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SERIALITY AND SCIENTIFIC OBJECTS IN THE NINETEENTH CENTURY

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> Perhaps the 'book', as it has been called, of nature is regularly paged; if so, no doubt the introductory parts will explain those that follow, and the methods taught in the first chapters will be taken for granted and used as illustrations in the more advanced parts of the course; but if it is not a 'book' at all, but a *magazine*, nothing is more foolish to suppose [than] that one part can throw light on another.
>
> James Clerk Maxwell, 1856[1]

Series represent much that was new and significant in the sciences between the French Revolution and the First World War. From periodical publication to the cinema, tabulation to industrialized screening, series feature in major innovations in scientific communication and the organization of laboratories, clinics, libraries, museums and field sites. Practitioners arranged embryos or electric sparks, fossils or flint weapons in terms of formal or functional resemblance, and related the resulting order to changes of state or of time. Progressive or evolutionary schemes commonly traced development from the primordial nebula to present society, via the formation of the Earth and the ages of life through human evolution and history. Behind the subtly graded and reliably calibrated sequences was often the sense that the world was serial in its basic structure, but series were also fiercely debated, as Maxwell's warning suggests. How can historians best approach their relations in nineteenth-century science?

This special double issue of *History of science* is the first attempt to investigate series' manifold properties and relations across the sciences. This introduction sets out our questions and draws some interim conclusions. What significant connections were there between different kinds of series, and especially between serial modes of organization, production and communication and the serial contents of nature? Beyond mere juxtaposition or the compilation of a list, some important extra meanings and powers are involved in the disposition of elements in series. How were these supplementary resources, which the term 'seriality' implies, developed and used to produce knowledge?

We start from a reluctance to use seriality as a grand explanatory cause, as if somehow, in the terms of the intellectual historian Arthur Lovejoy, a generalized "temporalizing of the chain of being" simply transformed a static scale of beings into a ladder of progress, an inventory into a developmental programme.[2] Nor did the combination of periodical publication, museum display and commodity production determine the new sciences of evolution and history. We would rather understand seriality as a range of practices, of the same order perhaps as those of standardization,[3]

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that pose a set of pervasive and prominent questions about continuity versus discontinuity, the play of difference through standardized objects, and the sequential display versus the array that could be seen at a glance.

For though serialization was often represented as an obvious response to matters of fact, it actually offered a technique for pressing a partisan claim that might be questioned, modified, rejected or ignored. By no means all science either embraced claims about series or depended on serial images and arguments. While developmental series were increasingly widely treated as self-evident frameworks for showing specimens and objects, many naturalists and physicians either vehemently denied the validity of unitary or parallel series or studiously avoided the problem altogether. Seriality was thus often a theme of polemic: traces, images and samples in graphic print or exhibitions were worked into arguments that produced or reinforced an experience of seriality in an audience; such dispositions and experiences could then be challenged or displaced.

Our period is the long nineteenth century. The notion of seriality seems especially apt in the age of revolutions, when series became central in fields ranging from zoology and political economy to periodical publication and newspaper journalism. The term was first adopted in English in the early seventeenth century for sequential disposition in time and space, such as in lists or catalogues, especially for valuable collections, notably of coins. But its sole technical use before 1800 was in mathematical analysis. Only in the nineteenth century was the word *series* used within specific sciences to describe the idiosyncratic arrangement and meaning of their objects: in accounts of entities such as strata and crystals from the 1820s, within statistics, palaeontology, chemistry and botany by the 1850s, and soon after in newer enterprises such as anthropology and analytic spectroscopy. The career of the French *série* is strikingly similar. First used in the mid-eighteenth century only in mathematics, it was not until the late 1700s that it was applied more generally to sequences of philosophical ideas, chemical substances and zoological entities. *Série* became a keyword in the visionary social and philosophical programmes of Charles Fourier and Auguste Comte. The German *Reihe* is older, in the sense of line and row, and the history of uses in the natural sciences less easily reconstructed, but only in the eighteenth century, it seems, did it begin to refer to temporal succession.[4] The decades around 1900, the era of the second industrial revolution and of cultural modernism, then saw major transformations with the emergence of new technologies and systems of knowledge production and communication.

The essays collected here examine relations between the arrangement of scientific and medical objects in series; the disposition of images and objects in print and museums; the use of such paper technologies as hospital records and library catalogues to order and analyse natural and social phenomena; and the role of periodical publication in the communication and organization of knowledge. Tracing the work of serial ordering and argument sheds new light on models of development, practices of image and claims making, and responses to serial arrangements and events. Lovejoy himself was jokily aware of possible connections between changes in temporal sequences and institutions of public culture. In his reflections on how the chain of being generated fascination with "missing links", he remarked that, "if Aristotle had been permitted to return … in the eighteen-forties, he would have made haste to visit [P. T.] Barnum's Museum".[5] Thinking in terms of series and seriality allows us to explore important connections in depth.

SERIALIZATION

Scholarship on the sciences of organic development as they emerged around 1800 has only patchily explored series as practical achievements made possible within new spaces of representation. Lovejoy's canonical account of the temporalization of the great chain of being mentioned the religious and moral difficulties prompted by reflection on the principles of plenitude and continuity, but paid more attention to what he saw as the straightforwardly logical problem of reconciling these principles with evident gaps and discontinuities: "Whenever, in any series, there appears … a different *kind* of thing, and not merely a different magnitude and degree of something common to the whole series, there is *eo ipso* [by that very fact] a breach of continuity" (Figure 1).[6]

Lovejoy's approach put a premium on the definition of 'true' seriality. None of the naturalists and anatomists who so actively debated definitions, such as Jean-Baptiste Lamarck, Georges Cuvier and Étienne Geoffroy Saint-Hilaire, features in *The great chain of being*, but they have played decisive roles in influential analyses of the appearance of the sciences of organic form. For Michel Foucault this was when life became

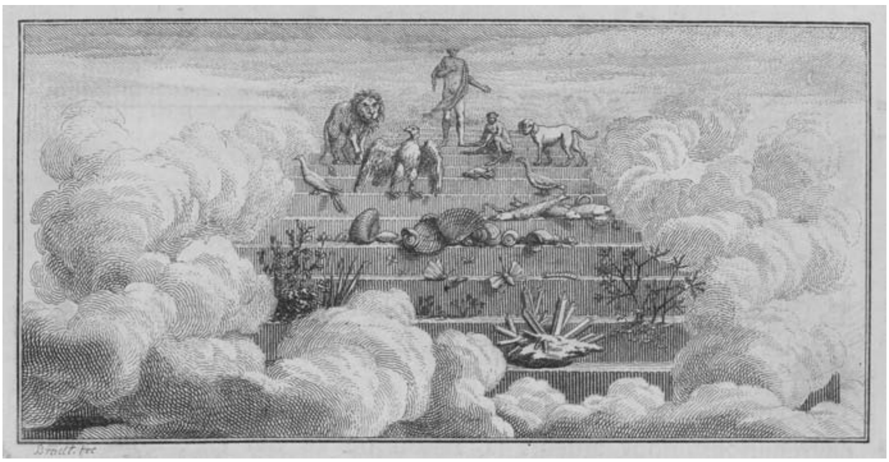

FIG. 1. The great chain of being. The Genevan naturalist Charles Bonnet posited an infinitely graded and all-encompassing chain that appeared only imperfectly to human understanding. In this header to his book on the contemplation of nature, the clouds have cleared to reveal a few representatives of the middle part, while the upper and lower reaches remain entirely obscured. From Bonnet, *Œuvres d'histoire naturelle et de philosophie*, iv/1: *Contemplation de la nature* (Neuchatel, 1781), 1, by kind permission of the Syndics of Cambridge University Library.

a property of the internal relations of complex and hierarchized organic structures. Natural history had been characterized by the "solidity, without gaps, of a network of species and genera, and the series of events that have blurred that network". Gardens and museums obscured anatomy and function in order to display visible forms in tables. Foucault condensed this complex transformation into the "iconoclastic gesture" with which at the end of the eighteenth century Cuvier smashed the glass jars of the Paris Natural History Museum, and so allowed anatomy to substitute for taxonomy and "series for tabulation". "For eighteenth-century thought, chronological sequences are merely a property and a more or less blurred expression of the order of beings; from the nineteenth century, they express, in a more or less direct fashion, and even in their interruptions, the profoundly historical mode of being of things and men." Separating temporal succession from classificatory order paved the way for a deeper historicity based in organic function.[7]

This made seriality a site of major ideological conflict. The zoologist and professor of medicine Carl Friedrich Kielmeyer, in a celebrated speech at the Hohe Karlsschule in Stuttgart in 1793, suggested that, "since the distribution of powers in the series [*Reihe*] of organisms follows the same order as their distribution in the developmental stages of a given individual, we can conclude that the power by which the production of the latter occurs, namely the reproductive power, corresponds in its laws with the power by which the series of different organisms of the Earth were called into existence". Yet Kielmeyer rejected the chain of being because the existence of different types of organization produced inevitable gaps.[8] Cuvier in comparative anatomy, like the Königsberg professor Karl Ernst von Baer in embryology, went further in insisting on discontinuities between different *embranchements* or types (Figure 2). In an 1827 essay on classification von Baer explained the limitations of seriality: "for every type there exist grades of development which here and there form considerable series [*Reihen*] indeed, yet which are in no uninterrupted succession of development, and are never equal through all grades."[9]

The very fact that these dominant naturalists so energetically opposed the animal series indicates the widespread appeal, in Romantic *Naturphilosophie* and democratic zoological philosophy, of an often recapitulationist transformism that traced the series from monad to human. For example, Henri de Blainville's important version of the animal series, quickly exploited by radical materialists and evolutionists, was based on traditional modes of the great chain of being and initially deployed for conservative apologetics. John Tresch's contribution to this collection explores the ways in which Comte's vastly influential formulation of serial positivism exploited and reorganized Blainville's model of serial progression.[10] To reconstruct such series philosophically and scientifically was thus often to characterize the forces that allegedly drove movement along its path.

