's analysis largely restated the account of 'thought collectives' and 'thought styles' propounded in Ludwik Fleck, *Entstehung und Entwicklung einer wissenschaftlichen Tatsache: Einführung in die Lehre vom Denkstil und Denkkollektiv*, Basel: Schwabe, 1935.

56 Thomas Kuhn, 'Reflections on receiving the John Desmond Bernal Award', *4S Review* (1983) 1(4), pp. 26–30, 26.

57 Steven Shapin, 'History of science and its sociological reconstructions', *History of Science* (1982) 20(3), pp. 157–211; Shapin, 'Here and everywhere: sociology of scientific knowledge', *Annual Review of Sociology* (1995) 21(1), pp. 289–321.

58 Steven Shapin and Simon Schaffer, *Leviathan and the Air-Pump: Hobbes, Boyle, and the Experimental Life*, Princeton, NJ: Princeton University Press, 2011, esp. p. xliv.

59 Shapin and Schaffer, op. cit. (58), p. xliv; E.P. Thompson, *The Making of the English Working Class*, London: Penguin, 2013.

60 Shapin and Schaffer, op. cit. (58), p. xlii; Carlo Ginzburg and Carlo Poni, 'The name and the game: unequal exchange and the historiographic marketplace', in Edward Muir and Guido Ruggiero (eds.), *Microhistory and the Lost Peoples of Europe*, Baltimore: John Hopkins University Press, 1991, pp. 1–11.

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transitions between categorically distinct epochs, rather than with changes in tempo (as we characterize them), the so-called 'social turn' in the history of science moved the discipline further still from crisis.[61]

As this sketch illustrates, the concept of crisis has fallen out of favour among historians of science, and not without good reason, given its associations with idealist, teleological or epochal accounts of scientific change. However, we contend that crisis can be shorn from these intellectualist associations and rehabilitated into accounts of the history of science that focus on social orders and practices. We can do so by attending to the mechanisms by which crises in social order are co-produced with transformations in cultures of knowledge. We thus ask ourselves: what happens in the sciences when the social orders in which knowledge production is arranged are thrown into crisis? And how do changes in the sciences in turn affect the realization of crises within social orders? To answer these questions, we must develop a firmer sense of what is meant by a crisis in social order.

Tempo and realization

In our analysis, crisis is reducible neither to the presence of a worldly danger (an invading army, a natural disaster, an exploding machine), nor to the psychological experience of panic in the face of a perceived threat. Rather, crises are contingent features of social orders as such, whose members realize themselves to be in a situation that demands urgent action. We use the term 'realize' deliberately, to connote the sense both of recognition or making aware, and of actualization or making real in a constructivist sense. Thus we conceive of crises as necessarily perspective-dependent constructions. Events realized as crises by one group of actors (and their responses) need not be treated as such by others. Importantly, whether or not actors realize themselves to be in a crisis does not change the fact that knowledge production is always characterized by processes of contestation. Rather, realization shifts the pace (and, perhaps, the perceived stakes) of contestation.

Crisis emerges in real time through a group's patterned response to perceived threats, via a distinct form of 'social consciousness'.[62] Crises must be made, through temporally extensive processes of recognition and communication among and between actors. At the same time, a threat might be present without immediate realization by the actors to whom it poses a danger, who will not at first respond to it as a crisis. Thus we can make sense of some climate activists' calls for apparent powerholders to, as a matter of priority, recognize and publicly declare that we are in a crisis.[63] Their demand is for powerholders to realize the crisis, in the hopes that they will be compelled to act.

However, as an emergent feature of social consciousness, a crisis is not to be understood as 'merely ideational' or 'merely discursive'. Crisis consciousness is materially manifested in patterned changes in the behaviours of the actors who realize that they are in a critical situation. We can describe these changes as dramatic shifts in tempo; in realizing the crisis situation, some actor behaviours are *accelerated*, while others are *decelerated*. The

61 It is worth noting that other fields, such as human geography, have continued to emphasize the primacy of crises in transforming social activity and knowledge systems. See David Harvey, 'The spatial fix: Hegel, von Thunen, and Marx', *Antipodes* (1981) 13(3), pp. 1–12; Erik Swyngedouw, 'Globalisation or "glocalization"? Networks, territories, and rescaling', *Cambridge Review of International Affairs* (2004) 17(1), pp. 25–48.

62 We use the term *patterned* to signal our methodological commitment to the view that coherent sociological explanations can be produced for disparate tempo changes in various actor behaviours, as they are engendered by the realization of a particular crisis. On social consciousness surrounding crises and the value of crisis as an analytical category for historical scholarship see J.B. Shank, 'Crisis: a useful category of post–social scientific historical analysis?', *American Historical Review* (2008) 113(14), pp. 1090–9.

63 Clare Farrell, Alison Green, Sam Knights and William Skeaping (eds.), *This Is Not a Drill: An Extinction Rebellion Handbook*, London: Penguin, 2019.

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size and direction of tempo changes are dependent on the heterogeneous particulars of the situation: in realizing the threat of an incoming military invasion, some – though not all – actors with the means to do so will quickly flee (those without such means may respond otherwise and with similar urgency). At the same time, those leading the military invasion may deploy crisis talk to reflect or reinforce an existing social order, characterizing their devastating actions as a necessary 'state of exception' required to bring back a 'natural' or 'normal' state of affairs.[64] In realizing the threat of an infectious disease transmitted by commonly circulated commodities, those threatened (whether directly or indirectly) will also typically work to minimize that circulation – reducing its tempo.

