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RESEARCH ARTICLE

Against revolutions

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Abstract

The history of science in public discussion is dominated by large-scale narratives of revolution. These locate epistemic violence within specialist communities, obscuring the role of science in environmental destruction and in silencing other ways of engaging with the world. At the same time, the language of revolution has fostered an unrealistic image of science, giving too much prominence to crisis, heroic challenges to authority and the wholescale abandonment of established theory. Revolutionary narratives in history of science were consolidated in the decades around 1900, as the genealogy for an emerging union of science, industry and imperial power. Even when explicitly rejected, they function as 'ghost narratives' within teaching and research. Relocating epistemic violence not only involves changing the geography and chronology of established narratives, a project that is well under way. It also requires understanding that revolution is the wrong category of event for communicating science and its history.

A revolutionary spectre haunts the story of science. Twenty-five years ago Mario Biagioli argued that the Scientific Revolution of the seventeenth century had become a useful box (a casket?) for a concept that is 'undead': an empty disciplinary signifier to be deployed in course descriptions and crossover book titles.[1] More recently, Lorraine Daston called it a zombie narrative – one that comes back again and again. The Scientific Revolution, however, is only the most celebrated of a succession of revolutions, many commemorating individual discoverers: Copernicus, Newton, Darwin, Einstein. Intellectual revolution – though not always identified as scientific in character – is also carried into the deep past, with the 'Cognitive Revolution' of the Palaeolithic. The view that revolution is the key category for understanding the history of science persists in universities and schools, but thrives on television programmes, Internet chatrooms and bestseller lists, particularly in the English-speaking world. For a short time in the 1990s there was even a store in the Mall of America called 'The Scientific Revolution' (Figure 1).

Despite the efforts of determined zombie hunters, the accounts most readily available to the public involve the revelation of a scientific method (or methods) occurring at a particular point in history, which is manifested through further revolutionary outbreaks and ultimately in technological applications and medical progress.[2] Existing critiques of

1 Mario Biagioli, 'The Scientific Revolution is undead', *Configurations* (1998) 6, pp. 141–48; Lorraine Daston, 'What does science have to do with modernity?', public lecture at CRASSH, University of Cambridge, 2 March 2017.

2 See, for example, 'Scientific Revolution', Wikipedia, https://en.wikipedia.org/wiki/Scientific_Revolution (accessed 25 November 2023), and also the Google Ngram for 'Scientific Revolution'.

Figure 1. 'The Scientific Revolution', Mall of America, Minneapolis, Minnesota, 1994. Appropriately, this was a short-lived offshoot of the Nature Company. The shop assistants wore white lab coats, and potential employees were reassured that 'The Scientific Revolution is an equal opportunity employer'. Photograph by the author.

revolution tend to focus on questions of speed and suddenness, or whether a particular sequence of events genuinely constitutes a revolution.

The problem, however, is more fundamental. As a category of large-scale event in history, revolution involves violence and the threatened or actual use of force. My central argument is that the dominance of revolution within science is a form of repression in the historical record, of displaced epistemic violence. There is a mismatch between the big picture of revolutionary scientific breakthroughs which still dominates public narratives, and the widespread acknowledgement that science – like all human activities – has been bound up with war, conquest, the exploitation of natural resources and the suppression of alternative ways of being. While science has been implicated in violence for thousands of years, this is almost never through the episodes that have been characterized as scientific revolutions. The dominance of revolution has also unwittingly abetted populist views that science is a matter of opinion, so provisional that it can be readily overturned. Revolution is the wrong category for telling stories about science.

As a contribution to the ongoing recasting of the history of science, this essay offers a new account of how and why revolutionary narratives were established, discusses the problematic relation between violence and science that they entail, and reviews some of the ways in which they are being replaced.

The revolutionary brand

How did the understanding of past science become tied to the language of violent political and social upheaval? Existing answers are misleading. They typically depict the eighteenth century as the point at which the notion of revolution, considered as a sudden

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break with the past, began to dominate narratives of science.[3] This view, however, relies on isolated rhetorical flourishes and brief revolutionary metaphors. In contrast, almost no attention has been paid to distribution, readership and other established conventions of use in introductory surveys, textbooks and the titles of books and articles.

The issue is not when people first thought of scientific developments as sharing some revolutionary characteristics, but when revolution became standardized as a dominant shorthand, what Harold Cook has described as a 'brand'.[4] In this important sense, the canon of named scientific revolutions has a relatively short history, dating from attempts in the decades around 1900 to construct a genealogy for the modern world and the scientific disciplines that created it.[5] When history of science emerged as a discipline after the Second World War, most practitioners worked within these established frameworks, and in many cases actively reinforced them. That is how the Scientific Revolution and similar constructs became revolutions with a capital R, a signal of their designation as major episodes in world history.

If charting the history of science as a revolutionary sequence is a development of the past century and a half, a stress on novelty and discovery has dominated accounts of science at least since the European encounter with what was tellingly called the 'New World' in the sixteenth century. In its original meaning the word 'revolution' drew primarily from astronomy and meant circular return rather than an irreversible shift. The metaphor of astronomical cycles underpinned references to revolutions of all kinds. For example, the 'Glorious Revolution' of 1688 that exiled the Stuarts from the English throne represented a renewal of peace and security after acute instability and conflict.[6]

During the eighteenth century the meaning of 'revolution' shifted. Projectors of what became known as the Enlightenment began to associate revolution with sweeping unidirectional change, albeit in ways that continued to gesture towards the grandeur of the original astronomical metaphor.[7] These references originated in philosophical contexts, as exemplified by Bernard de Fontenelle's mention in 1719 of a well-marked revolution ('une révolution bien marqueé') in mathematics and Antoine Lavoisier's ambitions in 1773 for a revolution in physics and in chemistry ('une révolution en physique et en chimie').[8] Towards the end of the century, however, the use of the word 'revolution' followed philosophy out of the salons and into the print shops and streets. Thomas Paine's writings played a key part by pirating the phrase 'the American Revolution' from authors who downplayed the significance of colonial grievances. The term was then applied to the French, Haitian and other upheavals. These shattering events created the template for revolution as the label of choice for dramatic transformation in politics and society.[9]

3 I. Bernard Cohen, *Revolution in Science*, Cambridge, MA: Harvard University Press, 1985; Roy Porter, 'The Scientific Revolution: a spoke in the wheel?', in Roy Porter and Mikuláš Teich (eds.), *Revolution in History*, Cambridge: Cambridge University Press, 1986, pp. 290–316.

4 Harold J. Cook briefly mentions the 'brand identity' of the Scientific Revolution in 'Problems with the word made flesh: the great tradition of the Scientific Revolution in Europe', *Journal of Early Modern History* (2017) 21, pp. 394–406, 395.

5 The key works on revolutions in science are H. Floris Cohen, *The Scientific Revolution: A Historiographic Inquiry*, Chicago: The University of Chicago Press, 1994; and (more generally) Cohen, op. cit. (3). My approach in this essay is indebted to William H. Sewell, *Logics of History: Social Theory and Social Transformation*, Chicago: The University of Chicago Press, 2005, esp. pp. 227–9.

6 Adrian Wilson, 'Up the revolution: 1687, 1688 and all that', in Dániel Margócsy and Richard Staley (eds.), *The Mantis Shrimp: A Simon Schaffer Festschrift*, Cambridge: The Cambridge HPS Collective, 2022, pp. 33–5.

7 Martin Jay, 'Mourning a metaphor: the revolution is over', *parallax* (2003) 9, pp. 17–20.

8 Fontenelle is quoted in Cohen, op. cit. (3), p. 214. The key work in defining an eighteenth-century Chemical Revolution as a named historical event was Marcellin Berthelot, *La révolution chimique: Lavoisier*, Paris: Germer-Baillière, 1890, where Lavoisier is quoted on p. 15.

9 Ilan Rachum, 'From "American Independence" to the "American Revolution"', *Journal of American Studies* (1993) 1, pp. 73–91.

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As the meaning of revolution shifted towards violent political change, the term was still not applied to a class of scientific events, but instead continued to function as an occasional metaphor for profound and rapid transformation. Thus Auguste Comte in the 1820s referred to 'revolution' in explaining his proposed stages towards a positive philosophy, as did Darwin in 1859 in expressing his hopes for the impact of *On the Origin of Species* on natural history.[10] In a similar way, Immanuel Kant had depicted his *Critique of Pure Reason* (1791) as the latest revolution in ways of thinking ('Revolution der Denkart') with reference to the rise of mathematics in ancient Greece and experimental science in Europe. Following Kant, the Cambridge polymath William Whewell's surveys of the history and philosophy of science in the 1830s and 1840s described scientific innovations as 'revolutionary'.[11] Again, revolution was never systematically employed as a category for a class of events. There were no book or chapter titles such as 'The Chemical Revolution' or 'The Astronomical Revolution', let alone 'The Scientific Revolution'.