Polemics around the 'ultraserialism' of Parisian naturalists and their British admirers much involved these questions of serial continuity and dynamics. One of the earliest British uses of the term 'evolution' to describe temporal transformations of fauna was in an anonymous paper on the scope of geology in Robert Jameson's

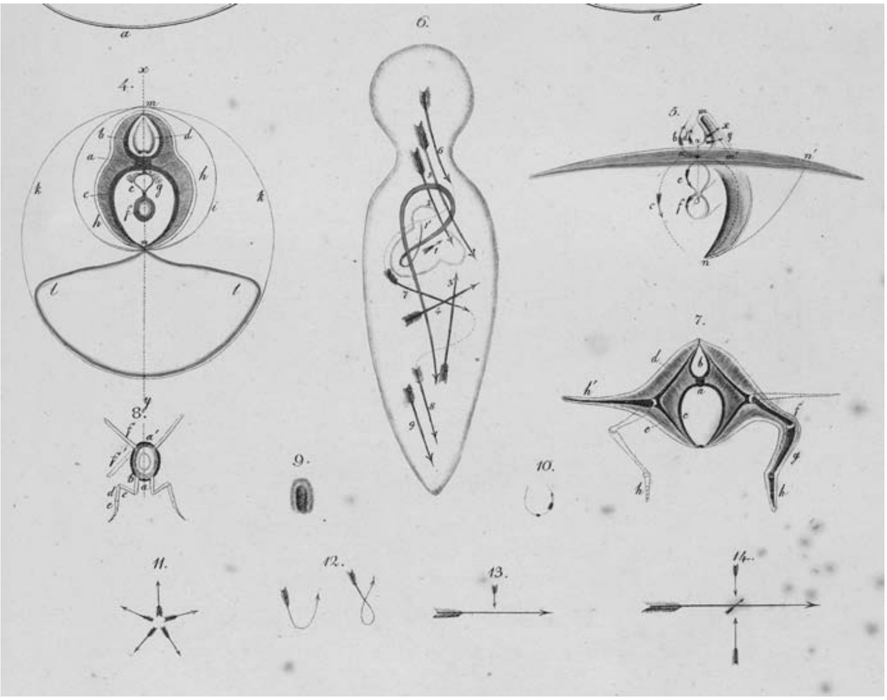

FIG. 2. The four types of development. While the first two plates in Karl Ernst von Baer's celebrated treatise give series of cross- and longitudinal sections through chick development, the complex third plate uses more schematic figures to illustrate his general propositions. There was no single series, he insisted, but the animal kingdom was rather divided into four fundamentally different types with different modes of development. Figure 4 is the much-reproduced "ideal vertical cross-section of the embryo of a vertebrate", while Figure 5 indicates the transformation of the embryo and Figure 6 its movements. Figures 7 and 8 compare vertebrate and 'articulate' (annelid and arthropod) extremities respectively, while Figure 9 shows a jellyfish embryo, and Figure 10 the articulate scheme of development. The last four figures represent the modes of development in the four types: (11) radiates, (12) molluscs, (13) articulates and (14) vertebrates. Coloured copper engravings from von Baer, *Über Entwickelungsgeschichte der Thiere: Beobachtung und Reflexion*, part 1 (Königsberg, 1828), Plate III (detail), by kind permission of the Syndics of Cambridge University Library.

Edinburgh new philosophical journal. The author linked the so-called "double series" of infusoria and parasitic worms he had learnt from the natural histories of Lamarck, Geoffroy Saint-Hilaire and Blainville.[11] Rival definitions of series were at stake in fights about evolution and development. The year after this paper, the idealist anatomist John Henry Green lectured in markedly political terms at the College of Surgeons in London that he accepted "a series of evolutions from the lowest to the highest. Not, allow me to remind you, in supposing that there is any power in the lower to become, or to assume the rank and privileges of, the higher … but in assuming that the ascent is the indication of a law, and the manifestation of a higher power".[12]

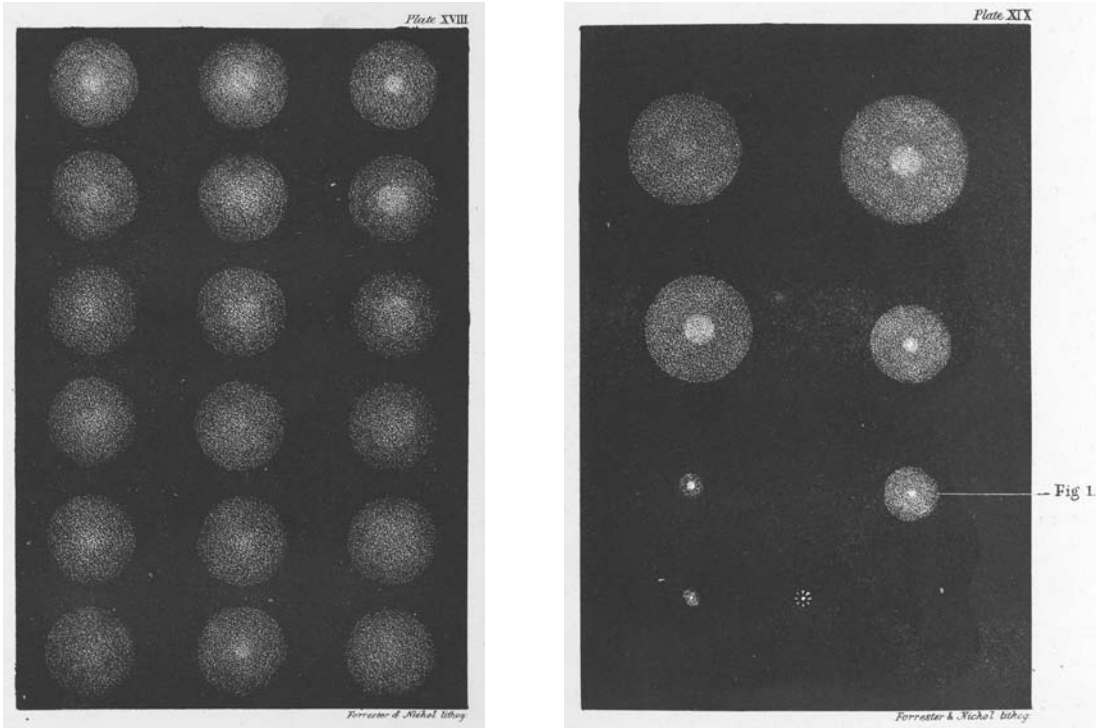

FIG. 3. To support his argument for progress in the heavens, the Glasgow astronomer John Pringle Nichol reorganized William Herschel's images of nebulae to produce a series of successively condensed forms culminating in stars. By the juxtaposition of figures standing for entire nebular classes, the reader was encouraged to trace "a series so well marked" stretching "from absolute vagueness to distinct structure and then on to the formation of a defined central nucleus" and finally "a STAR thoroughly organized with a mere bur around it". Lithographs from Nichol, *Views of the architecture of the heavens: In a series of letters to a lady* (Edinburgh, 1837), Figures 18 and 19 on pp. 137 and 139.

The puzzle of serial projection, including inferences to the existence of intermediate forms and thus, by implication, to progressive and developmental forces at work in the cosmos, troubled the sciences more generally. In the 1811 and 1814 summaries of the massive surveys of nebulae in his "natural history of the heavens" the astronomer William Herschel explained how he had sought to show that widely-diffused nebulous fluid would eventually condense under gravity into globular clusters of compressed stars: "to make this connection gradually visible, I have arranged my observations into a series of collections." The serial order of these observations in print was not the same as the order in which they were first made. Observing books, kept over decades by Herschel and his sister Caroline, needed to be transformed into ordered sequences for publication in the Royal Society's *Philosophical transactions*. Serialized nebular images were arguments, requiring innovations in printing to represent nebular clouds and globular clusters.[13]

These powerful images encouraged readers to extend the gravitational series from nebular fluid via globular clusters to stars and planets, including Earth. In 1826 William Herschel's son John more prudently cautioned members of the new Astronomical Society of London against such extended serialization by explicit analogy with the great chain of being: similar objects arranged in plausible series did not necessarily change one into the next. Writing in the radical *Westminster review*, the Scottish astronomer and political economist John Pringle Nichol was one of the first to use the term 'nebular hypothesis'. He retorted to the younger Herschel that "the nebulae are arranged … in a regular series, *each successive term of which shows a progressing augmentation of light about the centre*", and that the series could be extended under the force of gravitational condensation to encompass the solar system (Figure 3). The verifiable action of a physical force warranted serial transmutationism. "A gradation or collection of similar appearances gently sliding into each other, can be met with nowhere without its flashing on our minds that there is something in that connection more than meets the eye." Praising Geoffroy Saint-Hilaire and Parisian transmutationism, Nichol strongly implied that the same would soon be demonstrated for organic beings.[14] Yet he believed that such a thoroughgoing view of universal progress needed to be presented to the public with care: not in a single volume, which would appear overambitiously speculative, but rather as separate treatises, each staying within the safer confines of a distinct discipline.[15]

What "met the eye" was vital: serial iconography loomed large in these debates about progressive development in heaven and on Earth. Historical writing has yet to explore systematically the relations between novel models of development and new forms of representation. For natural history, Giulio Barsanti importantly complicated the assumption that trees simply replaced ladders by highlighting the prominent role of maps.[16] In geology, too, innovations in visual technique made it possible to depict complex strata sequences. Maps themselves developed from simple records of the superficial distribution of minerals into sophisticated tools for revealing underlying structures and sequences of distribution. Maps that failed to do this were considered literally "superficial" and valued less.[17]

For the making of embryology, perhaps the leading science of development, historians are beginning to reconstruct a shift to developmental series around 1800. We have the richest account for the case of human embryos, which was special because the transformation appears especially sharp from representations that focused on the uterus and its membranes and/or still showed the contents of the womb as a symbol of the child to come. With a little exaggeration, the German anatomist Samuel Thomas Soemmerring's images of 1799 are generally regarded as the first developmental series of human embryos. They were motivated by interest in epigenesis and indebted to a typical pressure for temporalization, the enlightened medico-legal concern to fix the course and duration of pregnancy. This was radically at odds with dominant understandings of a fundamentally precarious and uncertain state. New anatomical and graphical techniques seem to have mattered less than a new aesthetics that, rather than taking the adult form as the standard of human perfection, recognized different criteria as appropriate to each age. The survival from this period of non- or minimally developmental series (growth with little change of shape) suggests that seriality and development were established separately.[18]

In their contribution to this volume Volker Hess and Andrew Mendelsohn tackle the hospital system and the seriality, not of the pictorial sequence, but of the table. They show how the serial disposition of patient records could be changed from narrative reportage, via tabulation, into an argument. Pierre Louis's *Researches on typhoid fever* (1825) — one of the most celebrated products of the Paris Clinical School — manufactured a disease-defining series by abandoning the primary serial order in which patients had been treated and reorganizing the grid of resemblance and difference. Like William Herschel's natural history of the heavens, display relied on a series distinct from that of production. This was supposed to teach a lesson about the diagnosis of underlying cause and type. The strategy became standard.