One kind of tempo change appears more ubiquitous across different crises, namely that of accelerated decision making. As Koselleck explains, the modern concept of crisis is genealogically linked to 'critique', 'prognosis' and 'judgement', emphasizing that crises are moments that demand decisions between starkly different alternatives.[65] The choices forced upon people during crises compel them to question their underlying assumptions about their situation, opening certain possibilities (but by no means necessities), while foreclosing others, for the generation of new knowledge and, accompanying that, new social formations.[66] Thus Koselleck identifies a generative relationship between 'subjective critique' and 'objective crisis'.[67] Complicating conceptions of crisis as moments of breakdown or reinforcement in social and/or intellectual order, he proposes that such moments entail a mixing of temporalities, transforming subjects' conceptions of the relationships between past, present and future. This mangling of actors' senses of time and pace accompanies the patterned shifts in tempo of actor behaviour that we take to constitute crises.

Shifting public consciousness and collective attributions of the climate crisis have altered many peoples' views about the relationships between their present situation, its origins in the emergence of fossil capitalism, and the prospects for future stability.[68] The 'slow violence' of the climate crisis (which sometimes appears as a sudden violence, especially to the world's dispossessed) motivates those affected to reckon with non-linear changes of pace in their relationships with their cosmoses.[69] In fact, the climate crisis is perhaps the most salient among familiar examples for illustrating one of the conclusions of this paper – that crises in social order are dialectically entangled with reorganizations of knowledge production.[70] Almost all climate scientists and activists attribute the causal origins of the crisis to the industrial capture of various technoscientific practices from the late eighteenth century onwards.[71] Fossil-fuel extraction, refinement, conversion and

64 Masco, op. cit. (17); Carl Schmitt, *Dictatorship* (tr. Michael Hoelzl and Graham Ward), Cambridge: Polity Press, 2014 (first published 1921); Giorgio Agamben, *State of Exception* (tr. Kevin Attell), Chicago: The University of Chicago Press, 2005.

65 Koselleck, op. cit. (14), p. 359; Reinhart Koselleck, *Critique and Crisis: Enlightenment and the Pathogenesis of Modern Society*, Cambridge, MA: MIT Press, 2000, p. 10.

66 Roitman, op. cit. (18), reminds us that while crises open some junctures, they foreclose others, leading to a disruption in existing (and often fruitful) practices of knowledge production.

67 Koselleck, op. cit. (14), p. 359.

68 Andreas Malm, *Fossil Capital: The Rise of Steam Power and the Roots of Global Warming*, London: Verso, 2016, esp. pp. 6–11.

69 Rob Nixon, *Slow Violence and the Environmentalism of the Poor*, Cambridge, MA: Harvard University Press, 2011.

70 On the mangling of scales, environments and social orders see Simon Schaffer, 'Of the body of politics and the body of nature', in Simon Schaffer, Bruno Latour and Pasquale Gagliardi (eds.), *A Book of the Body Politic: Connecting Biology, Politics and Social Theory*, Venice: Fondazione Giorgio Cini, 2020, pp. 263–84.

71 Synthesis report of the IPCC Sixth Assessment Report, at https://report.ipcc.ch/ar6syr/pdf/IPCC_AR6_SYR_LongerReport.pdf, p. 6 (accessed 18 January 2024).

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waste disposal technologies are perhaps most salient among the causal contributors to anthropogenic climate change. Thus historic developments in technoscience are understood as one of the causes of the crisis (or, in our analysis, a cause of the dangers realized as such in a crisis). Moreover, contemporary climate scientists have themselves often played a central role in processes of the realization of the climate crisis, in two related ways. First, they have been among the principal investigators of climate change, its causal history, and its past, present, and future effects, and they realize the crisis (for themselves) through their scientific activity. Second, climate scientists have often taken the role of public communicators on climate change; their assertions are taken by many as reliable and authoritative descriptions of the crisis character of their current situation. And, even further, in responses to widespread realization of the climate crisis, contemporary scientists and engineers have developed new energy and carbon-capture technologies, which are being taken up by (some) institutions as part of strategies in crisis management. Thus at every stage the climate crisis reveals the mangling of technoscience and social orders.[72]

The COVID-19 pandemic has similarly highlighted the inseparability of technoscience from society and the temporal character of crises. In an extraordinarily short period of time, threatened by a 'natural' foe, governments across the world pulled the brakes on the circulation of people and capital, and redirected previously unthinkably vast resources towards vaccine research.[73] Despite the pandemic's unquestionably disruptive nature, many scientists viewed it as an opportunity – particularly with 'supercharged' funding for mRNA technologies – to establish a new 'paradigm of what is possible in vaccine development'.[74] Such a paradigm, they suggested, could have ramifications for the prevention and treatment of, inter alia, malaria, ebola, zika and several cancers.