How, then, did revolution become the brand signifier for irrevocable scientific change? The sequence of revolutions crystallized in something close to its current form between the late nineteenth and the mid-twentieth centuries, when science began to transform everyday life in the era of high imperialism, global conflicts and industrial development. Larger narratives about scientific progress and method were proposed by philosophers, economists and general historians, while episodes labelled 'the chemical revolution' and 'the Darwinian revolution' were promoted by scientists engaged in establishing their disciplines. Revolutions provided a drama attractive to students preparing to enter the new institutions of science-based industry, education and colonial commerce. The concept of revolution was especially salient in the wake of political upheavals around the time of the First World War, such as the Mexican Revolution, the Philippine Revolution, the Xinhai Revolution and the Russian Revolution.

In an age of marketing and mass consumption, 'revolution' became a potent way to advertise the power and historic significance of science. This period also saw the creation of other easily communicated categories for describing political, social, literary and intellectual movements. Readily identifiable '-isms', such as 'Romanticism', 'capitalism', 'Marxism', 'imperialism' and 'Darwinism', became shorthands in the mass circulation press.[12] Ideas and intellectual movements could be marketed like Pears soap or Imperial Leather.[13]

Around 1900 two main candidates competed for the title of 'the' scientific revolution. One was Darwinian evolution, with its potential for the racial management of populations and challenges to traditional religion. The other, more far-reaching and encompassing the evolutionary movement, was the emergence of a global system of science-based industry. When relativity theory became generally known in 1919, journalists dubbed it a 'revolution in physics' or yet another 'revolution in science'.[14] Branding such episodes 'revolutions' acknowledged the newly felt role of science as a progressive historical

10 The Comte references are collected in Cohen, op. cit. (3), pp. 332–7. For relevant essays on Darwin see Ian Hesketh (ed.), *Imagining the Darwinian Revolution: Historical Narratives of Evolution from the Nineteenth Century to the Present*, Pittsburgh: University of Pittsburgh Press, 2022, with Darwin's use referenced on p. 24.

11 William Whewell, *The Philosophy of the Inductive Sciences Founded upon Their History*, London: John W. Parker, 1840, vol. 2, p. 208; for Kant, see Cohen, op. cit. (3), p. 245.

12 James Moore, 'Socializing Darwinism: historiography and the fortunes of a phrase', in Les Levidow (ed.) *Science as Politics*, London: Free Association, 1986, pp. 38–80.

13 Good starting points are Anne McClintock, 'Soft-soaping empire: commodity racism and imperial advertising', in McClintock, *Imperial Leather: Race, Gender and Sexuality in the Colonial Contest*, New York: Routledge, 1994, pp. 207–31; and Jackson Lears, *Fables of Abundance: A Cultural History of Advertising in America*, New York: Basic Books, 1994.

14 Alistair Sponsel, 'Constructing a "revolution in science": the campaign to promote a favourable reception for the 1919 solar eclipse experiments', *BJHS* (2002) 35, pp. 439–67.

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force – compared, for example, with religion or economics – and the power of European civilization, both for students and for the public at large.

The significance of the decades around 1900 for the establishment of revolutionary narratives is evidenced by the curious history of Kant's supposed claim to have initiated a 'Copernican Revolution' in philosophy. Like other eighteenth-century commentators, Kant had emphasized the novelty of his philosophy by referring to revolutions, but the parallel he made between himself and Copernicus was nothing more than an acknowledgement of the need to trial fresh ideas when old ones are in chaos. It was only from the later nineteenth century that this comparison hardened into to an event labelled the 'Copernican revolution' involving a new role for the observer. The phrase soon began to be attributed (wrongly) to Kant as a direct quotation.[15]

Among all the revolutions that gained currency around this time, the most significant was 'the scientific revolution' of the seventeenth century.[16] Emerging after the devastation of the First World War, this concept was a product of the 'New History' at Columbia University in New York, which urged that the past should be studied only insofar as it could shape the present. In the historian James Harvey Robinson's *The Mind in the Making: The Relation of Intelligence to Social Reform* (1921), the scientific revolution established a pragmatic scientific method that spread from European civilization to the rest of the world. The phenomenal success of Robinson's book and others in the same vein led to chapters on 'The Scientific Revolution' appearing in textbooks in the United States used by millions of high-school and college students. As the progressive educator Harold Rugg wrote in 1932, new ways of thinking were central to 'the scientific revolution, the real basis of the march toward democracy' (Figure 2).[17] A fundamental aim of this redefined 'scientific revolution' was to show that intellectual preceded economic change. The key episode of modernity shifted from science-based industrial capitalism in the age of empire to a handful of 'frontier thinkers' three hundred years in the past.

During the era of academic expansion following the Second World War, debates about the seventeenth-century Scientific Revolution provided a key selling point for the emerging discipline of history of science. The English historian Herbert Butterfield argued in his widely translated *The Origins of Modern Science* (1949) that the new ways of thinking had nothing to do with economics or experiment. His Marxist opponents, such as the Irish crystallographer John Desmond Bernal, also adopted the concept of the Scientific Revolution, while disputing its causes and consequences. In his expansive *Science in History* (1954), history was a 'science of science'. Bernal followed Lenin and other founders of the Soviet Union who viewed the revolutionary events of 1917 as scientific. In China the intellectuals of the May Fourth Movement in 1919 similarly hailed 'Mr Science' as a revolutionary hero.[18] The relations between science and revolution look very different outside the perspectives that have dominated historical writing in the West.

Although revolutionary accounts of the history of science have been challenged for the past half-century, many general historians, economists and social theorists continue to rely upon a story little changed since the 1920s, depicting a secular scientific philosophy paving the way for the Enlightenment and the triumph of Darwin.[19] Among these

15 Norwood Russell Hanson, 'Copernicus' role in Kant's revolution', *Journal of the History of Ideas* (1959) 20, pp. 274–81; also Cohen, op. cit. (3), p. 241.

16 James A. Secord, 'Inventing the scientific revolution', *Isis* (2023) 114, pp. 50–76.

17 Harold Rugg, *Changing Governments and Changing Cultures: The World's March towards Democracy*, Boston, MA: Ginn, 1932, p. 88.

18 Fa-ti Fan, '"Mr. Science", May Fourth, and the global history of science', *East Asian Science, Technology and Society* (2022) 16, pp. 279–304.

19 The critiques are reviewed in Thomas Nickles, 'Scientific revolutions', in *Stanford Encyclopedia of Philosophy*, 2009, revised 2017, at https://plato.stanford.edu/entries/scientific-revolutions (accessed 8 April 2023).

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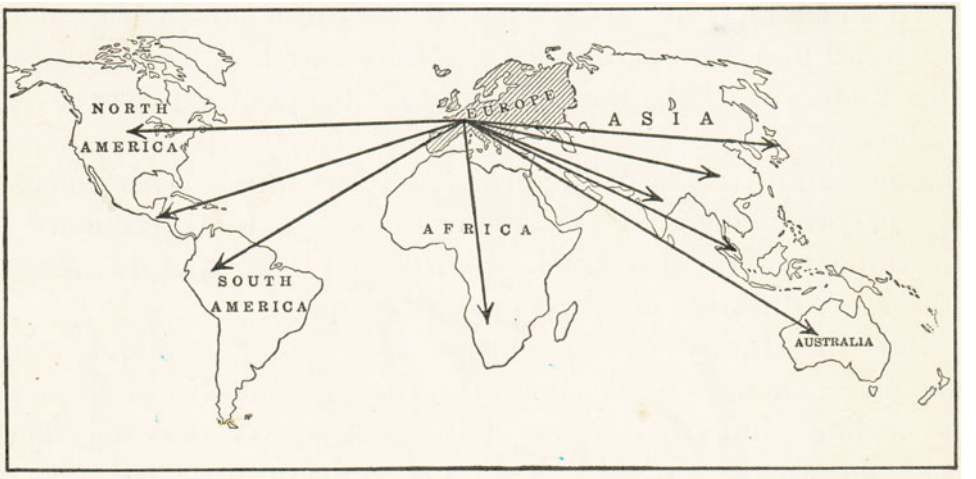

FIG. 7. After the 1500's a new kind of civilization began to develop in western Europe and to spread to every continent of the earth

Figure 2. Science diffuses from Europe. From Harold Rugg, *Changing Governments and Changing Cultures: The World's March towards Democracy*, Boston, MA: Ginn, 1932, p. 22. Photograph by the author.

accounts are 'big histories' which begin with the formation of the universe and conclude with the Internet and artificial intelligence. These aim to decentre humans while making human destiny the teleological end of a vast interplanetary drama.[20] Revolutionary narratives of science also continue to play a role in accounts of the path to modernity, whether these invoke the rediscovery of Archimedes, the New World, or the power of steam.[21] The centrality of the Scientific Revolution has been reinforced on a global scale by Yuval Noah Harari's *Sapiens: A New History of Humanity* (2014), which has sold over twenty-five million copies in sixty-five languages.[22] Harari offers a gripping account of human history as a series of mental transformations extending towards a future dominated by machine algorithms. Whether or not Harari is right, revolution is a key word in marketing and likely to gain traction through generative artificial intelligence and Internet search engines. The bestselling historian Niall Ferguson has identified the Scientific Revolution as one of the 'six killer apps' separating 'the West and the Rest'. Another, he claims, is consumerism.[23] The two are related, although perhaps not in the way he imagines.