Such innovations were especially salient in new sciences such as electromagnetism, where, from the 1820s, practitioners invented ways of representing experimental phenomena such as the interactions of current-carrying wires and magnets and the behaviour of the spaces surrounding them, in which curves and fields were both detected and pictured. These combinations of image and text were simultaneously designed to manage series of trials, communicate protocols within specialist communities of experimenters, and show the results to wider audiences. The organization of these inquiries as sequences of tests and observations was newly and importantly related to their description, presentation and display. Yet these two kinds of sequence were never identical; rather, the passage between the sequencing of inquiry and that of presentation demanded considerable scientific work. The stages of experiments and observations painstakingly recorded in diaries, laboratory notebooks and correspondence could not be treated as an unproblematic resource for a serial presentation capable of commanding public authority in establishing matters of fact and corresponding inferences. Rather, the power of serialization was such that authors worked hard to exploit its appeal; and in so doing they reworked both the order of events and the iconography with which those events were represented. From the early 1820s full-page illustrations of specialized electromagnetic phenomena and hardware began to appear in British scientific journals in place of heterogeneous plates showing materials from various different sciences.

The order of disposition of these specialized plates became sensitive. The principal British electromagnetic experimenter and lecturer of the period, Michael Faraday, began to organize his results as explicitly labelled *series*, and to publish them in the *Philosophical transactions*, in late 1831, at precisely the moment that he launched his inquiry into the sequences of phenomena that he attributed to magnetic curves in space. The order in which he conducted these experiments in his basement laboratory, and then recorded their sequencing in private diaries, was artfully reorganized both visually and serially so as to produce some of the period's most effective public expositions of the emergent phenomena of force and motion (Figure 4). Well aware of their rhetorical power, Faraday told his readers that these series were made up of discrete components presenting discoveries as they happened: "it does surprise even my partiality, that they should have the degree of consistency and apparent general accuracy which they seem to me to present." In tracing the aftermath of these celebrated series, Chitra Ramalingam's article on electrical discharges in high vacua explains how later physicists, giving up the order in which they had initially made the discharges, printed photographs in vertical series to embody arguments about their true character. The issue was temporal succession and the right visual rhetoric for making it compelling.[19]

By then, development was established as the basic principle of organization for texts, plates and displays. In some fields visual juxtapositions are nevertheless rarer than histories of theory would lead one to expect. In embryology, where developmental series within species were legion, and organs compared between them, vivid comparisons across the series of whole embryos even of different vertebrates appear until the late 1860s few and far between. Specimens were scarce, teachers stressed unity within the type, and there was rarely enough pressure to make comparative displays accessible to wider audiences.[20] Yet polemical inferences between serial dispositions, not just within a science but in different sciences, could be powerful weapons. Human and natural history could be linked, as Nathan Schlanger shows in his paper here, by ingenious transpositions of serializing practices between collections of coins, prehistoric artefacts and bones, and museologists' and collectors' exploitation of similar methods of visualization. These cases raise again the more general question: what kinds of interactions were there between novel models of serial development and new spaces of representation, on printed pages and in museums and observatories, and what barriers to interaction were set up or had to be overcome?

Answers will require historians to pay much more attention to the radical instability of publication genres for science. It is often assumed that the dominance of the refereed scientific paper was established with the foundation of the *Philosophical transactions* in the seventeenth century. But it never was. Periodical publication was always a resource, found in combination with other forms of communication, from conversation to the encyclopaedic textbook survey. The special properties of the serial

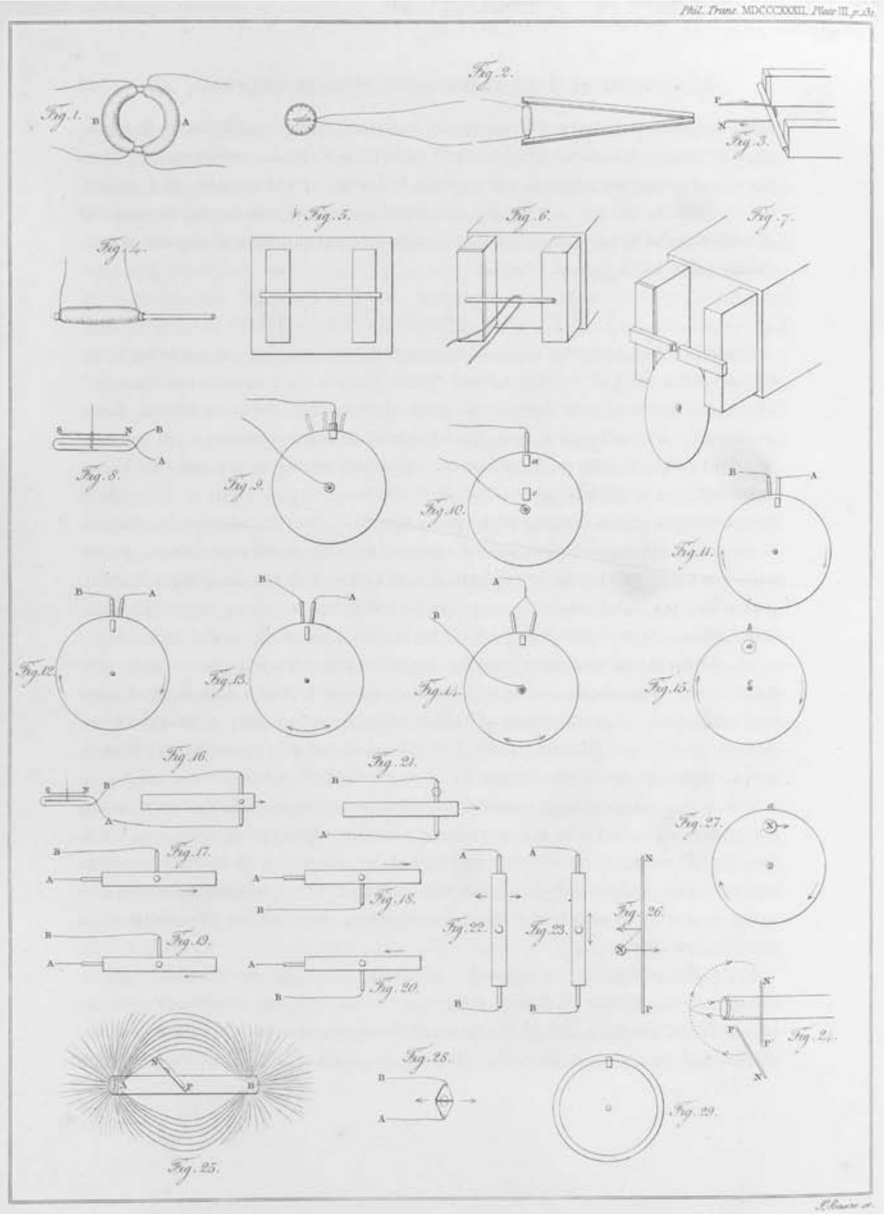

FIG. 4. In late 1831 Michael Faraday started to publish a long series of experiments on electricity and magnetism, accompanied by images extracted from his laboratory diary showing series of set-ups with a copper disc rotating between the poles of a magnet to generate a detectable current in the disc (Figures 7–15) and what he called the "magnetic curves" (Figure 25) in the neighbourhood of the magnet. Engraving from Faraday, "Experimental researches in electricity", *Philosophical transactions of the Royal Society*, cxxii (1832), 125–62, p. 131, Plate 3.

are better seen as underpinning debates about genre than as constituting a stable genre in itself. Just as the novels of Charles Dickens, Victor Hugo and William Makepeace Thackeray were initially published as serials, so too were the leading monuments of nineteenth-century science. Cuvier's *Ossemens fossiles* (1812) first appeared as periodical articles, and the greatest book in the physical sciences, Pierre-Simon Laplace's *Mécanique céleste*, was published over nearly a quarter of a century in separate volumes, each of which incorporated ongoing work from periodical articles. The English anatomist Richard Owen's monographs on vertebrates, like all works for the Palaeontographical Society, originally came out in parts.[21] Sequenced publication of this kind provided a direct analogue in print for the gradual unveiling of nature by men of science. It gave possibilities for tying synoptic works into contemporary controversy, and for announcing new results even in writings that aspired to Olympian objectivity. In this way, the younger Herschel could comment on the "decline of science" in England in a footnote to an article for an encyclopaedic partwork; and French naturalists could engage in warfare over transmutation in the *Dictionnaire classique des sciences naturelles* (1822–31).[22]

The flourishing of serial publication in the sciences is most evident in the remarkable rise of specialist periodicals across Europe and the United States, from the *Annales de chimie* (f. 1789) in Paris to the *Journal of natural philosophy* (f. 1797) in London and the *American journal of science* (f. 1818) in New Haven. It is equally marked by the significance granted to a bewildering variety of forms of scientific reporting targeted at a wide range of general readers, from encyclopaedia parts to quarterly reviewing journals.[23] The increasing dominance of genres in which dates and timing mattered acutely was based in the conversational culture of salons and other genteel gathering places, where science was regularly discussed along with politics, literature and the arts. As part of the concept of 'fashion' that developed at this time, knowledge about nature was seen as constantly changing, innovative and progressive.[24] The stress on novelty and timeliness also became a means for establishing the public reputations of heroic discoverers, men such as William Herschel and Antoine Lavoisier who epitomized the 'spirit of the age' in the very act of transcending it.[25] Reports of their latest findings were seen as the founding documents of new disciplines, and at the same time recognized as perishable commodities, the fashions of a season.

DISPLAY, AUDIENCES, EVOLUTION

Public display was crucial. The vividly serial arrangements of the age of capital responded to pressure to communicate more widely and more powerfully on the page and in exhibitions. A key symbol of public seriality was the cheap newspaper, which heralded the idea that an informed, rational polity would be defined as the readership for sequentially communicated information. Newspapers and other periodicals defined knowledge as a material commodity distributed, consumed and disposed of on a regular basis. Readers were presented with the spectacle of life ordered by print into defined sequences of time: dailies, weeklies, monthlies, quarterlies, annuals.