With the pandemic came acute breakdowns and restructurings of social networks, as well as sudden shifts in the tempo of socialization.[75] Those privileged enough not to be seen as expendable by their governments and employers were confined to the relative safety of their homes, disrupting the normal rhythms of social interaction and, accompanying it, the production of knowledge. Academic conferences – enculturation events for scientific practitioners – ceased to take place in person and were replaced by virtual meetings with strikingly different norms of sociability and, accordingly, stark consequences for scientific knowledge production.[76] As Harry Collins, Willow Leonard-Clarke and Will Mason-Wilkes explain, 'communication among natural scientists serves the purpose of socializing new scientists into domains characterized by bodies of tacit knowledge and taken-for-granted procedures … [whereby] assumptions are transferred and maintained through personal interaction.'[77] While, as Collins, Leonard-Clark and Mason-Wilkes have

72 As the ongoing Making Climate History project (2019–24) at the University of Cambridge emphasizes, the technoscientific construction and measurement of climate is dialectically mangled with the production and realization of climate change. See Richard Staley, 'Understanding climate change historically', in Alexander Elliott, James Cullis and Vinita Damodaran (eds.), *Climate Change and the Humanities: Historical, Philosophical and Interdisciplinary Approaches to the Contemporary Environmental Crisis*, Basingstoke: Palgrave, 2017, pp. 43–68; Dipesh Chakrabarty, 'Anthropocene Time', *History and Theory* (2018) 57(1), pp. 5–32; Simon Naylor and Simon Schaffer, 'Nineteenth-century survey sciences: enterprises, expeditions and exhibitions', *Notes and Records of the Royal Society* (2019) 73(2), pp. 135–47.

73 Ball, op. cit. (11); Elie Dolgin, 'The tangled history of mRNA vaccines', *Nature* (2021) 597(7876), pp. 318–24.

74 Ball, op. cit. (11), p. 16.

75 Bruno Latour, 'Imaginer les gestes-barrières contre le retour à la production d'avant-crise', *AOC*, 30 March 2020, at https://aoc.media/opinion/2020/03/29/imaginer-les-gestes-barrieres-contre-le-retour-a-la-production-davant-crise (accessed 18 January 2024); Malm, op. cit. (9).

76 Harry Collins, Willow Leonard-Clark and Will Mason-Wilkes, 'Scientific conferences, socialization, and the Covid-19 pandemic: a conceptual and empirical enquiry', *Social Studies of Science* (2023) 53(3), pp. 379–401.

77 Collins, Leonard-Clark and Mason-Wilkes, op. cit. (76), p. 2.

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shown, the suspension of such rituals risks having 'damaging consequences … for the very nature of science', the emergence of remote conferences (overly optimistically) promised an increase in accessibility, helping to bring marginalized scientists into closer dialogue with their peers.[78] Similar such thoughts, with perhaps more profound and far-reaching implications, can be developed with regard to the training of future scientists in systems of general and technical education. Schools and universities underwent dramatic changes in practice and procedure, altering several generations of pupils' and students' experiences of teaching and learning.[79] While the ramifications of these changes are as yet unclear, future generations of scientists might well have different attitudes and approaches to online environments given their presences in formative stages of their training.

The cases of climate and COVID-19 both show that some social formations can, by a multiplicity of mechanisms, generate resistance to the realization of crises. While we do not have space to explore these mechanisms here, we note the wealth of literature by STS scholars on the manufacture of doubt regarding climate change and vaccine efficacy.[80] Further, the legislative and political architecture of many economies made it procedurally difficult for many governments to arrive at consensus about the scale and depth of the COVID-19 pandemic. By contrast, state governments in other (typically mixed) economies exhibited a greater capacity to quickly reorganize circulation of people, labour and capital.[81] Processes of realization are accelerated or slowed depending on other features of the concrete social orders in which they take place. This is another sense in which tempo is a central problematic for our analysis of crises.

Reassembling the big picture

Both in readily appreciated cases and in those that have required sophisticated archival and hermeneutic investigation, we can correlate (if not necessarily causally connect) familiar, critical historical moments with less familiar technoscientific transformations. For example, as Jenny Bulstrode has meticulously demonstrated, enslaved black metallurgists in eighteenth-century Jamaica developed new techniques to transform pig and scrap iron into valuable bar iron – processes that lay at the heart of the Industrial Revolution – for their own distinct purposes rooted in the new articulations of their African heritages and experiences in the diaspora.[82] The war-torn years of Napoleon Bonaparte's regime in France (1799–1815) have been characterized as 'the most glorious in the whole of French science', staging the meteoric rise of Laplacian physics.[83] A 'crisis of culture and science'

78 Wu Juncheng *et al*., 'Virtual meetings promise to eliminate geographical and administrative barriers and increase accessibility, diversion and inclusion', *Nature Biotechnology* (2022) 40(1), pp. 133–7. Collins, Leonard-Clark and Mason-Wilkes, op. cit. (76), p. 18, challenge this view, suggesting that remote conferences risk replacing the current social processes involved in the construction of scientific credibility with even more inegalitarian interpersonal interactions, such as those of social media. See also Charlotte Bigg, 'Communicating science, mediating presence: reflections on the present, past and future of conferencing', *BJHS* (2023) 56(4), pp. 567–77.

79 Ken Jones, 'Notes on a crisis: the pandemic in English schools', *Changing English* (2020) 27(3), pp. 235–43.

80 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*, London: Bloomsbury Press, 2010; Lukas Verburgt and Peter Burke, 'Introduction: histories of ignorance', *Journal for the History of Knowledge* (2020) 2(1), pp. 1–9.

81 Sara Reardon, 'Cuba's bet on home-grown COVID vaccines is paying off', *Nature* (2021) 600(7887), pp. 15–16; Fiona Samuels, 'Cuba's response to COVID-19: what underlies its apparent success?', *Bulletin of Latin American Research* (2020) 39(1), pp. 62–6.