Ghost narratives

Arguments against revolutionary narratives have almost entirely failed to penetrate the public sphere. This is partly the consequence of a small discipline like history of science confronting a century-old consensus, but it is also the result of the lack of appropriately scaled alternatives that challenge existing accounts of the *longue durée*. The move since the 1970s towards cultural anthropology and micro-sociology has proved immensely fruitful

20 Ian Hesketh, 'The story of Big History', *History of the Present* (2014) 4, pp. 171–202.

21 Reviel Netz, *A New History of Greek Mathematics*, Cambridge: Cambridge University Press, 2022; David Wootton, *The Invention of Science: A New History of the Scientific Revolution*, London: Allen Lane, 2015.

22 See www.ynharari.com/about (accessed 26 November 2023).

23 Niall Ferguson, *Civilization: The West and the Rest*, London: Allen Lane, 2011.

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for the field in challenging overgeneralized narratives of the filiation of ideas. However, the resulting stress on the local and particular has often led to a narrowing of horizons, a trend exacerbated by the demands of tenure committees and journal editors for discrete outputs.[24] Although this orientation towards cultural specificity collectively challenges revolutionary accounts, it has not been conducive to the discipline developing its own larger narratives. Instead, local studies are read and re-presented in a patchwork of inherited frameworks.

The problem is not just the plethora of textbooks and trade books advertised under the banner of 'revolution'.[25] For in their most dangerous form, scientific revolutions are not zombies, but ghosts: hidden subtexts, implicit, often even rejected, but still framing the way in which stories are told, read and received. Revolution narratives are to histories of science what for literature Frederic Jameson termed 'the political unconscious', expressing the relations of our stories to the economics of capitalism, empire and environmental destruction. Terms such as 'the Darwinian Revolution' and 'the Scientific Revolution' are put in scare quotes (as is appropriate for ghosts), or they are used with the ritually dismissive 'so-called'. Even worse, 'revolution' is treated as a neutral chronological label – a period designation rather than an event. Such references can never operate as such, because the language of revolution feeds directly into assumptions about a single scientific method invented by white male Europeans as the route to modernity. The invention of the Scientific Revolution and its successors created a geographical imbalance that could only be overcome through diffusion from Europe (Figure 2), a view of scientific communication that has been universally rejected. Every time we refer to scientific revolutions, we are reinforcing this Eurocentric bias.

The ambiguities of these ghost narratives are best summed up by the celebrated opening of Shapin's *The Scientific Revolution*: 'there was no such thing as the Scientific Revolution, and this is a book about it'.[26] As an expression of ambivalence, this quip just about worked in 1996, but that it is repeatedly invoked three decades later is a disappointment. Similarly, much survey teaching remains dominated by stories that lead up or away from Darwin, Einstein and other heroic discoverers, or by other reference points used in ways that echo revolutionary narratives. Ghost narratives of revolution pervade all aspects of how the history of science is communicated, invisibly infiltrating the work of otherwise ordinary-appearing, well-intentioned and conscientious authors and lecturers.

For example, the introductory course I taught at Cambridge for nearly thirty years could be easily assimilated to a revolutionary narrative. I began with the changes in science around 1800, with what has been described as the Second Scientific Revolution. This was followed by lectures on developments from evolutionary theories to relativity and genetics. I never called these episodes revolutions, but, to be honest, that's what I was looking at, because my students in the natural sciences would already know about them as transformative moments. Although I told the stories in new ways, the sequence was familiar. An exam question in 1999 asked, 'Is the history of science the history of great men?' The expected answer was 'no', but many students recognized that the lecturer might have inadvertently suggested it was 'yes'.

24 Steven Shapin, 'Hyperprofessionalism and the crisis of readership in the history of science', *Isis* (2005) 96, pp. 238–43.

25 For a sampling, see John Henry, 'The Scientific Revolution: five books about it', *Isis* (2016) 107, pp. 809–17. More recent examples include Ofer Gal, *The Origins of Modern Science: From Antiquity to the Scientific Revolution*, Cambridge: Cambridge University Press, 2021; and David Marshall Miller and Dana Jalobeanu (eds.), *The Cambridge History of Philosophy of the Scientific Revolution*, Cambridge: Cambridge University Press, 2022.

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

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The problem is especially acute for the most revolution-ridden part of the story. However much we try to get away from the Scientific Revolution – and serious attempts to do this were made in the 1980s and 1990s – it keeps coming back through campaigns to depict science as the unique achievement of Western civilization. Although these works offer a wealth of interpretation, they can all be assimilated to a major break that initiates the making of the modern world. The explicit reaffirmation of the Scientific Revolution is exemplified by David Wootton's *The Invention of Science: A New History of the Scientific Revolution* (2015). Caught in a time warp of the 1990s science wars, yet marked by many fascinating discussions, Wootton's book attacks most working historians of science as radical postmodernists for abandoning the Scientific Revolution.

Ironically, the authors Wootton criticizes can be interpreted as reinforcing the concept. Daston, who gave a generally positive review of Wootton's book, edited, with Katharine Park, the volume of the *Cambridge History of Science* for the corresponding period. This superb work, notable for never mentioning the Scientific Revolution, offers essays on a cornucopia of topics, from exploration and alchemy to natural history and experimental natural philosophy. The editors justify their emphasis on the 'new' as Europe's 'own myth of modernity – one at least as spellbinding as that created for us by latter-day historians'.[27] That myth is carefully dissected in the volume. Yet the difficulties are not easy to resolve. The chronological limits of 1490 to 1730 broadly match those of the traditional story; and the title, *Early Modern Science*, has a similar teleology, while avoiding the worst pitfalls of the revolutionary metaphor.[28] The picture would look quite different even from European perspectives if the dates were set earlier or later.

Shapin and Simon Schaffer's classic *Leviathan and the Air-Pump: Hobbes, Boyle, and the Experimental Life* (1985) likewise never mentions the Scientific Revolution, the origins of modern science, or Robert Boyle as a founding father. Yet readers who approach the text from the old framework can still find their assumptions reinforced by a conclusion claiming that the book has 'examined the origins of a relationship between our knowledge and our polity that has, in its fundamentals, lasted for three centuries'.[29] This is not the traditional view, but it can be interpreted as repositioning the Scientific Revolution into the realm of experiment and deepening its significance. Assumptions from older narratives still haunt the reading of these accounts.

Kuhn's ghosts

To understand the persistence of revolution, an obvious starting point is Thomas Kuhn's *The Structure of Scientific Revolutions*.[30] When first published in 1962, *Structure* played a vital role in countering the common assumption that science progressed through the accumulation of positive discoveries. Talk about revolutions underlined the potential depth of

27 Lorraine Daston, review of David Wootton, *The Invention of Science*, *The Guardian*, 28 November 2015, at www.theguardian.com/books/2015/nov/28/invention-of-science-scientific-revolution-david-wootton-review; Katharine Park and Lorraine Daston (eds), *The Cambridge History of Science*, vol. 3: *Early Modern Science*, Cambridge: Cambridge University Press, 2006, p. 17.

28 For the origins of 'early modern' see Jerry H. Bentley, 'Early modern Europe and the early modern world', in Charles H. Parker and Jerry H. Bentley (eds.), *Between the Middle Ages and Modernity: Individual and Community in the Early Modern World*, London: Bowman and Littlefield, 2007, pp. 13–31.