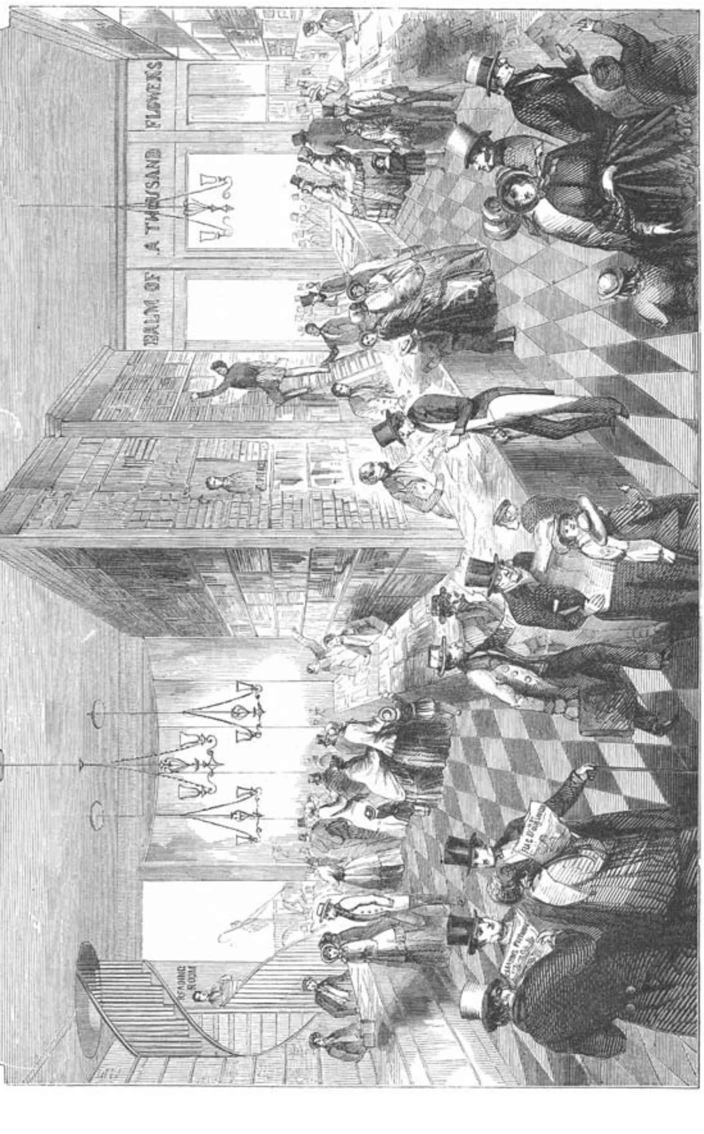

FIG. 5. By the mid-nineteenth century, the distribution and manufacture of serially published journals of all kinds was a large-scale international business, shown here in an idealized view of readers flocking to the counters at Fetridge & Co.'s periodical arcade in Boston, Massachussetts. From *Gleason's pictorial drawing room companion*, iv, issue of 31 July 1852, 80.

The idea that knowledge could be constituted by this form, for the largest possible audience, was variously imagined in the early decades of the nineteenth century — perhaps most notably by the projectors of the weekly *Magasin pittoresque* in Paris, and the *Penny magazine* and *Illustrated London news* across the Channel (Figure 5). Towards the end of the century, with rotary machine printing and typesetting, it was virtually universal, and spreading to urban centres from Cairo to Beijing.[26]

The other great symbol of serial practice was the world's fair. Developing from early industrial shows in Paris, the Great Exhibition of 1851 in London sparked a long succession of followers: New York in 1853, Paris in 1855, London in 1862, Vienna in 1873, Philadelphia in 1876, Melbourne in 1880, and many more. Wandering through vast pavilions, visitors experienced the onward rush of progress, with inventions and discoveries continually emerging from laboratories and workshops of the new science. Exhibitions were hailed as the quintessence of an age of progress, industry and empire; arresting the flow of historical change, they allowed the moment to be grasped (Figure 6).[27]

Men of science exploited these new media of public display as well as publication, from quarterly specialist journals to weekly newssheets. These offered innovatively sequential arrangements and experiences that played a central role in the serialization of scientific objects. The disposition of collections and experimental reports, and ingenious techniques for their display and interpretation, involved decisions about how to make and show series of objects sufficiently similar to count as comparable, yet distinct enough to allow directional sequencing. At once stories and arguments, such shows occupied a place in what we could call the serialization of everyday experience, including the preparation of specimens for display, the enterprise of publication and design, and the activities of visitors and readers.

Suggestively, several innovations in making developmental series evident were part of deliberate museological strategies, such as John William Salter's unprecedented reconstruction of the evolutionary history of a single group of fossil organisms on show in a chart of brachiopods at the Museum of Practical Geology in London, or Melchior Neumayr's publication in Vienna of one of the earliest continuous series of forms (*Formenreihen*) of fossilized freshwater molluscs. Both Salter and Neumayr, significantly, were members of national geological surveys and concerned with arranging specimens in public displays. Serial exhibits, of objects or their proxies in graphic print, depended for legibility on the reading practices of their viewers (Figure 7).[28]

Salter and Neumayr were impressed by evolutionary accounts of serial development. Darwinism made comparison count in new ways and demanded new forms of exposition: more vivid, more comparative and increasingly synthetic. It became important to exploit audiences' familiarity with conventions of serial experience, in reading family trees or sequences of related images, to back up polemical claims about evolutionary development. Thomas Henry Huxley's primate skeletons make the most famous series. The series of equine fossils provided by the Yale museum head Othniel Marsh for Huxley's lecture tour of the United States is another controversial example of the ways in which artful exploitation of collections sought to aid

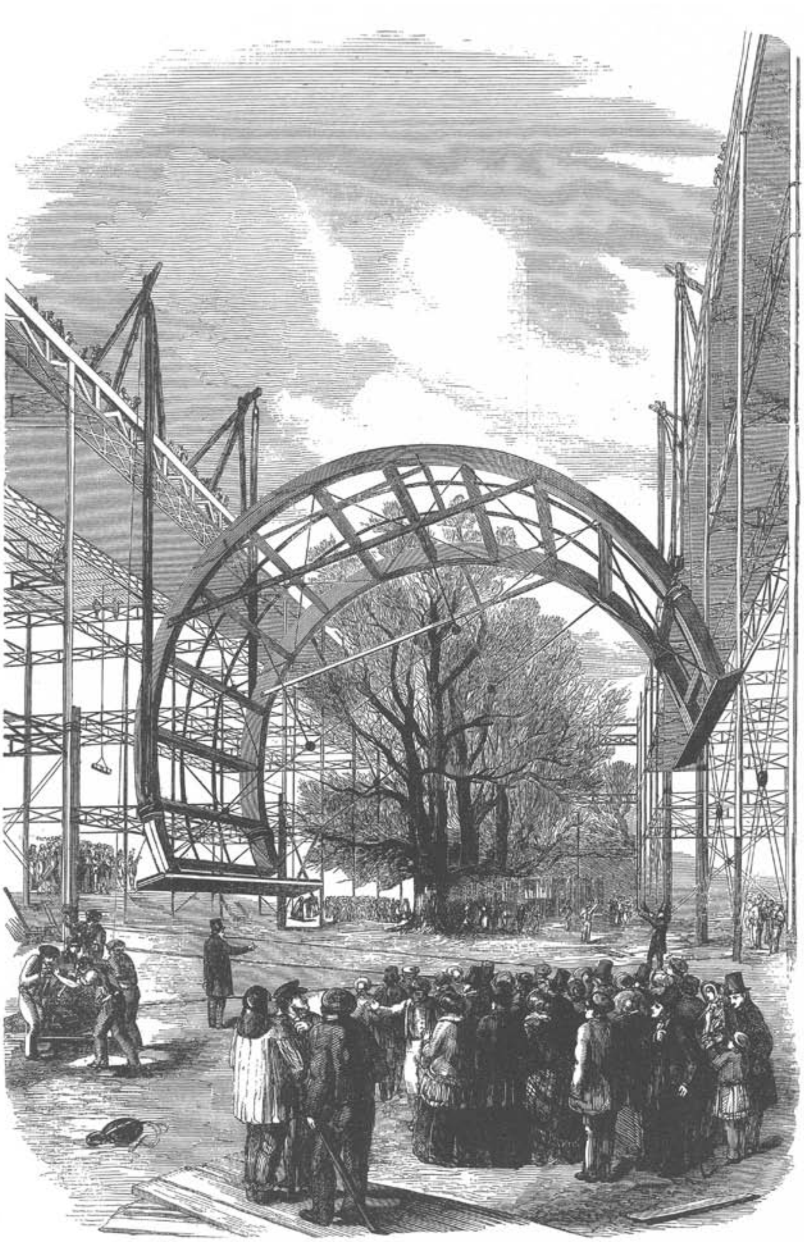

FIG. 6. The experience of seriality in exhibitions. In this wood-engraving, a group of onlookers in London's Hyde Park marvel at the pioneering use of modular construction in building the gigantic iron and glass structure that would become known as the 'Crystal Palace'. The *Illustrated London news,* with its large format pictures, offered middle-class families a sense of direct participation. From *Illustrated London news*, xvii, issue of 14 Dec. 1850, 453.