82 Jenny Bulstrode, 'Black metallurgists and the making of the Industrial Revolution', *History and Technology* (2023) 39(1), pp. 1–41, esp. 11, 19.

83 Robert Fox, 'The rise and fall of Laplacian physics', *Historical Studies in the Physical Sciences* (1974) 4, pp. 89–136, 89.

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in the chronically politically perturbed Weimar Republic, instead, has been famously, albeit controversially, linked to the advent of acausal philosophies and acceptance of quantum mechanics.[84] The rise of National Socialism in Germany and Hitler's purge of 'non-Aryans' from university positions in April 1933 spurred the mass exodus of Jewish scientists, many of whom – among others Leo Szilard, Otto Frisch, Rudolf Peierls, Hans Bethe – joined the Manhattan Project.[85] The collapse of the Soviet Union in 1991 generated a large emigration of IT specialists who helped create new networks of programmers in the US, transforming digital cultures both in the West and in post-Soviet states.[86] These, among countless other cases, suggest a spatiotemporal correlation between scientific transformations and material crises experienced by knowledge makers. That said, we ought to remember that supposedly 'stable' polities such as the Hellenistic world, the Abbasid Caliphate and the so-called 'Sanskrit Cosmopolis' were exceedingly fertile contexts for knowledge production too.[87] Thus we do not wish to claim that periods of stability and continuity (as perceived by actors) did not give rise to substantial knowledge production. Rather, complementing rather than contesting continuity-oriented histories of the sciences, we maintain that the increased tempo of social activity among actors realizing a state of crisis can (but does not always) engender sudden shifts in cultures of knowledge.

Crises need not be 'huge', nor of any predefined scale. And, of course, they need not be in Europe, nor in any predefined part of the world. Crises can happen anywhere, at any time, and can operate on any scale, within any polity (although they appear to be realized especially often in imperial contexts, probably due to the shock mechanisms on which imperial governance often relies).[88] Thus, as long as they are socially realized episodes that engender rapid shifts in tempo and breakdowns or reinforcements in social order, critical events lend themselves to microhistorical analysis just as readily as to macroscopic examination. In the case studies that follow, we explore the ways in which three crises (the first two of which have been linked by historians) generated new, unexpected shifts in cultures of knowledge.[89] These examples vary in scale, chronology and geopolitical setting. Methodologically, they lend themselves well to the methods of global microhistory, which relate situated, localized examinations of events to far larger-scale patterns of social and scientific change.[90] One reason why these episodes appear especially fruitful

84 Paul Forman, 'Weimar culture, causality, and quantum theory, 1918–1927: adaptation by German physicists and mathematicians to a hostile intellectual environment', *Historical Studies in the Physical Sciences* (1971) 3, pp. 1–115, 58. See also Cathryn Carson, Alexei Kojevnikov and Helmuth Trischler (eds.), *Weimar Culture and Quantum Mechanics: Selected Papers by Paul Forman and Contemporary Perspectives on the Forman Thesis*, Hackensack, NJ: World Scientific Publishing, 2011.

85 Jeff Hughes, *The Manhattan Project: Big Science and the Atomic Bomb*, New York: Columbia University Press, 2003.

86 Mario Biagioli and Vincent Antonin Lépinay (eds.), *From Russia with Code: Programming Migrations in Post-Soviet Times*, Durham, NC: Duke University Press, 2019. On transformations in the sciences more broadly after the collapse of the USSR see Loren D. Graham and Irina Dezhina, *Science in the New Russia: Crisis, Aid, Reform*, Bloomington: Indiana University Press, 2008.

87 G.E.R. Lloyd, 'Hellenistic science', in F.W. Walbank, E.A. Astin, M.W. Frederiksen and R.M. Ogilvie (eds.), *The Cambridge Ancient History*, Cambridge: Cambridge University Press, 1984, pp. 321–52; Seyyed Hossein Nasr, *Science and Civilization in Islam*, Chicago: ABC, 2001, pp. 193–5; Sheldon Pollock, *The Language of the Gods in the World of Men: Sanskrit, Culture, and Power in Premodern India*, Berkeley: University of California Press, 2009.

88 Serge Gruzinski, *The Mestizo Mind: The Intellectual Dynamics of Colonization and Globalization*, New York: Routledge, 2002, p. 33–51; Klein, op. cit. (22).

89 Parker, op. cit. (50). On the impact of the Little Ice Age on the Ottoman empire see Sam White, *The Climate of Rebellion in the Early Modern Ottoman Empire*, Cambridge: Cambridge University Press, 2012.