29 Steven Shapin and Simon Schaffer, 'Coming up for air', in Shapin and Schaffer, *Leviathan and the Air-Pump: Hobbes, Boyle, and the Experimental Life*, Princeton, NJ: Princeton University Press, 2011 (1985), pp. xi–l, xxxi, also 343.

30 Thomas Kuhn, *The Structure of Scientific Revolutions*, Chicago: The University of Chicago Press, 2012 (first published 1962).

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scientific change. Kuhn believed that the demand for precision in the use of terms made the sciences liable to problems in accommodating shifts in theory and practice, thereby leading to irreconcilable conflict between what he famously termed 'paradigms'. In Kuhn's view, piecemeal translation, the ordinary way of moving between one language and another, does not work.[31] The key idea of incommensurability between paradigms was consequently derived not from linguistics, but from mathematics: old and new paradigms have no more chance of meeting than two quantities without a common measure.

With its references to perceptual ambiguity and gestalt switches, *Structure* placed a strong emphasis on individual psychology. The book, which became one of the most influential of the twentieth century, established the history of science as a model for revolutionary transformations in the mind. This psychological emphasis enabled students storming the barricades at Berkeley in the 1960s (where Kuhn was teaching when his book appeared) to welcome paradigm shifts as exemplars of what a 'head revolution' could be.[32] Kuhn did not consider views of nature held by whole cultures and populations, or even across disciplines. Rather, his revolutions occur on a variety of scales, with great frequency and within professionally trained groups of a hundred or fewer working scientists.[33] The physiologist A.V. Hill had put forward a similar view in the 1930s as a joke. 'The revolution to which this paper refers broke out on the last day of December 1926, when Eggleton and Eggleton sent to the *Biochemical Journal* a paper describing "phosphagen".'[34]

The often profound insights of *Structure* into the scientific process tended to get lost when its claims were assimilated into the dominant historical narrative. Appearing when history of science was being established as an academic discipline, *Structure* crystallized, but did not singlehandedly or intentionally create, the story of science as a roll call of world-changing theoretical revolutions. The book was widely understood as connecting the dots between a well-known sequence of historical events, and the examples deployed in the book (Copernican astronomy, the discovery of oxygen, the origins of relativity) did little to undermine this assumption. Most readers of *Structure* came away with the impression that all important episodes in science were revolutionary. Everything else was 'normal' science, a kind of puzzle solving that seemed by comparison a bit dull. Not surprisingly, then, the instigators of plate tectonics, genomics and AI framed these later developments as revolutions on what they considered a Kuhnian model, with themselves as revolutionaries.

In this way, *Structure* became at once the greatest promoter and the greatest victim of the narrative ghosts of revolution. Following Kuhn's lead in later writings, the analysis of scientific revolutions has been driven by perspectives from philosophy rather than from history. There have been attempts to show the compatibility of revolutions with an evolutionary view of science and to moderate the more extreme implications of

31 Kuhn, op. cit. (30), p. 149. See Deborah Coen, 'Rise, *Grubenhund*: on provincializing Kuhn', *Modern Intellectual History* (2012) 9, pp. 109–26. For helpful starting points in the literature on translation see Scott L. Montgomery, *Science in Translation: Movements of Knowledge through Cultures and Time*, Chicago: The University of Chicago Press, 2000; and Lydia H. Liu (ed.), *Tokens of Exchange: The Problem of Translation in Global Circulations*, Durham, NC: Duke University Press, 1999.

32 For Kuhn's difficulties in controlling his readers see several of the essays in Robert J. Richards and Lorraine Daston (eds.), *Kuhn's* Structure of Scientific Revolutions *at Fifty: Reflections on a Science Classic*, Chicago: The University of Chicago Press, 2016, especially David Kaiser, 'Thomas Kuhn and the psychology of Scientific Revolutions', at pp. 72–95; and Steven Shapin, 'Paradigms gone wild', *London Review of Books*, 30 March 2023, pp. 27–32.

33 Kuhn, op. cit. (30), p. 177, 'Postscript'.

34 A.V. Hill, 'The revolution in muscle physiology', *Physiological Review* (1932) 12, pp. 56–67, 56.

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incommensurability, although these have had limited success in overcoming the force of the original mathematical analogy.[35] Most historians and sociologists have considered revolutions the least convincing part of *Structure*, which is used for modelling case studies rather than developing alternative theories of historical change at larger scales.[36] As a consequence, revolutions in science have been analysed almost entirely apart from those in politics and society.[37]

Revolutionary violence

The central issue is the relation of science to violence. Violence – actual or threatened physical violence – is involved in all discussions of political and social revolutions. Some revolutions are said to be non-violent, such as the 'colour' uprisings of recent decades, but are almost always responses to violence by the state.[38] Campaigns for the overthrow of the ruling order have the potential for spilling over into physical repression or public terror, involving either violence or a reaction to it. As Hannah Arendt wrote in 1963, 'the mere fact that revolutions and wars are not even conceivable outside the domain of violence is enough to set them both apart from all other political phenomena'.[39] Social upheavals such as the Industrial Revolution have involved the mass displacement of communities, violence to the living world and the disappearance of established ways of life. In rhetorical terms, all revolutions are violent, characterized by denunciation, counterclaims and narratives which divide the old order from the shape of things to come.

By comparison, even great controversies in science are conducted in measured language. Verbal battles are seen as exceptional and regrettable. The rhetorical register of science, even in controversy, is measured, and the drive to achieve consensus within the scientific community means that terms – although always open to dispute – are typically closely defined. In democratic polities, science is supposed to serve as a model for disputation, even if this ideal is never fully achieved. During the French Revolution, many savants fled Paris to pursue enquiries with 'a pure and sensible eye', away from the violence of the barricade and guillotine.[40] On the eve of the American Civil War, science was classed among the 'peaceful pursuits'. Disagreements and conflict are essential to science – but these operate in a different register than anything to be found in political revolutions. Direct physical violence involving scholarly elites is condemned as horrific.

35 For the fullest exposition of how Kuhn later tried to put the revolutionary genie back in the bottle see Bojana Mladenović (ed.), *The Last Writings of Thomas S. Kuhn: Incommensurability in Science*, Chicago: The University of Chicago Press, 2022.

36 E.g. Barry Barnes, *T.S. Kuhn and Social Science*, London: Macmillan, 1982. On scale, James Poskett, this issue.

37 An exception is Porter and Teich, op. cit. (3), which includes literature, music and other subjects. Jack A. Goldstone, *Revolutions: A Very Short Introduction*, Oxford: Oxford University Press, 2014, offers an accessible overview of the social-science literature. Among philosophical accounts that mention social and political analyses see K. Brad Wray, *Kuhn's Evolutionary Social Epistemology*, Cambridge: Cambridge University Press, 2011, p. 28.

38 For the changing nature of revolutions see Jack A. Goldstone, Leonid Grinin and Andrey Korotayev (eds.), *Handbook of Revolutions in the 21st Century: The New Waves of Revolutions, and the Causes and Effects of Disruptive Political Change*, Cham: Springer, 2022.

39 Hannah Arendt, *On Revolution*, New York: Viking, 1963, p. 9. See also Jeff Goodwin, *No Other Way Out: States and Revolutionary Movements, 1945–1991*, Cambridge: Cambridge University Press, 2001; and Arno Mayer, *The Furies: Violence and Terror in the French and Russian Revolutions*, Princeton, NJ: Princeton University Press, 2002.

40 Dorinda Outram, 'The ordeal of vocation: the Paris Academy of Sciences and the French revolutionary terror, 1793–1795', *History of Science* (1983) 21, pp. 251–73. For the phrase, see Outram, 'The pure and sensible eye: the man of science and revolutionary culture in France', paper presented at the University of Kent at Canterbury, noted in 'Report of Council for the British Society for the History of Science for the year 1983–4', *BJHS* (1984) 17, pp. 341–44, 344.

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The brutal murder in 415 CE of the Alexandrian astronomer and philosopher Hypatia scandalized the learned world, as did the guillotining of Lavoisier in 1794.