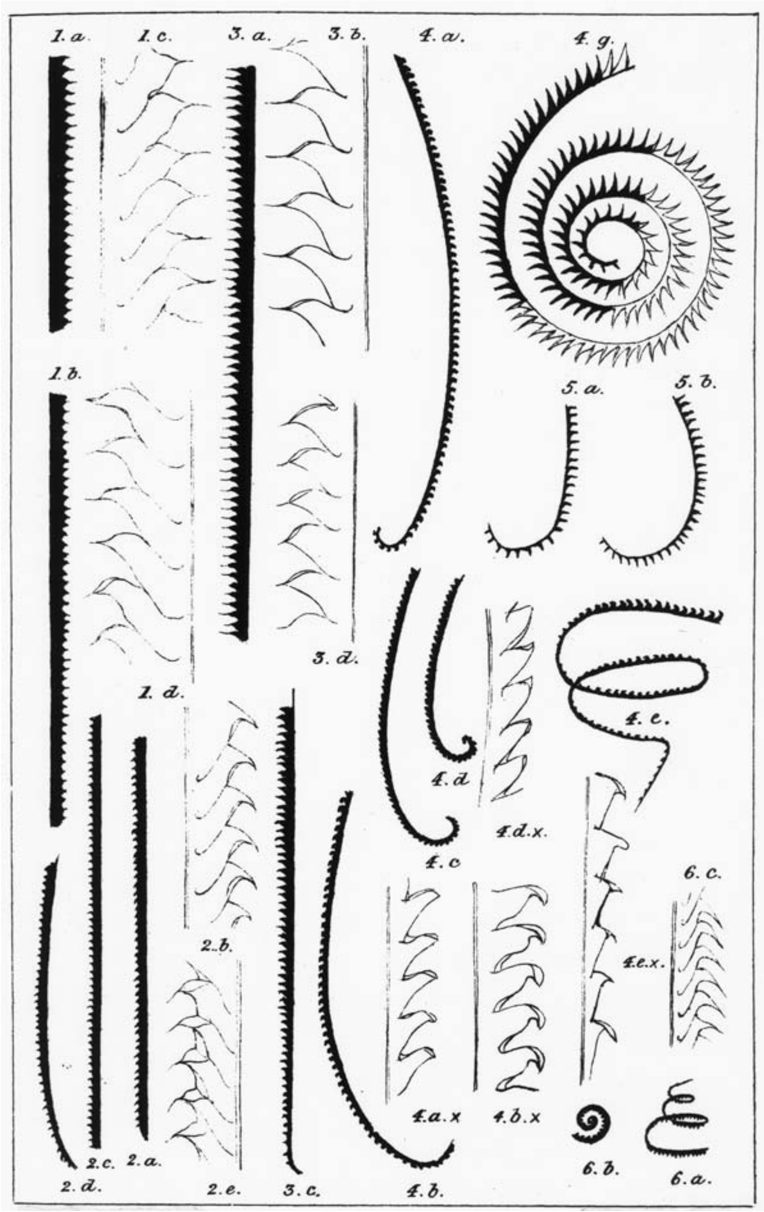

FIG. 7. Graptolites from the Lower Palaeozoic of Scotland, as illustrated by the geologist Charles Lapworth. Close study of slightly varying forms of these obscure fossils made it possible to trace sequences of strata with great precision during the final decades of the nineteenth century. Later work attempted to order the forms in evolutionary series. From Charles Lapworth, "On Scottish Monograptidae", *Geological magazine,* 2nd decade, iii (1876), Plate 13, by permission of the Syndics of Cambridge University Library.

the public show of evolutionary sequence.[29] Ernst Haeckel, the leading systematizer and visual innovator of Darwinism, not only made his phylogenetic speculations appear as natural as the growth of a tree. He also took the vertebrate embryos that were among his most important evidence of common descent, and arranged them in grids that innovatively aligned developmental species for several different species. Charges of forgery led these to become exceptionally contested, but critics routinely accused Darwinists of being carried away by their own expectations, and caricatures played with the alleged arbitrariness of their series (Figure 8).[30] Evolutionists fought back by claiming that comparisons through and between series allowed them successfully to predict missing links.[31]

In a celebrated 1868 lecture in Edinburgh, soon published in the *Fortnightly review*, Huxley explicitly appealed to serial logic to argue for "the phenomena of life" as emergent properties of protoplasm's chemical complexity: "I see no break in this series of steps in molecular complication and I am unable to understand why the language which is applicable to any one term of the series may not be used to any of the others." So Huxley moved straight from this serialization of vital chemistry to a serial understanding of the threat of materialism, instructing his audience that "in accepting these conclusions you are placing your feet on the first rung of a ladder" which "in most people's estimation" led to damnation. Chemical series risked warranting a materialism that Huxley sought to guard against by ingeniously blocking an obvious serial inference. He worked hard to manage the ways his audiences read the language of series.[32]

As Ramalingam points out here, there were fascinating relations between the vocabulary of the serialized dispositions of strata and organic remains described in public lectures such as Huxley's, and physicists' representations of the stratified forms of electrical discharge in highly evacuated tubes. She also points out how these representations were decisive resources for J. J. Thomson's development in the 1880s and '90s of the corpuscular model of negative charge and thus for the identification of the electron. The images and classifications developed from these experiments convinced him that electrical conduction took place as a serial process, discontinuous rather than smoothly uniform, and that negative charges behaved in an idiosyncratic manner at very short time scales and over minute distances. The graphic display of series of electrical stratifications made unprecedentedly clear a contradiction between the comparatively small force needed to ensure conduction through the tube and the vast one needed to separate positive and negative charges. These convictions about the status and subatomic discontinuity of the negative charges drove Thomson and his colleagues towards their model of tiny corpuscles of negative electricity. So one of the most important developments of *fin-de-siècle* physics was intimately linked with strategies of showing serialized micro-phenomena.[33]

For these electrical experimenters seriality meant discontinuity. In classical notions of seriality, a series had been marked most by the continuous and unbroken succession of its elements. But in the display of electrical discharge, what might seem smooth and continuous at the gross level was revealed as truly discrete and punctual. This

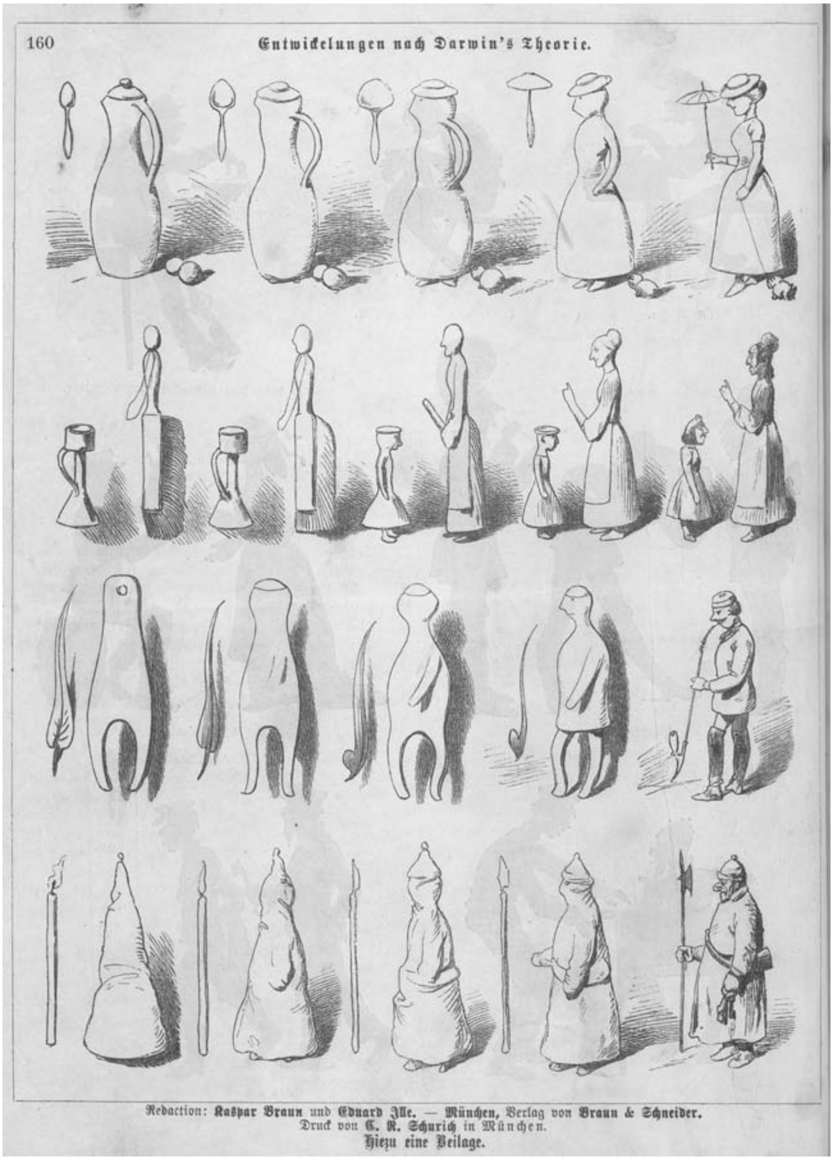

FIG. 8. "Development according to Darwin's theory" in the *Fliegende Blätter*, the Bavarian equivalent of *Punch*, in the early 1870s. In the progressive evolution of social types from everyday objects, additional humour comes from the simultaneous evolution, for example, of the lady from a coffee pot, her parasol from a carefully placed spoon and her small dog from a pair of balls. Four pseudo-evolutionary series are aligned in a comparative array. This highlights an increasingly standard visual strategy of Darwinism, as well as the commonness of both evolutionary series and spoofs thereof. "Entwickelungen nach Darwin's Theorie", wood-engraving from *Fliegende Blätter*, lvi (1872), 160. Niedersächsische Staats- und Universitätsbibliothek Göttingen.

was, perhaps, a characteristic feature of late nineteenth-century technical projects concerned with the production of sequences of subtly organized images: the very term *series* thus shifted its sense specifically to indicate the deliberate fragmentation of duration into successions of instantaneous moments. Then these fragments were to be recomposed through juxtaposition and substitution to offer a more powerful analysis of dynamic appearance. These processes of decomposition and reassemblage typified many science shows.[34]

Scientists who taught serial lessons of progress and development were much preoccupied with audiences' visual and scientific literacy. In ethnological collections such as those of Gustav Klemm in Dresden at mid-century or the displays orchestrated by Augustus Pitt Rivers in London and southern England from the 1870s, series of technical artefacts were supposed to allow the implicit sequencing of entities, such as mentalities and institutions, of which the underlying serial evolution was by no means so evident to the untutored gaze or the glance (Figure 9). "Those missing links must be supplied by conjecture which in the material arts can be arranged in rows so obvious that those who run may read."

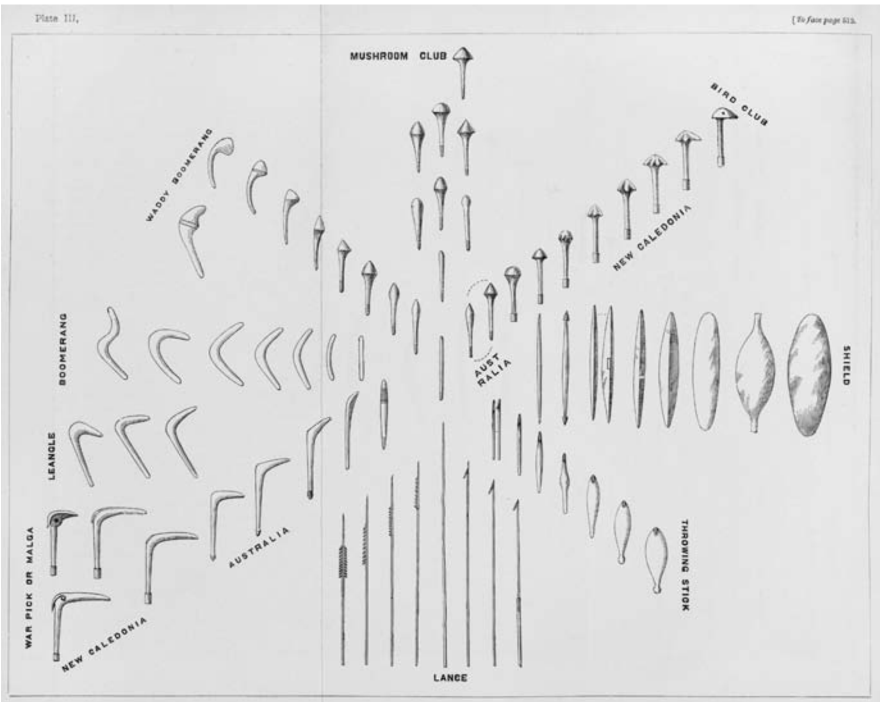

FIG. 9. The military officer, archaeologist and museum entrepreneur Augustus Pitt Rivers arranged contemporary Aboriginal Australian and Melanesian weapons in series to argue for their development from a single primordial form. Augustus Henry Lane Fox [Pitt Rivers], "On the evolution of culture", *Proceedings of the Royal Institution*, vii (1875), 496–520, Plate 3.