90 John-Paul Ghobrial, 'Introduction: seeing the world like a microhistorian', *Past & Present* (2019) 242 (Supplement 14), pp. 1–22, 14; Ginzburg and Poni, op. cit. (60); Carlo Ginzburg, 'Microhistory and global history',

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for microhistorical examination is that crises (particularly in imperial contexts) often require actors to jump across scales, following the spatial configuration of empires. Reciprocally, the methods of global microhistory tend to mirror such leaps in scale, following their actors' distinctive trajectories across social and geographical boundaries.[91]

Let us begin with the collapse of the Ming dynasty, itself a constituent element of what analysts (not actors) have called the 'global crisis of the seventeenth century'. As Geoffrey Parker explains, social unrest across the world in the seventeenth century coincided with the Little Ice Age, which may, in turn, have been connected to the reforestation that followed the European genocide of Indigenous Americans.[92] This same historical period has long also been characterized as one of 'revolutionary' scientific transformations.[93] The latter decades of the Ming dynasty (1368–1644) were plagued by interconnected cosmological, political, public-health, sustenance and climatic crises.[94] As a Shanghai local gazetteer noted in 1641, the empire was afflicted: 'Massive droughts. Locusts. The price of millet soared. The corpses of the starved lay in the streets.'[95] Confucian scholar–officials had an actor category to describe such events: *tianzai* (calamities from Heaven). According to imperial state ideology, a dynasty's *tianming* (mandate) to rule *tianxia* (all under Heaven) came from Heaven itself, which manifested its approval or discontent with the actions of a regime through the cosmos.[96] If displeased, Heaven could revoke an emperor's mandate by causing *tianzai* such as floods, droughts, diseases or astronomical anomalies. Thus the fate of political regimes was intimately imbricated with regimes of natural knowledge.[97] Anomalies in the official calendar issued by the Qintianjian (Imperial Astronomical Bureau), such as incorrectly predicted solar eclipses, were particularly damning indictments of the incumbent dynasty.[98] In 1612, 1614 and 1615, for example, the Jurchen khan Nurhaci – then engaged in warfare against the Ming – claimed that bright lights in the sky indicated that Heaven was abandoning the Ming.[99] The agglomeration of *tianzai* was taken by the Ming's subjects and enemies alike to mark a juncture of radical cosmo-political change – change that took hold across knowledge production too.

The decades either side of the fall of the Ming in 1644 reshaped knowledge making in different ways for actors embedded in diverse settings.[100] The Qing dynasty (1644–1912),

in Jerry H. Bentley, Sanjay Subrahmanyam and Merry Wiesner-Hanks (eds.), *The Cambridge World History*, vol. 6: *The Construction of a Global World, 1400–1800 CE*, part II, Cambridge: Cambridge University Press, 2016, pp. 446–73.

91 See, for example, Natalie Zemon Davis, *Trickster Travels: A Sixteenth-Century Muslim between Worlds*, London: Faber and Faber, 2008.

92 Parker, op. cit. (50), pp. 3–25; Simon L. Lewis and Mark A. Maslin, 'Defining the Anthropocene', *Nature* (2015) 519, pp. 171–80. For a problematization of claims of causal connection between the depopulation of the Americas and global cooling see Dagomar Degroot, 'Did colonialism cause global cooling? Revisiting an old controversy', *Historical Climatology* (online), at https://www.historicalclimatology.com/features/did-colonialism-cause-global-cooling-revisiting-an-old-controversy (accessed 18 January 2024).

93 For example, Toby E. Huff, *The Rise of Early Modern Science: Islam, China, and the West*, Cambridge: Cambridge University Press, 2017.

94 Timothy Brook, *The Troubled Empire: China in the Yuan and Ming Dynasties*, Cambridge, MA: Harvard University Press, 2010.

95 Quoted and translated in Brook, op. cit. (94), p. 250.

96 David Pankenier, 'The cosmopolitical background of heaven's mandate', *Early China* (1995) 20, pp. 121–76.

97 Dagmar Schäfer, *The Crafting of the Ten Thousand Things: Knowledge and Technology in Seventeenth-Century China*, Chicago: The University of Chicago Press, 2011, p. 59; Mark Elvin, 'Who was responsible for the weather? Moral meteorology in late imperial China', *Osiris* (1998) 13, pp. 213–37.

98 Chu Pingyi, 'Archiving knowledge: a life history of the Calendrical Treatises of the Chongzhen Reign (*Chongzhen Lishu*)' *Extrême-orient, extrême-occident*, 2007, pp. 159–84; Benjamin Elman, *On Their Own Terms: Science in China, 1550–1900*, Cambridge, MA: Harvard University Press, 2005, p. 70.

99 Gertraude Roth Li, 'State building before 1644', in Willard J. Peterson (ed.), *The Cambridge History of China*, vol. 9, part I: *The Ch'ing Empire to 1800*, Cambridge: Cambridge University Press, 2002, pp. 9–72, 38 n. 78.

100 Schäfer, op. cit. (97).

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established by the Manchu ethnic minority, rapidly expanded China's imperial borders, absorbing new climes, peoples, flora and fauna into *tianxia*.[101] Carla Nappi has shown that Chinese naturalists 'struggled to cope with a pharmacy's worth of new and unfamiliar substances, texts, and terms, as plants, animals, and the drugs made from them traveled into China across land and sea', leading to the transformation (but not abandonment) of the older, dominant *bencao* (pharmacopoeia) genre.[102] As He Bian recently explained, 'the convulsions of war and conquest [left] a clear mark on the diverse corpus of *bencao* compiled during the seventeenth century'.[103] While there are many actors whose trajectories we could follow, we will focus on the activities of the high-ranking scholar–official and Christian convert Xu Guangqi (1562–1633).