The problem of violence is confronted in *Structure* through a direct comparison of political and scientific revolutions. Both are said to involve abandoning an institutionalized system of authority and the use of 'techniques of mass persuasion, often including force'. The situation in politics and science is characterized as 'very similar', demanding nothing less than a 'choice between incompatible modes of community life'.[41] At the time Kuhn originally wrote, such references to the failure of the normal means of agreement offered a vital corrective to the assumption that the social dimensions of science had little to do with its making. From today's perspective, however, when scientific experts are under attack for being elitist, authoritarian and anti-democratic, a history of science centred on revolutions is misleading. Should historians, following the logic of Kuhn's argument, consider the rewriting of introductory chemistry primers as analogous to the events that unfolded after the storming of the Bastille in 1789 or of the Winter Palace in 1917? In one of the book's less convincing moves, *Structure* does something close to this, comparing the suppression of outdated science textbooks to the dystopian, post-revolutionary world of George Orwell's *1984*.[42]

Structure immediately sidesteps the violent implications of the revolutionary metaphor by drawing a line between science and all other human activities. Science is 'special', the book argues, because in it revolutions occur only among self-validating groups of specialists, who guarantee competence through shared expertise and commitment to common values. The problem of violence can be circumvented because all members of these scientific communities, whatever their differences, pursue an approach that developed in 'Europe during the past four centuries'. As noted in *Structure*, 'No other place and time has supported the very special communities from which scientific productivity comes.' Although *Structure* never mentions it by name, the Scientific Revolution, building on the achievements of ancient Greeks, underpins the book's entire scheme.[43] Kuhn almost certainly learned about the Scientific Revolution in junior high school in the 1930s from Rugg's progressive textbooks, and its significance was enhanced by the experience of decolonization and the Cold War.[44] For Kuhn, without the heritage of Western civilization there could be no genuinely *scientific* revolutions.

Talk of scientific revolutions thus offers two equally unappetizing options: either isolate science from all other cultures and the rest of history through a unique set of shared standards, or give disjuncture, misunderstanding and the use of force an implausible place in the scientific enterprise. The revolutionary metaphor is not just strained (as Kuhn acknowledged), but broken. When the Hungarian philosopher Imre Lakatos accused *Structure* of importing 'mob psychology' into science he misinterpreted what Kuhn was trying to do, but the comment did capture something important about the way the book would be read.[45] Lakatos began his career as an ardent Stalinist and participant in several genuine revolutions in Central Europe. He knew that science and politics could be intimately related, and hence the dangers of importing the most dramatic form of political transformation into the philosophy of science.[46]

41 Kuhn, op. cit. (30), p. 94.

42 Kuhn, op. cit. (30), p. 166.

43 Kuhn, op. cit. (30), pp. 166–7. For a somewhat different development of this argument see Thomas S. Kuhn, *The Road since Structure: Philosophical Essays, 1970–1993, with an Autobiographical Interview* (ed. James Conant and John Haugland), Chicago: The University of Chicago Press, 2000, pp. 105–20.

44 Secord, op. cit. (16), p. 66; for the general context see Richards and Daston, op. cit. (32).

45 Imre Lakatos, 'Falsification and the methodology of scientific research programs', in I. Lakatos and Alan Musgrave (eds.) *Criticism and the Growth of Knowledge*, Cambridge: Cambridge University Press, 1970, pp. 91–196, 178.

46 Lee Congden, 'Possessed: Lakatos's road to 1956', *Contemporary European History* (1997) 6, pp. 279–94.

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It could be argued that to talk of incommensurability within so-called revolutionary science as a form of violence is to be overly literal about what is, after all, a metaphor. However, given the deepening divisions in our own political systems, a history of science grounded in irreconcilable argument and failed communication is no longer a helpful way to think about science. It encourages populist views that science is simply a matter of opinion and subject to abandonment through the power politics of an expert elite.[47] Conversely, in heroic biographies and popular journalism, revolutions are often unrealistically associated with singular discoveries, individual genius and campaigns against entrenched dogma. The novelty and excitement of a few moments in science are exaggerated at the expense of the essential, and often intensely engaging, regular work of science that Kuhn described as 'normal'.

Why should the history of science be dominated by large-scale revolutions more often than these are invoked in the history of politics? This is not the case for music, art, literature or theology, where the language of revolution is far less frequently employed. For example, while the talk of 'warfare' in relation to religion and science is now pilloried by historians, the language of the Darwinian Revolution remains intact, with its implication that traditional theological views of creation were being violently overthrown (Figure 3). The Darwinian Revolution, invented as part of a secular strategy to reform biology and free minds from religion, is the final bastion of the conflict model.[48]

The place of violence

The relations between science and violence are subtle and pervasive, in ways obscured by the language of revolution. This is evident in shifts in the gendering of science from the late medieval period onwards. The development of science in Europe, with its stress on personal character and trustworthiness, was founded on masculine codes of honour. These rested in turn on threats of violence: when efforts to defuse an affront failed, the true gentleman had to defend the 'point of honour' in a duel. It is often claimed that Tycho Brahe lost part of his nose in a dispute over who was the better mathematician, although the evidence that this was why they fought is weak.[49]

Although there were later threats of pistols at dawn, these never came to anything, as when a young Swiss physiologist was accused of presenting faulty observations of infusoria at the Société de biologie of Paris in 1857. 'These are things', the hapless physiologist wrote half-jokingly, 'one only sees in the Congress at Washington and the learned societies of Paris'.[50] Yet politics, as the reference to Washington makes clear, was different

47 For related comments see Ava Kofman, 'Bruno Latour, the post-truth philosopher, mounts a defense of science', *New York Times Magazine*, 28 October 2018; and Steve Shapin, 'Is there a crisis of truth?', *Los Angeles Review of Books*, 19 November 2019, at https://lareviewofbooks.org/article/is-there-a-crisis-of-truth (accessed 1 December 2023). Also Niles G. Mede and Mikes S. Schäfer, 'Science-related populism: conceptualizing populist demands toward science', *Public Understanding of Science* (2020) 29, pp. 473–91.

48 For discussion of the problems of using military metaphors to characterize science and medicine see Jeff Hardin, Ronald L. Numbers and Ronald A. Binzley (eds.), *The Warfare between Science and Religion: The Idea That Wouldn't Die*, Baltimore: Johns Hopkins University Press, 2018; and Bernard V. Lightman (ed.), *Rethinking History, Science, and Religion: An Exploration of Conflict and the Complexity Principle*, Pittsburgh: Pittsburgh University Press, 2019. For a contemporary case see Franiska E. Kohlt, '"Over by Christmas": the impact of war-metaphors and other science–religion narratives on science communication environments during the Covid-19 crisis', https://osf.io/preprints/socarxiv/z5s6a (accessed 30 March 2023).

49 Victor E. Thoren and John Robert Christiansen, *The Lord of Uraniborg: A Biography of Tycho Brahe*, Cambridge: Cambridge University Press, 1991, pp. 22–5.

50 Quoted in Robert A. Nye, 'Medicine and science as masculine "fields of honor"', *Osiris* (1997) 12, pp. 60–79, 64.

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Figure 3. Derek Chatwood, 'Jesus! vs Darwin!'. An imagined opening spread juxtaposing 'True Belief Comics' and 'Science Action Stories', 31 July 2014; courtesy of the artist. At www.poprelics.com/author/admin/page/4 (accessed 24 November 2023).

from science – only a year before the bizarre challenge at the Société de biologie, the abolitionist Charles Sumner had been caned unconscious on the Senate floor.[51]

Science in the European tradition has continued the hierarchical culture of genteel masculinity by means other than violent confrontation. By the end of the nineteenth century, codes of scientific masculinity were expressed through cultures of drinking, sexual innuendo in university lectures, all-male clubs and societies, and especially contests for priority and the high-stakes competition for resources and reputation. Women, people of colour and others deemed incapable of defending honour were defined as dependants and placed on the margins of practice. Resort to force in science was (and continues to be) viewed as pathological; physical violence has been supressed. In many ways the opening up of careers to women from the late nineteenth century onwards, and people of colour in more recent years, has only made the existence of male codes of conduct more apparent. A culture of long hours and late nights combined with hierarchal structures of authority leads to frequent episodes of harassment, discrimination and bullying.

These issues have long been recognized in the literature on race, gender and science, but the tendency has been to retain existing long-term narratives even when the moral lessons are turned on their heads. The Scientific Revolution remains a singular historical event brought about by distanced white male reason, what Bacon termed 'the masculine

51 Minisha Sinha, 'The caning of Charles Sumner: slavery, race, and ideology in the age of the Civil War', *Journal of the Early Republic* (2003) 21, pp. 233–62.