Schlanger's paper on the relation between numismatics and palaeontology in projects to serialize narratives of high antiquity explains in detail the ways in which Pitt Rivers sought to exploit the disciplined eye of the coin collector and the flint knapper in teaching lessons about incrementally serialized human evolution. Pitt Rivers and his allies proposed "a great National Anthropological Collection" set out in the double series of typological form and geographical provenance. Typological serialization would teach sociological principles, geographical serialization would instruct audiences in the principles of ethnology. These displays took very seriously the precise relationship between disposition and order. In 1891, for example, at a meeting of the Society of Arts, the geologist and antiquarian Frederick Rudler even suggested that the best way of serializing ethnographic collections would be in a vast spiral, on the scale of the Albert Hall, so that visitors could ineluctably trace the continuous development of human technique and culture from the Palaeolithic to modern society.[35]

From the perspective of the dominant German anthropologists, however, such serial arrangements were sadly doctrinaire. The anti-evolutionary Berlin Anthropological Society prided itself on the completeness of its series, but refused to impose developmental order on its displays; the vast Ethnographic Museum rather adopted a geographical arrangement as the most neutral. The curators designed cases so as to present the objects as directly and openly as possible to the gaze of the knowledgeable visitor, in whose mind connections were supposed eventually to emerge. In practice, these ever more cluttered research collections failed to deliver on this empiricist ideal. They either adapted to audiences and patrons, or visitors — increasingly surrounded with colonialist representations of non-Europeans — tended to enter and leave with their own often serial ideas intact.[36]

Even in the most didactic museums, "those who run" would not always read designers' lessons. Marianne Sommer's contribution addresses the early twentieth-century murals of animal and human evolution at the American Museum of Natural History in New York. As she shows, the production and interpretation of the displays required constant negotiation and compromise between the artist Charles Knight and the museum president Henry Fairfield Osborn. Not surprisingly, audiences already habituated to linear developmental narratives did not necessarily appreciate the more complex serialization, involving processes of degeneration and loss, that Osborn intended them to learn.[37]

New styles of training, both in classroom arrangements and in the order of teaching materials, reorganized and encouraged the serialization of instruction. This pedagogical serialization of disciplines was often accompanied by proposals that the worlds these disciplines described were themselves intrinsically serial. Thus sciences such as chemistry, which had a long tradition as an enterprise of intensive training and classificatory order, exploited the effect of serial dispositions of chemical substances on students and wider audiences.[38] The notion of the series as a peculiarly natural, lucid and even precise mode of arranging entities was reinforced, no doubt, by the strong links between chemists and naturalists. Indeed, early nineteenth-century projects to construct serialized arrangements of chemical substances according to tables of affinity, or of their electrical properties, seemed viable not least because of the strong analogy with the great chains of the natural historians. Furthermore, the turn towards classification of chemical elements in autonomous groups rather than in a single scaled series took place at the same period and within the same communities in Paris and in the German lands as the development of notions of distinct anatomical types. Thus in 1816 Cuvier's colleague André-Marie Ampère, also concerned with an entire system of knowledge, produced a sketch of a chemical classification that abandoned the attempt "to establish a natural order among simple bodies, by arranging them in a single series" of affinities, because "we are not able to establish in any way the complete separation which will be required by the reduction of the system into a single series". Like the Cuvierian *embranchements*, Ampère proposed instead three vast groups of elements distinguished by their melting points and oxides, further subdivided by genera and species.[39]

The institutionalization by the European chemical community in the 1860s of a workable set of atomic weights, and the ever more pressing need to set out chemical doctrine and processes in textbook order, were among the decisive interests in the construction of serialized tables of the elements from mid-century. The question of the existence of a single series, however, remained controversial. Textbooks produced the concepts of order and disposition they were also designed to illustrate. As Michael Gordin has shown, Dmitrii Mendeleev's formulation of the periodic table in 1869 is exemplary: "having undertaken the compilation of a guidebook to chemistry", he wrote, "I had to set up simple bodies in some kind of pattern so that their distribution was not governed by accidents, as if by intuitive guesses, but by some definite exact principle". The association between periodic repetition of similar properties and a gradual increase in atomic weight suggested to some of Mendeleev's readers a genuinely evolutionary series at work in the emergence of the elements.[40] Once again, the comparison between chemistry and the life sciences was powerful even if there seemed to be no extinct elements. Models made for public display in the later nineteenth century show how inorganic evolution might drive the series of elements into existence by natural development (Figure 10). But Mendeleev rejected such readings: "the periods of the elements correspond to points, to numbers … and not to a continuous evolution". The problem of seriality and discontinuity reappears in these major contests about the accessible display of development.[41]

GOVERNANCE, LABOUR, LEISURE

If the production and interpretation of serial displays depended on serial experiences, we need to explore further how practices of governance, labour and leisure helped serialize everyday life. Factory work and bureaucratic surveillance, statistical regulation and periodical publication could all play such roles.

A key issue was management by and of paper. In the half-century before 1914, output of paper rose nearly tenfold in Britain (where the industry was in relative decline) and in the United States by forty times. As Simon Eliot has noted, the vast

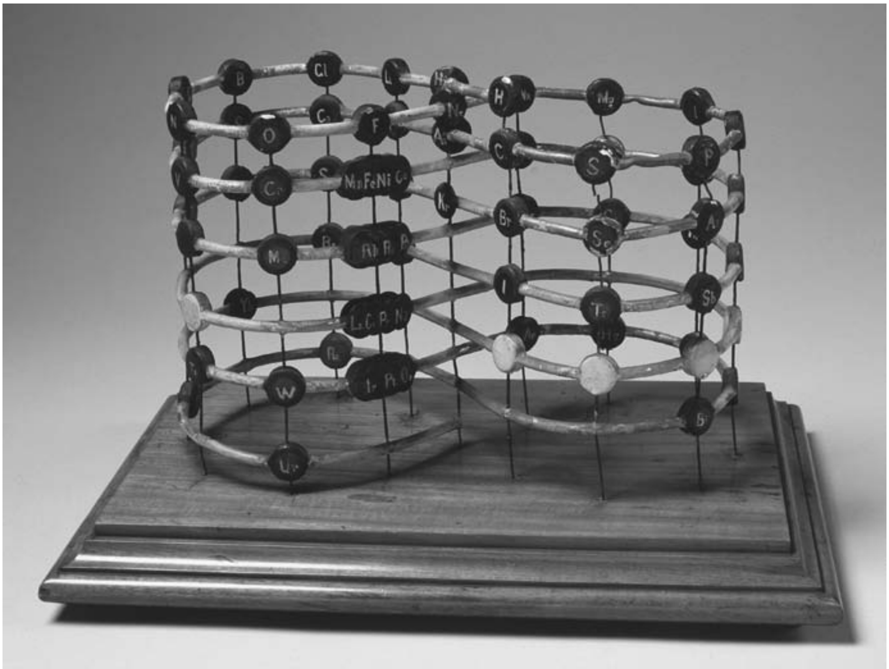

FIG. 10. The chemical journalist and consultant William Crookes told the British Association in 1886 that the periodic order of the elements was analogous to the evolutionary series of animals and plants. In 1888 he made a spiral model to show how successive elements were arranged in an evolutionary series generated through secular cooling marked by cycles when elements were formed. Model in wood and metal, just over 30 cm tall, courtesy of Science Museum / SSPL.

bulk was used not for books, but for newspapers, government forms, financial records, railway timetables and inexpensive periodicals. The ability to read such documents became increasingly indispensable among all classes of society and for both women and men. Literacy was, for the vast majority of the population, primarily a way of participating in a serial culture. More than anything else, the experience of sequential reading of printed paper tied diverse groups together: it was often said that a political group or religious sect did not really exist until it issued a periodical or newspaper. The domestic delivery of such items, encouraged by new paper-based technologies such as postage and tax stamps, located the mundane occurrences of life in wider contexts of national and global progress. Contemporaries experienced the rise of statistics from the early nineteenth century as a highly ordered and pervasive activity, involving the daily recording and collection of previously private information. For those who lived through it, this was not primarily about finished lists of numbers, but about creating and filling in forms.[42]

In their account here of the means through which variations in the bureaucratic regulation of patient records in clinics and hospitals helped develop dominant models of disease, Hess and Mendelsohn reveal administrative categorization, through the paper technologies of formatting and indexing, as a precondition for the serialization of medical records. It was by tabulation that Louis constructed an argument in eighteen cases. Hospital medicine depended on this method, and even after the introduction of laboratory instruments and graphs, the same basic operations of formatting, extracting and listing remained central.