Xu, who experienced an astonishing 160 floods, sixty-eight droughts, twenty earthquakes, fifty-seven famines and twenty-six epidemics, realized that he was living through a severe crisis and spent much of his career producing knowledge aimed at returning harmony to the *sancai* (Three Realms) of Heaven, Earth and Man.[104] Having joined the prestigious Hanlin Academy in Beijing in 1604 after taking his palace degree, Xu initially studied 'Western Ocean' geometry, translating the first six chapters of Euclid's *Elements* into Chinese.[105] Following a solar eclipse on 15 December 1610 that had been incorrectly predicted by the Qintianjian, Xu – put forward by the Ministry of Rites – began working with foreign Jesuit missionaries on a new calendar, seeking to supplement the Chinese Datong li (Grand Concordance System of Calendrical Astronomy) with European astronomical data.[106] Although a succession of Ming emperors failed to realize the cosmo-political crisis and adopt the new calendar until just a year before the dynasty collapsed, the new Sino-Jesuit calendar was rapidly appropriated by the Manchu regent Dorgon of the Qing dynasty, restoring cosmo-political order among the *sancai*.[107]

Xu, whose knowledge-making activities extended far beyond mathematics and astronomy, was also deeply concerned with agriculture, particularly as the Ming army was engaged in warfare in the arid north, far from a steady supply of grain. Unlike the mythical golden past in which, Xu purported, there had been 'plenty to eat and to wear, good implements and much wealth', he realized his present as a sustenance crisis.[108] As he judged, 'the state has failed to establish high-level posts for agriculture, high-level officials have failed to carry out their administrative duties concerning agriculture, local officials have failed to disseminate agricultural knowledge, and peasants have failed to transmit the agricultural calling – the rot started long ago'.[109] In response to the crisis, Xu undertook rice-growing experiments at his country estates in Longhua and Tianjin (over two

101 Laura Hostetler, *Qing Colonial Enterprise: Ethnography and Cartography in Early Modern China*, Chicago: The University of Chicago Press, 2001.

102 Carla Nappi, *The Monkey and the Inkpot: Natural History and Its Transformations in Early Modern China*, Cambridge MA: Harvard University Press, 2009, p. 141.

103 He Bian, *Know Your Remedies*, Princeton, NJ: Princeton University Press, 2020, p. 18.

104 Liang Jiamian, '*Nongzheng quanshu* zhuanshu guocheng ji ruogan youguan wenti de tantao', in Zhongguo ke xue yuan zhong guo zi ran ke xue shi yan jiu shi (ed.), *Xu Guangqi jinian lunwen*, Beijing: Zhonghua shuju, 1963, pp. 78–109, 82.

105 Elman, op. cit. (98), pp. 90–1.

106 Catherine Jami, Peter Engelfriet and Gregory Blue, 'Introduction', in Jami, Engelfriet and Blue (eds.), *Statecraft and Intellectual Renewal in Late Ming China: The Cross-cultural Synthesis of Xu Guangqi (1562–1633)*, Leiden: Brill, 2001, pp. 8–9; Elman, op. cit. (98), p. 92.

107 Han Qi and Catherine Jami, 'The reconstruction of imperial mathematics during the Kangxi Reign (1662–1722), *Early Science and Medicine* (2003) 8(2), pp. 88–110, 89; Frederic Wakeman Jr, 'Romantics, stoics, and martyrs in seventeenth-century China', *Journal of Asian Studies* (1984) 43(4), pp. 631–65, 640.

108 Lewis Maverick, *China, a Model for Europe*, vol. 1, San Antonio, TX: Paul Anderson Co., 1946, p. 95.

109 Maverick, op. cit. (108), p. 92.

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thousand kilometres away from one another) in the 1610s to challenge the Chinese agricultural dictum that 'a plant will only grow well in the region of its origin'.[110] He composed the mammoth *Nongzheng quanshu* (Complete Treatise of Agricultural Administration), which – among other things – argued on the basis of his experiments that the state ought to transform the north-western 'wastelands' into *tuntian* (rice-farming colonies) through irrigation projects.[111] Xu maintained that such a transformation, if implemented quickly enough, could restore social order across the fractured empire and feed Ming soldiers in the north-west.[112] In realizing a state of crisis, Xu Guangqi critiqued existing cultures of knowledge, spurring novel forms of experimentation that, over the course of the crisis, helped bring about a new epistemic and political order.

Our next sketch describes strikingly different epistemic transformations brought about by an array of material crises in seventeenth-century Istanbul. This case is not centred around cross-cultural clashes, but rather discusses a crisis in which actors with disparate backgrounds and interests all realized themselves to be in a state of crisis. Harun Küçük's picture of seventeenth-century Istanbul is characterized by seemingly ubiquitous job precarity and a rapid tempo of life. As he explains, the city's many fires, plagues, wars, political intrigues and earthquakes in the seventeenth century led to a near-universal 'subjective sense of urgency – the opposite of leisure'.[113] Once-elite social positions lost their prestige and job security. For example, during the late seventeenth century the Janissaries, once an elite military order of boys kidnapped from Christian families, grew to over 50,000 members, many of whom were artisans or defectors, leading to a sharp drop in their incomes and social status. Ottoman governance, which had earlier been based on complex theoretical *akaid* Arabic treatises on Islamic philosophy, now relied on short, Turkish-language *ilm-i hal* catechisms, which instead privileged ritual practice over philosophical explorations.[114]

Scholarship, education, and medicine in Istanbul underwent similar structural transformations during the same period. Despite the city then being populated by the largest number of scholars in all of Islamdom, it did not give rise to any 'philosophical' sciences, but rather proliferated 'practical naturalisms' that were closely attuned to material needs. Rather than theoretical astronomy, Istanbulites practised astrology, which could bring about employment as foretellers at court; instead of scholastic medicine, they wrote about *tıbb-ı cedid*, a new chemical medicine that responded to the city's booming drug trade and new diseases; and in the place of natural philosophy, scholars practised alchemy, which could help identify counterfeit coins.[115] In other words, to Küçük, science in seventeenth-century Istanbul was science without leisure, driven by practical necessities and a highly precarious job market.