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birth of time'. In works such as Carolyn Merchant's pathbreaking *Death of Nature*, this cold and objective European approach then confronts forms of knowing in other parts of the world. Bacon remains the progenitor of 'the scientific method', so that ghost narratives of the Scientific Revolution live on.[52]

When considering the relation between science and violence, the most significant issues are systematic and institutional, not about individual agency or blame. What should we make of the fact that Isaac Newton, like many men of his status, owned shares in a company engaged in the slave trade? It is certainly worth pointing out that Newton participated in a plantation economy based on enslavement, and even more so that his calculations depended on information from correspondents across what James Poskett terms 'the wider world of empire, slavery, and war'.[53] But what this means for Newton's science or the broader historical story is unclear. Newton's natural-philosophical work had power precisely because it could be depicted as, and in many practical ways was, isolated from the exploitative economic system in which it was embedded. What matters is the opportunity that people like Newton had to pursue their inquiries in solitude, while simultaneously being placed in relation to systems of conquest and control.[54]

New relations between scientific research, industry and the nation state have facilitated unprecedented cultural dispossession and violence against the living world. Scientists have transformed the possibilities of human life, but in doing so have also contributed to developing weapons of war; racial, gender and class hierarchies; and inventions that have exploited the natural environment.[55] At the same time, practitioners tend to be emotionally, geographically and temporally distanced from these activities: it is exceptionally rare for a scientist to acknowledge 'blood on my hands', which is why Robert Oppenheimer's statement after the dropping of the atomic bombs is so famous.[56] Today those working in universities, government institutes and commercial laboratories typically have a high sense of vocation and a commitment to a common enterprise – often focused on specific tasks resulting in innovation and remarkable benefits.[57] Turning heroes into villains and discipline-founding discoveries into cultural catastrophes simply perpetuates the old revolutionary mythology.

The two-handed engine

Revolution gives drama to the story of science, but it is a false drama, or rather drama of the wrong kind.[58] Mythic moments of sudden change within science – whether or not we call them revolutions – turn attention away from the place of science in wider, deeper and systematic forms of epistemic violence towards the living world and people from other cultures. Epistemic violence was defined by Gayatri Chakravorty Spivak as 'a complete

52 Carolyn Merchant, *The Death of Nature: Women, Ecology, and the Scientific Revolution*, New York: Harper, 1980, p. 170; also Porter, op. cit. (3), p. 292.

53 James Poskett, *Horizons: A Global History of Science*, London: Viking, 2022, p. 133.

54 Steven Shapin, 'The philosopher and the chicken: on the dietetics of disembodied knowledge', in Christopher Lawrence and Steven Shapin (eds.), *Science Incarnate: Historical Embodiments of Natural Knowledge*, Chicago: The University of Chicago Press, 1998, pp. 21–50.

55 As Shapin has said, it is 'never pure': Steven Shapin, *Never Pure: Historical Studies of Science as if It Was Produced by People with Bodies, Situated in Time, Space, Culture, and Society, and Struggling for Credibility and Authority*, Chicago: The University of Chicago Press, 2010.

56 Kai Bird and Martin J. Sherwin, *American Prometheus: The Triumph and Tragedy of J. Robert Oppenheimer*, London: Atlantic Books, 2021 (first published 2005), pp. 188–9.

57 Steven Shapin, *The Scientific Life: A Moral History of a Late Modern Vocation*, Chicago: The University of Chicago Press, 2008.

58 For the power of revolutionary storytelling see Eric Selbin, *Revolution, Rebellion, Resistance: The Power of Story*, London: Zed Books, 2010.

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overhaul of the episteme', in which the overall system of knowledge – the episteme – is implicated in forced attempts to subjugate, control and repress. The example she uses is the celebrated discussion by Michel Foucault of the redefinition of the 'mad person' through incarceration in asylums at the end of the eighteenth century, but it also applies to the transformations in the sciences of life, economics and linguistics at the same time. The difficulty, Spivak suggests, is that Foucault's views take account of only one side of the story: 'But what if that particular redefinition was only a part of the narrative of history in Europe as well as in the colonies? What if the two projects of epistemic overhaul worked as dislocated and unacknowledged parts of a vast two-handed engine?'[59]

The centrality of science to Spivak's 'vast two-handed engine' is rarely acknowledged in global histories, a point illustrated by the multi-authored *Cambridge World History*. In the two volumes covering what is generally called the early modern period, there are two pages focused on 'advances in the pure sciences' leading up to Newton, with only a few further mentions of natural philosophy or natural history.[60] The volumes are largely silent on the exchange of information between the indigenous peoples and voyaging Europeans, an issue that has long been examined by Latin American historians of science and now acknowledged more widely as central to understanding the conquest.

Among the most promising approaches are those that aim to set science within a wider picture of economic history. Until recently, this involved giving the Scientific Revolution a foundational role in encouraging industrious innovation in Britain during the eighteenth century. This widespread view, however, has been challenged by William Ashworth, who argues that what mattered were state policies supporting trade and commercial expansion.[61] New attitudes towards information, invention and discovery, as Jessica Riskin has suggested, can best be understood in the context of a material transformation in the global economy which led to European ascendency over Asia.[62]

Situating science within what historians have termed 'the Great Divergence' has led to a renewed appreciation for the importance of the decades around 1800 as a turning point. The significance of this period was always marked by Foucault, but in ways (as Spivak and others pointed out) that were difficult to relate to concrete historical changes, even such proximate episodes as the French Revolution, let alone for nearly simultaneous transformations in empires across the world. Identified by Christopher Bayly as the 'imperial meridian',[63] these decades are now seen as pivotal for retooling science to meet the demands of a changing world order. For the French, science became a way of forwarding

59 Gayatri Chakravorty Spivak, 'Can the subaltern speak?', in Rosalind C. Morris (ed.), *Can the Subaltern Speak? Reflections on the History of an Idea*, New York: Columbia University Press, 2010, pp. 21–78, 35. For further developments of this theme see the essays in that volume, and also the helpful review in Claudia Brunner, 'Conceptualizing epistemic violence: an interdisciplinary assemblage for IR', *International Politics Reviews* (2021) 9, pp. 193–212. For discussion specifically relevant to history of science see Timothy Sim, 'Decolonize HPS', at www.hps.cam.ac.uk/news-events/seminars-reading-groups/decolonise; and Warwick Anderson, 'Decolonizing histories in practice and theory: an introduction', *History and Theory* (2020) 59, pp. 430–8; and the other articles in the accompanying special issue.

60 Jack A. Goldstone, 'Political trajectories compared', in Jerry H. Bentley, Sanjay Subrahmanyam and Merry E. Weisner-Hanks (eds.), *The Cambridge World History: The Construction of a Global World, 1400–1800 CE*, part 1: *Foundations*, Cambridge: Cambridge University Press, 2015, pp. 447–489, 477–9.

61 William J. Ashworth: *The Industrial Revolution: The State, Knowledge and Global Trade*, London: Bloomsbury Academic, 2017; his work challenges that of Joel Mokyr, *The Enlightened Economy: An Economic History of Britain*, New Haven, CT and London: Yale University Press, 2009; and Margaret C. Jacob, *The First Knowledge Economy: Human Capital and the European Economy, 1750–1850*, Cambridge: Cambridge University Press, 2014.

62 Jessica Riskin, 'The great data divergence: global history of science within global economic history', in Patrick Manning and Daniel Rood (eds), *Global Scientific Practice in the Age of Revolutions*, Pittsburgh: University of Pittsburgh Press, 2016, pp. 237–54.

63 Christopher Bayly, *Imperial Meridian: The British Empire and the World 1780–1830*, London: Longman, 1989.

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the interests of a centralized state and revolutionary warfare. The British adapted many of the new ways of proceeding, in ways that made possible the management of a vast trading network, rapidly developing industries and a restive domestic population. The literature on this critical period is extensive and sophisticated, but is only starting to make a wider impact.[64] Remarkably, the most widely read survey of what happened to science in the period around 1800 remains the article by Andrew Cunningham and Perry Williams published thirty years ago as a result of the first Big Picture conference.[65]

The two-handed engine of colonial domination and science is not another of Europe's inventions.[66] It has operated throughout history, evidenced in the changing ways in which specialist elites are implicated in the exercise of power, and the ways in which that power is resisted. It is present in the ways in which land is measured in the ancient Middle East, sacrifices are organized in Aztec temples, and insurance contracts are managed in twentieth-century America. In his contribution to the 1991 conference, John Christie noted that if there is to be a 'big picture', it would involve configuring – a grasping together – the different ways in which science works into 'a unified plot of power'.[67] This remains the central challenge.