Yet scale and division of labour increased dramatically during the second industrial revolution. Axel Huentelmann's analysis of the management of pharmaceutical production in early twentieth-century Frankfurt traces the intimate ways in which paper control in large systems of manufacture both directed and produced the serialization of the throughput system. Similarly, in new agro-industrial enterprises and 'scientific' breeding institutes elaborate techniques of serial recording and calculation — in registers, genealogies and tables — were preconditions both for the marketing of 'pure' seed and stock and for such key objects of the new science of genetics as the 'pure line'. The mass collection of data in asylums, psychiatric institutes, anthropometric laboratories and eugenics record offices allowed Mendelian analysis of the frequencies of alleles in populations that were deployed, using genealogical diagrams and graphs, to justify policies that promised serial improvements in the national germ plasm.[43]

Alex Csiszar's contribution, which details the massive use of paper technologies and over-ambitious bureaucratic techniques to manage the problems of scientific serials, reveals the tight connections between journalism and statistics. What Ian Hacking called "the avalanche of printed numbers", launched in force in Restoration Paris from the 1820s as part of campaigns for the statistical survey of social and moral behaviour, depended on fundamental reorganizations of state and civil institutions through surveillance and discipline. "Police makes statistics necessary, but police also makes statistics possible", Foucault argued.[44] However, as Hacking adds, to render these newfangled numerical series meaningful and useful, "there had to be readers of the right kind". Exploiting these widely distributed statistical series, the Brussels astronomer Adolphe Quetelet famously applied the principle to the maintenance of social order: "the larger the number of individuals, the more individual will fades out, and allows the series of general facts to predominate, the facts which depend on general causes, and in virtue of which society exists and is conserved." That such serial tables often appeared in public print, and were integral to public debate and mobilized in controversy, aided the sense of social order as registered in long series of data. Understandings of statistical laws as meaningful only through frequencies in well-constructed and "sufficiently extensive series of events", urged by writers such as the Jena professor Jakob Friedrich Fries and the influential English historian Henry Buckle, had become common sense by the late nineteenth century.[45]

Relations between the methods of field surveys and of statistical inquiries had already helped motivate appeals to statistical seriality in managing the results of fieldwork. Charles Lyell's arguments for statistical palaeontology and uniformitarian stratigraphy envisaged the work of "commissioners appointed to visit each province in succession" to produce "a series of statistical documents". The aim was to array populations in series so that they could be known through outward visibility and thus subject to a penetrating diagnosis. He assumed that readers would be familiar with the social order of censuses and statistical surveys.[46] Similarly, the Geological Survey launched in 1835 was a census designed to reconstruct ancient environments and populations using methods cognate with those of contemporary sanitary and statistical surveys. It made sense for surveyors such as the geologist John Phillips directly to explain the appearance of seemingly older fossil fauna in more recent strata through the historical principle that "new social systems may be traced and even have periods of activity and influence before the older systems have died away". What has been called a "statistical view of nature" offered resources for making series seem valid then exploiting their interpretation.[47]

In several important scientific enterprises, notably observational astronomy and meteorology, the increasing dominance of serial forms of publication, those which most often carried the printed numbers on which statisticians reasoned, seems to have been connected with a vision that helped natural order appear serial and developmental. One of the oldest genres of mass print, almanacs, had long carried calendars and directories that set out celestial and earthly phenomena in vast arrays of serial information. Their layout mixed sequences of ordered events, dates and signs with more prophetic divinations. In epochs of agricultural crisis and widespread poverty, attention evidently focused on seemingly unusual celestial signs and weather marvels. Early nineteenth-century reformers who aimed to redirect and control public opinion well understood the profit and appeal of almanacs in the mass market. They often sought to manufacture their own versions that would somehow displace prognostications by statistical commentaries on meteorological events. Theresa Levitt has shown how in France the liberal reformer and astronomical expert Dominique Arago used the serial *Annuaire* of the Bureau of Longitude as a weapon in the fight against what he saw as superstition peddled by the vulgar almanacs. Yet this metropolitan astronomer's apparent capacity to predict series of celestial events tended to reinforce his status as a prophetic visionary.[48]

Daily newspaper reports of the weather were still commonly retrospective rather than predictive. In the United Kingdom, Robert FitzRoy introduced science-based weather reports and charts soon after mid-century and equally intended them to reinforce rational habits of thought through daily repetition and routine. The strategy had only limited success — it was not until 1875 that the Meteorological Office was confident enough to release daily weather charts in *The Times*. As Katharine Anderson explains, such serially produced maps were designed to teach the difficulty of meteorological prediction. "As soon as they appear in our afternoon papers", *Nature* reported, "we may hope for a more intelligent comprehension of the difficulties which beset any attempt to foretell the weather of these islands for the space of even twenty-four hours".[49]

Anderson's account of the making of meteorological expertise can be compared with Sommer's reconstruction of the production of the restorations at the American Museum: in both cases, the public press emphasized the speed, reliability and technological complexity of the process of manufacture in order to reinforce the esoteric authority of expert science. In the management of visual data and in stories about the making of meteorological series, the aim was to rationalize public knowledge by insisting on its subservience to and thus reliance on expert, centralized planning.[50] The argument is echoed in Csiszar's suggestion that later nineteenth-century attempts to manage and refine scientific publication were not so much a response to information overload as deliberate strategies to differentiate and defend specialist forms against genres seen as vulgar or for the masses.

As hand labour gave way to mass production, similar developments can be traced in the more general discourse on machinery and manufacture. Accompanying the serially organized and mechanized printed numbers that filled the pages of social surveys, forecasts and censuses, representations of factory order debated serial production. In 1835 the Glasgow chemist and political economist Andrew Ure set out one of the first public analyses of what had just come to be called the *factory system*. Ure's judicious definition of a "factory" excluded any institution "in which the mechanisms do not form a connected series". Because they were not serial like this, establishments such as breweries and dye-works could not count as factories: "This title, in its strictest sense, involves the idea of a vast automaton, composed of various mechanical and intellectual organs, acting in uninterrupted concert for the production of a common object, all of them being subordinated to a self-regulated moving force."[51] Socialist radicals soon denounced the principle that any labour process that could be serialized must be automated. Engineers such as the Berlin designer Ludwig Kufahl pointed out that whereas in British factories layout seemed dictated by the need for strict surveillance, it was in German production systems that the principle of continuous throughput had most developed layouts for serial mechanization (Figure 11).[52] Hüntelmann's study of the political economy of Paul Ehrlich's experimental therapy institutes confirms the dependence of these systems of production on the serialization of labour and explores the role of numerical series in the management of assistants, animals, chemicals and data.

In question here is the character of mechanical labour and machinofacture, in their contemporary realization in systems of work discipline and as forms of production utopia, for which idealized schemes for continuous flow and co-operation were proposed. Such utopias were especially in evidence in the socialist programmes that Tresch describes here. He reconstructs the relations between the serializations of history and of social order that these visions combined. Csiszar's study of later nineteenth-century projects to reform international scientific communication discusses similar links between utopian visions of production and communication and the serial management of information. It is no coincidence that the protagonists often also produced socialist visions of global reorganization. One aim was to link the social order of information more immediately with that of rationalized labour.

Astute observers of the factory system such as the visionary mathematician and engineer Charles Babbage and Karl Marx used the extent to which production had been serialized and inspected to construct serial accounts of its history. Schlanger's

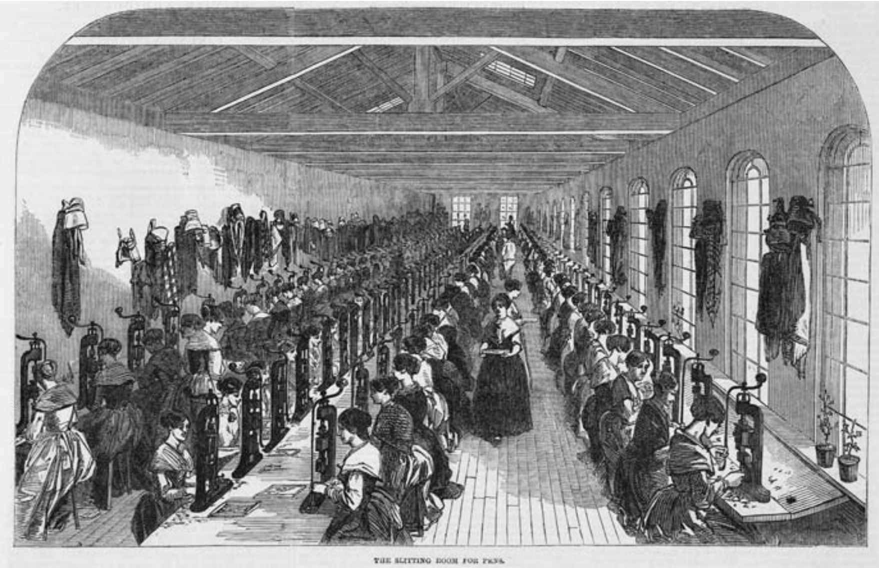

FIG. 11. Nineteenth-century political economists debated how serial organization defined the character of the factory system through the division of labour into minutely distinct tasks and their recomposition in continuous flow production governed by systematic mechanization. At George Hinks's and John Wells's Buckingham Street factory in Birmingham, where almost one million pens were made each day, more than a dozen different processes were sequenced to accelerate output. In the slitting room rows of young women worked at cutting machines to make a slit in each steel nib. Wood-engraving from *Illustrated London news*, xviii, issue of 22 Feb. 1851, 149.

paper on numismatics and palaeontology recalls the fraught character of histories of technology and of economic production as sites where rival models of historical development were worked out. The attribution of skill, or of social progress, to any set of technologies was always political. In the chapters of *Capital* most indebted to Ure and Babbage, Marx traced the change from heterogeneous manufacture to its "perfected form" in which articles "go step by step through a series of processes", a serial set-up that generated the collective worker, to be expropriated and displaced in turn by the highest stage of machinofacture, the collective working machine, in which "the object of labour goes through a connected series of graduated processes carried out by a chain of mutually complementary machines". Marx explicitly understood the serial disposition of collective work as "organic", but this was no mere analogy between biological and economic series. Rather, he and contemporary political economists insisted that, in Ure's "vast automaton, composed of various mechanical and intellectual organs", serial organization of production depended on the expropriation and maximization of labour power.[53]

Crucial for this analysis was the principle that in serial manufacture, and even more clearly in the collective working machine, each component must be forcibly separated and then recombined under a regime of surveillance. This principle, set