Consider the case of Ibn Sellum (d. 1669), an Aleppo-born medic.[116] After studying in his home town, Ibn Sellum encountered İbşir Mustafa Paşa, the new governor of Aleppo, and cured him of a battle wound. In 1654, the two men travelled to Istanbul, where İbşir Paşa rapidly rose to grand vizier and Ibn Sellum established himself as a practitioner of *tıbb-ı cedid*, becoming chief physician to Sultan Mehmed IV (1642–93, r. 1648–87) in August 1656. As chief physician, Ibn Sellum translated many European medical texts, selectively appropriating the elements best suited to Istanbul's fast-paced,

110 Francesca Bray and Georges Métailié, 'Who was the author of the *Nongzheng Quanshu*?', in Jami, Engelfriet and Blue, *Statecraft and Intellectual Renewal in Late Ming China*, op. cit. (106), pp. 322–59, 332, 341.

111 Bray and Métailié, op. cit. (110), pp. 338–9.

112 Bray and Métailié, op. cit. (110), p. 338.

113 Küçük, op. cit. (23), pp. 35–6.

114 Küçük, op. cit. (23), p. 36.

115 Küçük, op. cit. (23), pp. 43–4.

116 This case is explored in much greater depth in Küçük, op. cit. (23), pp. 144–9.

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disease-afflicted, highly precarious life. He translated Oswald Croll's *Basylica Chymica*, Johann Jacob Wecker's *Antidotarium* and Daniel Sennert's *De chymicorum* and *Institutiones medicae*, but stripped them of their 'philosophical' content, presenting these texts as a treasure trove of chemical recipes with which to confront new crisis-driving diseases.[117]

In his *Gayetü'l-Beyan* (1664), Ibn Sellum reflected on the way his present's critical conditions were transforming older medical cultures into the new *tıbb-ı cedid*. As he wrote,

> Wonderful drugs and composites have emerged in our times, but not a single member of the '*ulema* [those who know] of the arts' … has written about them yet. And there are many new diseases, which are different from the ones you will find in the books. There are many recent cures, which you will not find in the established classifications.[118]

Spurred by the joint crises of new diseases and a precarious job market, both of which increased the pace of life, Ibn Sellum reshaped older medical works to address his present circumstances, resulting in a substantial shift in medical cultures of knowledge in late seventeenth-century Istanbul. This episode reminds us that epistemic shifts during times of crisis need not lead to 'better' sciences. Rather, they merely engender transformations in cultures of knowledge.

A final vignette provides a salient example of Masco's observation that crises can enforce existing social orders. On 21 March 1960, in the township of Sharpeville in Vereeniging, Johannesburg, the South African police opened fire on a protest organized by the Pan-Africanist Congress of Azania (PAC) against the 'Pass Laws', which required all black South Africans above the age of sixteen to carry a 'passbook' in whites-only areas.[119] Shooting unarmed protesters, the police killed at least sixty-nine and injured 180, including many children. The massacre was widely described as a watershed – a moment of realization – in apartheid South Africa, in terms of both the country's international relations and its internal social order, spurring even many white South Africans to 'rethink "in earnest" the policies that addressed "the Native question"'.[120] Paul Sauer, the acting prime minister from the ruling National Party, acknowledged the critical nature of the massacre, declaring that 'the old book of South African history was closed at Sharpeville'.[121] Nelson Mandela recollected in his autobiography that 'Sharpeville provoked national turmoil and a government crisis. Outraged protests came in from across the globe, including one from the American State Department'.[122]

The massacre was rapidly recognized both within South Africa and in the wider world (albeit in different ways by actors with different material positionalities) as a crisis, transforming the nation's foreign relations and the internal struggle against apartheid, spawning the African National Congress's (ANC) armed wing, uMkhonto we Sizwe. Because of the country's growing international (diplomatic and scientific) isolation following the massacre, the government redirected funding from fields such as astronomy,

117 Küçük, op. cit. (23), p. 148; Natalia Bachour, *Oswaldus Crollius und Daniel Sennert im frühneuzeitlichen Istanbul: Studien zur Rezeption der Paracelsismus im Werk des osmanisches Arztes Salih b. Nasrullah Ibn Sallum al-Halabi*, Freiburg: Centaurus, 2012, pp. 286–7.

118 Quoted in and translated by Küçük, op. cit. (23), p. 147.

119 For the history of the event see Tom Lodge, *Sharpeville: A Massacre and Its Consequences*, Oxford: Oxford University Press, 2011.

120 Lodge, op. cit. (119), p. 169; Lewis Sowden, *The Land of Afternoon: The Story of White South Africans*, London: Elek Books Limited, 1968, p. 219.