Decolonizing the deep past

As the false drama of revolution within laboratories and learned societies is abandoned, it is being replaced by more powerful and engaging stories about the entanglement of scientific practices in trade, war, transport, colonial governance and the use of resources. Spivak, following Foucault, tended to view knowledge as a totalizing system, underpinned by structures defining what it was possible even to think at a particular time. The great virtue of recent historical writing has been to retain a sense of the depth of these changes, while showing how diverse and contingent they could be, and how embodied in physical practices. The language of entanglement, exchange and resistance has replaced talk of incommensurability and epistemic breaks. Originally founded to teach students about the triumph of Western civilization, the history of science is now at the leading edge of global history.[68]

In important ways, however, the field is only partially prepared for such a dramatic shift. A crucial issue is knowledge of languages other than English. Historians of science often come to the subject after undergraduate study of the sciences, where (especially in Britain) English is the main currency of exchange.[69] As all graduate students know, there is also the challenge of mastering historiographical traditions across national boundaries, a particular difficulty when so little of the best secondary literature has been translated. Collaboration between colleagues in different countries is proving essential.

64 See Sujit Sivasundaram, *Waves across the South: A New History of Revolution and Empire*, London: Collins, 2020; Manning and Rood, op. cit. (62); and Poskett, op. cit. (53).

65 Andrew Cunningham and Perry Williams, 'Decentring the "big picture": *The Origins of Modern Science* and the modern origins of science', *BJHS* (1993) 26, pp. 407–32.

66 Dmitri Levitin, 'The G word', *Literary Review*, May 2022, at https://literaryreview.co.uk/the-g-word (accessed 27 March 2023).

67 J.R.R. Christie, 'Aurora, Nemesis and Clio', *BJHS* (1993) 26, pp. 391–405.

68 Within a large literature, useful orientations are available in Sujit Sivasundaram, 'Global histories of science', *Isis* (2010) 101, pp. 95–158; Warwick Anderson and Gabriela Soto Laveaga (eds.), 'Forum: decolonizing histories in theory and practice', *History and Theory* (2020) 59(3), pp. 369–447; and Kapil Raj, 'Beyond postcolonialism ... and postpositivism: circulation and the global history of science', *Isis* (2013) 104, pp. 337–47. The general issues are clearly surveyed in Sebastian Conrad, *What Is Global History?*, Princeton, NJ: Princeton University Press, 2016.

69 It will be obvious from my limited range of references that this essay is intended primarily for an English-speaking audience.

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One problem receiving renewed attention is the way in which global histories can unintentionally reproduce the dynamics of old colonial relations. Perhaps inevitably, historians of science in Britain have often tended to frame global events through the lens of the British Empire. For a long time this led to minimizing the significance of land-based empires, as in East Asia and Central and Eastern Europe. It also encouraged a tendency to downplay the role of geography, cosmography and other sciences in the Spanish and Portuguese conquest of the Americas during the sixteenth and seventeenth centuries. The assumption of a dividing line between the 'British Atlantic' and the 'Iberian Atlantic' has accorded the positive side of modernity – science, religious toleration, freedom of thought – to the north, leaving the south mired in slavery, dogmatism and decay. The work of Jorge Cañiares-Esguerra and others has shown that the two empires were intimately connected through common practices and constant exchanges of people, goods and ideas.[70]

The older assumptions are now disappearing even from introductory textbooks. We cannot simply turn European histories of empire into global histories, any more than we can take events such as the Scientific Revolution and broaden them to cover other parts of the world.[71] The most promising work is exploring relations across and between different parts of the global South. This has involved transcending old geographies based on national and continental boundaries, replacing them with a focus on oceans, rivers, mountains, islands, deserts, the movement of goods and the circulation of people.[72]

An important part of the challenge is to avoid seeing 'Europe' or the 'West' as a single entity. This is partly because – even with research of the past fifty years – stories of European science remain incoherent and radically incomplete. It is all too easy to forget that 'Europe' is not the same as Western Europe, or equivalent to elites in Paris, London, Madrid or other imperial centres. Even within well-studied countries such as Britain, France and Germany, work on marginalized or little-known groups is vital to understanding. And as has been convincingly shown, Europe itself is a concept borne out of a wish to distinguish Western civilization from the perceived oriental despotism of the East.[73]

The process of 'provincializing Europe' involves more than problems with geography.[74] As historians have long recognized, it is also a question of chronology – not so much 'where' is the history of science, but 'when'. In addressing the problem of decolonializing science, especially in the classroom, historians of science need to think about longer timescales than the past fifty, two hundred or five hundred years. In recent decades the history of science has overwhelmingly focused on the twentieth and early twenty-first centuries. This tendency to prioritize the immediate past has serious consequences for encouraging the understanding of cultural difference. English-speaking students in the 'bad old days' of

70 Jorge Cañizares-Esguerra, 'Introduction', in Cañizares-Esguerra (ed.), *Entangled Empires: The Anglo-Iberian Atlantic 1500–1830*, Philadelphia: University of Pennsylvania Press, 2018, pp. 1–15.

71 This is, in my view, a potential danger in adopting the terminology of 'scientific revolution' as in Poskett, op. cit. (53); and also Jorge Cañizares-Esguerra, 'On ignored global scientific revolutions', in *Globalizing Early Modern Science*, special issue of the *Journal of Early Modern History* (2017) 27, pp. 1–13.

72 Among many examples see David Armitage, Alison Bashford and Sujit Sivasundaram (eds.), *Oceanic Histories*, Cambridge: Cambridge University Press, 2018; and Lachlan Fleetwood, *Science on the Roof of the World: Empire and the Remaking of the Himalaya*, Cambridge: Cambridge University Press, 2022; and for a general overview of geographical approaches, David N. Livingstone, *Putting Science in Its Place: Geographies of Scientific Knowledge*, Chicago: The University of Chicago Press, 2003.

73 Martin W. Lewis and Kären Wigen, *The Myth of Continents: A Critique of Metageography*, Berkeley and Los Angeles: University of California Press, 1997.

74 Dipesh Chakrabarty, *Provincializing Europe: Postcolonial Thought and Historical Difference*, Princeton, NJ: Princeton University Press, 2000. For a useful discussion of the problem of timescales see Conrad, op. cit. (68), pp. 141–61.

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the 1950s and 1960s at least learned to appreciate one apparently 'alien' culture – ancient Greece – in empathetic terms. That was the basis of Kuhn's celebrated 'Aristotle experience', when he realized that there were other ways of approaching the world than those he had learned as a physicist. But inclusion of in-depth accounts of different cultures, other than through encounters with Western forms of science, requires a strong defence. As we approach the present, science inevitably begins to look like science at the contemporary research front, and it is easier to convince administrators, students and funding bodies about relevance.

Looking at the deep past is imperative. The last few centuries are in significant ways a story of European conquest of other cultures and the environment. This is the literature of encounter, subjugation and resistance, when (as Mauricio Nieto Olarte has argued) Europe 'comprehended' the rest of the world.[75] Put another way, we are looking at what Sujit Sivasundaram has called a tsunami, in which the power of specific elites in Europe becomes dominant.[76] There are other voices to be recovered, both within Europe and in colonial situations, but these are often viewed at a point of maximal weakness, when the traditions, institutions and resources upon which they depend are being marginalized, supressed or destroyed. This, however, can be partially overcome by considering the deep history of past civilizations, whether that be Aboriginal Australia, Tang China, medieval Europe, ancient Egypt or the Mayan Empire. As Helen Tilley has asked, 'What if histories of science for Africa paralleled those for that other mythical entity, Western Europe, for which historians have often adopted a "Plato to NATO" timescale?'[77]

If we teach only with reference to traditional chronologies of Western modernization, we are bound to tell a story dominated by European elites. Either alternative forms of science can end up being seen as intellectual and institutional arrangements that failed, or our histories amount to what James Delbourgo has decried as 'contributionism'.[78] In such accounts, the cultures of China, Greece, India, Iraq and other regions may be sensitively analysed and displayed, but once they cease to provide foundations for events centred in the West, they disappear from view.[79] Alternatively, accounts of cross-cultural interaction can become particularized and anecdotal, finding revealing but rare instances in which local practices feed into dominant ways of knowing. We cannot write a history that is based on 'go-betweens' or singular instances of direct interaction, for such stories depend upon on what the historian Jan de Vries has termed UCIs – 'unusually cosmopolitan individuals'.[80] A narrative limited to specific cases is not a decolonized history. Rather, the answers are being found in uncovering the ways in which science has been pursued in situations *not* in imminent danger of destruction, and by understanding the opportunities

75 Mauricio Nieto Olarte, 'The European comprehension of the world: early modern science and Eurocentrism', in Michael Kuhn and Hebe Vessuri (eds.), *The Global Social Sciences under and beyond European Universalism*, Stuttgart: Ibidem, 2016, pp. 101–40.

76 See https://pressblog.uchicago.edu/2021/05/27/six-questions-with-sujit-sivasundaram-author-of-waves-across-the-south.html (accessed 25 March 2023).

77 Helen Tilley, 'History and historiography of science', in *Oxford Research Encyclopedia of African History*, 20 November 2018, at http://oxfordre.com/africanhistory/abstract/10.1093/acrefore/9780190277734.001.0001/acrefore-9780190277734-e-353 (accessed 1 December 2023).

78 James Delbourgo, 'The knowing world: a new global history of science', *History of Science* (2019) 57, pp. 373–99.

79 For an example of the extensive work in this area see Mirjam Brusius, 'On connecting the ancient and the modern Middle East in museums and public space', in Sharon McDonald, Katarzyna Puzon and Mirjam Shatanawi (eds.), *Islam and Heritage in Europe: Pasts, Present and Future Possibilities*, London: Routledge, 2021, pp. 183–201.

80 Jan de Vries, 'Playing with scales: the global and the micro, the macro and the nano', *Past and Present* (2019) issue supplement 14, pp. 23–36.

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existing communities create in altered circumstances. Not least, this is revealing how structures of science are adapted through the interaction of many cultures.[81]

Taking a long view has been one way of demonstrating the ongoing vitality of different meanings of 'science' and diverse ways of life, even when these are faced with the juggernaut of European practices. The new approaches are grounded in categories applicable to diverse cultural perspectives: origins, species and cosmologies, rather than the rise of evolutionary thinking; the nature of change, rather than the movement of physical bodies in an abstracted space.[82] The most important shift has involved adopting frameworks that are appropriately general in terms of shared human experience in the environment. Agriculture, navigation, timekeeping and healing now feature in journals and book series that would previously not have considered such topics. The history of science continues to make sense as a way of framing these issues: not only is science understood by readers as an important element of life today, but the word encourages a sense of practical engagement with the world around us.[83]

In approaching these questions, historians for several decades now have become attentive to material objects, practical engagement and bodily experience – traditionally the purview of medicine and technology.[84] These fields were separated into distinctive subjects during the nineteenth century, a process accompanied by notions of 'pure' and 'applied'. Before that in Europe, and through most of history in many other cultures, these distinctions did not exist in anything like the same way. Today they are breaking down again, as science is produced not as abstract 'knowledge' but as computer chips, software systems, rockets, wind turbines, vaccines and drugs. In this regard, a longer time span and an expanded geographical scope are reconfiguring the histories of science, medicine and technology towards a more unified understanding of humans as part of nature.

Revolutionary apocalypse

As the 1968 film *Night of the Living Dead* revealed, the only way to destroy zombies (a term later sequels freely appropriated from Haitian vodou) is to destroy their brains.[85] That is probably too extreme a solution for revolutionary narratives, but it does suggest that getting rid of them is not going to be easy. They are only fading as we find more compelling and substantial stories to take their place. This means contributing to public discussion at

81 For a useful survey see Silvia Figueirôa, 'Postcolonial and decolonial historiography of science', in Mauro Condé and Marlon Salomon (eds.), *Handbook for the Historiography of Science*, Cham: Springer, 2023, pp. 523–41.

82 Jonathan Hodge, 'Against "revolution" and "evolution"', *Journal of the History of Biology* (2005) 38, pp. 101–21.

83 At least in English, understanding what it means to 'do' science is easier than what it means to 'do' knowledge. On the issue of replacing history of science with the history of knowledge, my views are almost identical to those in Yulia Frumer, 'What is and isn't in a name', *Berichte zur Wissenschaftsgeschichte* (2019) 42, pp. 150–66. Also relevant is Jan Golinski, 'Is it time to forget science? Reflections on singular science and its history', *Isis* (2012) 27, 19–36.

84 Research in this area is too extensive to cite, but see the work of Pamela H. Smith, e.g. her recent *From Lived Experience to the Written Word: Reconstructing Practical Knowledge in the Early Modern World*, Chicago: The University of Chicago Press, 2022; and Lissa Roberts, 'Exploring global history through the lens of history of chemistry: materials, identities and governance', *History of Science* (2016) 54, pp. 335–61.

85 In vodou, to become a zombi after death was to be condemned forever as a field hand, with no chance of release from bondage or a return to Africa. In the twentieth-century American popular culture, zombies no longer referred to the tragedy of enslavement but instead to fear of the colonized outsider. Zombies then became a commodified spectacle in films, graphic novels and video games. See Amy Wilentz, 'A zombie is a slave forever', *New York Times*, 12 October 2012, at www.nytimes.com/2012/10/31/opinion/a-zombie-is-a-slave-forever.html (accessed 29 November 2023); and David R. Castillo, David Schmid, David A. Reilly and John Edgar Browning, *Zombie Talk: Culture, History, Politics*, London: Palgrave Pivot, 2016.

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an appropriately general scale, drawing on approaches that are transforming views of what the history of science is about.[86] It involves acknowledging a wider range of problems than the pressing (but partial) one of a history dominated by Europe. It involves providing accounts that deal not only with encounters and exchanges, but also with specific settings considered in terms of contemporary experience and long-term pasts.

A particular need for Anglo-American historians is to acknowledge the range and distinction of writings in other languages than English, and the traditions in which these have been produced. It also involves supporting supposedly 'marginal' subjects and studies that are threatened for want of immediate economic relevance. The tendency to shorten the temporal range of the human experience needs to be resisted. There is a clear general argument: if the value of history is to give perspective, then the perspective of centuries and millennia is likely to be especially worth pursuing. A claim that the recent past is what really matters is likely to end up by eliminating the need for history at all. If we follow the geologists in pinpointing the start of the Anthropocene around 1950, then why look at anything before?[87] Why, for that matter, not just focus on the future? The Anthropocene debates have demonstrated that existing chronological and disciplinary divisions ignore interactions between the human and non-human worlds – hence counterproposals for the Plantationocene, the Capitalocene and the Chthulucene.[88] It will be interesting to see whether these alternatives continue to have traction now that the geologists have drawn their boundary (according to the narrow rules of stratigraphy) in the middle of the last century.

As Rebecca Solnit has written, 'the revolt against brutality begins with a revolt against the language that hides that brutality'.[89] The shortcomings of revolutionary narratives of the rise of science are even clearer now than they were thirty years ago, given the collapse of Earth systems and associated issues of mass migration, pandemic and war. There is no single narrative that can or should replace the progressive drive towards modernity that underpinned the story of scientific revolutions. There is never going to be one big picture, nor would that be desirable. An assemblage of instances – revealing only localism and the potential for resistance – will not do either. Nor will an account that stresses the inevitability of biology, capitalism or any single historical force. All history should be relational, but it does not need to be global. What matters is thinking about who our histories are for and what longer-term issues they are intended to illuminate. The science in 'history of science' is not a topic, but a question.

We may dismiss the Scientific Revolution and kindred upheavals as outdated relics, but they are built into basic assumptions our audiences have about when our studies should start, who they should include, and how they can challenge the status quo. Until we think through such issues, the task of transforming the history of science can scarcely begin.

86 Reconciling general frameworks and specifics in history teaching is discussed in Peter N. Stearns, Peter Seixas and Sam Weinburg (eds.), *Knowing, Teaching and Learning History: National and International Perspectives*, New York: New York University Press, 2020, esp. the chapter by Denis Shemilt, 'The caliph's coin: the currency of narrative frameworks in history teaching', pp. 83–101.

87 Kathryn Yusoff, *A Billion Black Anthropocenes or None*, Minneapolis, University of Minnesota Press, 2018. For the need to reframe narratives to meet the ecological crisis see Arran Stibbe, *Ecolingusitics: Language, Ecology and the Stories We Live By*, 2nd ed., Abingdon: Routledge, 2021 (first published 2015).

88 See, for example, Donna Haraway, 'Anthropocene, Capitalocene, Plantationocene, Chthulucene: making kin', *Environmental Humanities* (2015) 6, pp. 159–65; and Dipesh Chakrabartky, *The Climate of History in a Planetary Age*, Chicago: The University of Chicago Press, 2021.

89 Rebecca Solnit, 'Call climate change what it is: violence', *The Guardian*, 7 April 2014, at www.theguardian.com/commentisfree/2014/apr/07/climate-change-violence-occupy-earth (accessed 12 December 2023).

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