121 Quoted in Lodge, op. cit. (119), p. 169.

122 Nelson Mandela, *Long Walk to Freedom*, London: Little, Brown and Company, 1994, pp. 225–6.

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palaeontology and sociology to nuclear technology and weapons research.[123] The shock electoral victory of D.F. Malan's National Party in 1948 reversed much of the previous administration's Commonwealth-oriented liberal internationalism in both science and diplomacy, instead fiercely promoting Afrikaner nationalism. Despite the National Party's clear change in direction, both politically and in terms of state-promoted sciences, South Africa remained a part of the Commonwealth of Nations until its declaration of independence in May 1961, little over a year after Sharpeville. The massacre and its immediate aftermath marked a radical conjuncture in South Africa's sciences, foreclosing rather than opening many scientific possibilities. As William Beinart and Saul Dubow put it, 'The Sharpeville crisis and growing international condemnation of apartheid created the impetus for autonomous nuclear capability'.[124]

Although research into nuclear physics had been conducted as early as 1922 at the University of Cape Town, and the national Atomic Energy Board was first approved in 1948, it was only after Sharpeville that the state began pursuing 'survivalist' techno-nationalist planning by integrating various nuclear programmes into a national, cost-sharing network.[125] The apartheid government deployed crisis talk to legitimize ever harsher crackdowns against any form of dissent, funding scientific activity imbricated with the exercise of this power. Despite superficial condemnation from the capitalist First World over Sharpeville, the staunchly anti-communist apartheid government's embrace of an autonomous nuclear programme reinforced (but also reshaped) South Africa's ties with the West, pushing them into covert territory. South Africa's collaborations with the West largely moved from links between universities to resource sharing between state-funded institutions. For example, despite the John F. Kennedy administration's 1963 arms embargo on the nation, an estimated ninety South Africans subsequently underwent training at US nuclear facilities.[126] Similarly, the South African nuclear programme involved secret cooperations with Israel and West Germany.[127] The key technical transformation enabled by this reshaping of networks was the 'indigenous' development of a uranium enrichment programme in South Africa in 1961.[128] South African scientists, operating under more stringent material constraints than their Western counterparts, did not pursue uranium enrichment processes that relied on expensive gaseous diffusion and gas centrifuges. Rather, possibly drawing on the Becker jet nozzle process developed at the Kernforschungszentrum Karlsruhe in Germany, they developed a novel process using a vortex tube to separate isotopes, which produced laboratory quantities of highly enriched uranium.[129]

As this brief case study emphasizes, the Sharpeville massacre constructed periods of accelerated decision making across vastly dissimilar scales: at the individual level for the families of those murdered by the state; a national political level for the black nationalist PAC, the non-racialist ANC, and the white-supremacist National Party; an international level for the UN Security Council and other individual nations, as the crisis – or crises,

123 On the broader shifts in scientific activity in South Africa during apartheid see William Beinart and Saul Dubow, *The Scientific Imagination in South Africa: 1700 to the Present*, Cambridge: Cambridge University Press, 2021, pp. 264–318.

124 Beinart and Dubow, op. cit. (123), p. 295.

125 Beinart and Dubow, op. cit. (123), p. 292.

126 H.E. Purkitt and S.F. Burgess, *South Africa's Weapons of Mass Destruction*, Bloomington: Indiana University Press, 2005, pp. 35–6; Beinart and Dubow, op. cit. (123), p. 293.

127 Beinart and Dubow, op. cit. (123), pp. 294–5; Purkitt and Burgess, op. cit. (126), pp. 27–8; S. Polakow-Suransky, *The Unspoken Alliance: Israel's Secret Relationship with Apartheid South Africa*, Auckland Park: Jacana, 2002, p. 43.

128 For a lengthier, technical account of this process see Purkitt and Burgess, op. cit. (126), p. 38.

129 Purkitt and Burgess, op. cit. (126), p. 38.

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which differed based on one's material and sociopolitical context – was realized at each scale. The accelerated decisions starkly reorganized social order in South Africa and reconfigured constellations of national and international alliances and collaborations, both politically and scientifically. 'South Africa's old commonwealth of knowledge', write Beinart and Dubow, was 'transmut[ed] into an autarkic republic of science and technology' by the Sharpeville massacre (among other critical events).[130] The crisis – an indisputably 'material' rather than 'intellectual' crisis – dramatically transformed scientific activities in apartheid South Africa.

Conclusion

While late twentieth- and twenty-first-century historians of science have, for good reasons, focused more of their attention on continuity over radical conjunctural change, we hope to motivate renewed interest in rupture, through a suitable conception of crisis – one devoid of epochal or teleological baggage. Our chosen case studies show that crises are realized across different scales, times and places, pointing to their usefulness for a global microhistorical methodology, as a means of building a 'big picture' of knowledge changes in context. As episodes marked by network reorganizations and dramatic tempo changes, especially with regard to decision making, crises open ground for new instances of critical judgement, which can in turn engender re-formations of regimes of scientific knowledge and practice – or lend motivation for powerful actors to reinforce and redouble the existing order. Indeed, this points to a further sense in which crises should be of particular interest to historians (and sociologists, philosophers) of science. Depending on the particulars of the case at hand, a crisis can either open up or foreclose opportunities for critical judgement, which in turn can either deepen or forestall processes of epistemic contestation. During crises, different casts of actors (including, perhaps, those whose behaviour is normally made passive with regard to regimes of knowledge) can, in disparate ways, participate in contestation. Thus we urge historians of science to return their attention to material crises as important and often overlooked episodes of epistemic transformation.

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130 Beinart and Dubow, op. cit. (123), p. 264.

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