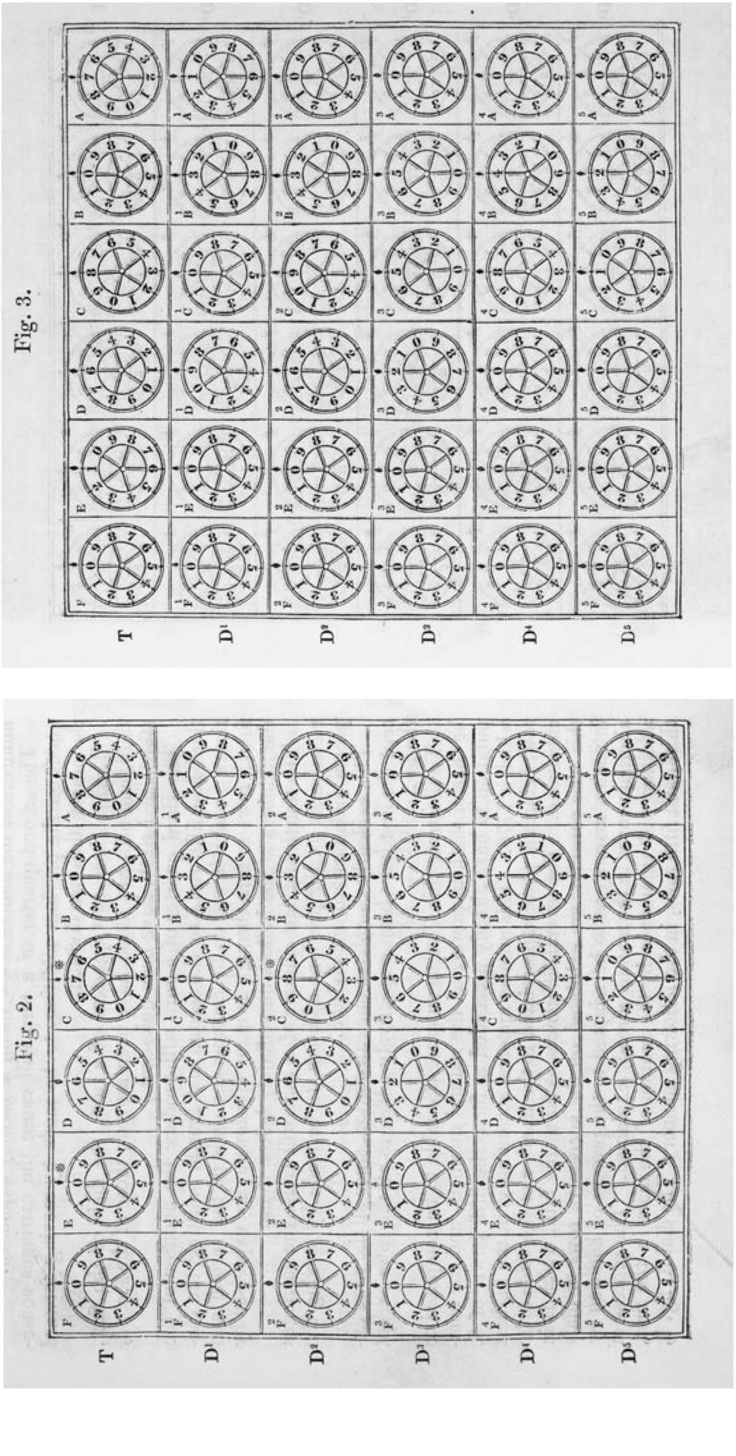

FIG. 12. To illustrate the method of differences used in Charles Babbage's calculating engines, the *Edinburgh review* printed a series of diagrams to represent the serial addition of a number expressed on a row of dials to the number represented by the row below it when computing a table of the fifth powers of the natural numbers. For example, to add the first difference line D^1 to the top line T, each dial in T would move through as many dial divisions as the index number beneath it in D^1, and so on. In one iteration of a quarter-turn of the engine's axis the dials would advance from the set-up in Figure 2 to that in Figure 3. [Dionysius Lardner], "Babbage's calculating engine", *Edinburgh review*, lix (1834), 263–327, Figures 2 and 3 on pp. 292–3.

out clearly in Babbage's writings on the factory system, gave peculiar importance to the way serialized production could be turned into public display. Babbage gained notoriety for these kinds of showmanship. As he extended the techniques of automatic serial manufacture from the factory to the work of calculation and computation, he designed an artful show, first displayed to a group of Anglican professors including the economist Thomas Malthus, in which his calculating machine could in principle be set to manufacture "the series of natural numbers in regular order from unity up to a number expressed by more than a thousand places of figures" (Figure 12). By setting up the machine in the right way, it could then suddenly change the apparent law of its operation, "each individual law being destined to govern for millions of ages the calculations of the engine and then give way to its successor". This was one of the more spectacular cases of serial mechanization as a form of theatre designed to teach a lesson about natural order. Babbage made the comparison clear with the appearance of new species evinced through geological fieldwork in the "series of strata". No simple analogy between mechanical generation of numbers and fauna, the display relied on a shared sense of how audiences would respond to the experience of serial development and its laws.[54]

The effect of Babbage's demonstration, in his celebrated London soirées of the 1830s, was not to institute conviction but to encourage conversation. Set in a particular way, the machine would always give the same answers; but those who saw it in action posed a variety of questions and differed on what the analogy might mean. Did it license crude materialism or mechanical evolution? Was it a fancy way of teaching a lesson about miracles that could be demonstrated by any clock that rang the hours? Or was the real lesson — that didactic teaching through machines might be out of place in a polite drawing room — to be learned from the entertaining mechanical dancer next door? Serial production tended towards ordered sequences, with slight differences targeted at consumers' perceived demands for novelty within the safety of conformity; but precisely what the variations might mean was the subject of constant speculation and debate.[55]

Not least, multiple experiences of serial order forced audiences to choose between alternatives. Many of these characteristically involved fine distinctions and slight variants: a novel cut of the sleeve, a fresh shade of a popular colour, a slight twist in a familiar fictional plot, a new variety of plant or a better way of conducting an old experiment. In this way, seriality was tied to notions of liberal individualism that spread widely in Europe, America and elsewhere in the later nineteenth century. In the expansive world of industrial capitalism, people increasingly defined themselves around choices of serial consumption: which newspaper did they read, at which times of day did they eat, which meetings did they attend, which fashions did they follow?

CONCLUSION

Given the transformation of historical studies of the sciences in recent decades, it may seem perverse to revive so hoary a text as Lovejoy's *Great chain of being*. Its unremitting intellectualism, outdated stress on "unit ideas" and blindness to social and economic conditions all make it an unpromising resource. Yet Lovejoy's predicament, as explored by Simon Schaffer in the final paper in this collection, still resonates today. Schaffer suggests that the status of the public intellectual in the later nineteenth and earlier twentieth centuries was much involved in the intellectual history of seriality. In the modern epoch of world war and social crisis, Lovejoy envisaged the management and control of social evolution by a cadre of disinterested but committed intellectuals. There was to be a vital connection between the ideal of progress as an expression of serial advance, and the understanding of that advance by those who studied its history. Seriality thus emerged as a key theme not only in the history of evolutionary thought, but also for the direction of evolution in society. The reflexive point remains relevant, for it shows how ways of describing the world as serially organized helped give authority to those who could use those series to project plausible or desirable futures in natural and social sciences.

Lovejoy's close readings often remain impressive in the way they historicize "the great chain of being"; but the greatest potential of his work lies in bringing forward the significance of seriality more generally, and in ways that go beyond the history of ideas agenda in which it was originally embedded. How, then, do the papers collected here suggest that engaging with seriality might be useful for historians now?

First, seriality is relational: to be part of a series is to be preceded and followed by something else. As a historical tool, seriality avoids static categories and definitions. Taken to its full extent, it undermines even Lovejoy's own concept of the "unit idea", for all ideas are inherently relational. Second, seriality can encourage a focus on practice, uniting approaches that have variously been dealt with as material (such as publications and exhibitions) and conceptual (such as developmental and evolutionary sequences). Third, seriality is about process, about science as work. It is particularly strong in relating different scales and perceptions of time, as well as of arrangements in space. It stresses the sequentiality of reading and viewing experiences, and the increasingly exploratory character of science. Fourth, seriality is about (but not confined to) communication. It highlights issues of audiences and authorship, readers and writers. It points to the need for further work on genre, in terms not just of publication but of the full range of forums in which science has been discussed.

Finally, the conditions for seriality as it developed during the long nineteenth century suggest relations to economic and social change at the broadest level. So one of the more important tasks for further inquiry in the study of seriality and scientific objects is to trace the range of ways in which public experiences of serialized phenomena allowed the development of rival models of social and natural orders. In addition to the practices of governance, labour and leisure already considered, mechanized travel produced characteristic forms of serialized experience that depended on the industrialization of space and time. Dolf Sternberger and Wolfgang Schivelbusch argued that rapid rail travel generated unprecedented relations between spectator, traveller and landscape, in which successions of panoramic visions substituted for intimate engagement with nearby phenomena now rendered invisible by speed. The spaces of travel "became a series of pictures or scenes created by the continuously changing perspective". Moving panoramas and the mechanically generated illusions of travel, speed and movement built on these technologies and exploited these affects and effects.[56]

This would also direct historians' attention once again to the exhibitions and museums where new technologies of display and sequencing were crucial resources for manufacturing experiences of serially organized phenomena. Some art historians have suggested, for example, that the new genre of renderings of the same object in series of works by Claude Monet and his fellow Impressionists from the 1870s was closely connected with innovations in techniques of printmaking and public exhibitions. Panoramic and dioramic technologies deliberately exploited shifts in illumination and environment to mimic the seriality of natural phenomena. In the manufacture of the image for display, changes of state in successive versions were no longer merely seen as moves towards a final form of the print. Rather, each proof would assume its unique quality and juxtapositions of successive states would reveal underlying principles of creativity and interpretative skill.[57]

In the same period and place, serialized objects exerted their power through the development of graphical methods to decompose processes of labour and life, to trace ephemeral phenomena and capture them as reliable sequences and traces, then display these images at the great exhibitions of the century's end. Thus when the photographer Eadweard Muybridge visited Paris in 1881 to show his notorious images of animal movement, the physiologist Etienne-Jules Marey was at once prompted to contemplate "if it were possible to obtain the images in series", thus to develop versions of chronophotographic registration that would allow the inscription and analysis of dynamic form. As the historian Anson Rabinbach has argued, these strategies of visualization of serial labour power helped launch "a modernist politics, the politics of a state devoted to maximizing the economy of the body".[58] The role of serialization in certain kinds of modernist experience, especially of work and consumption, thus represents an important area for further study.

Seriality, based in material arrangements rather than idealized abstraction, is a promising category for historical analysis. It provided nineteenth-century commentators with indispensable frameworks, from which, on the evidence of the following essays, historians of science also have much to learn. Its integrative virtues are particularly important in understanding a period for which the greatest challenge remains identifying general ways of locating the increasingly technical, specialist work of the sciences within wider processes of historical change. Historians have found other concepts effective: statistics, standardization, networks, models. The study of the establishment of electrical standards, for example, has been vital in creating accounts that move between university laboratories, coastal telegraph stations and the offices of colonial administrators. Such concepts share with seriality a focus on process and practice that has been vital to their success. Not coincidentally, they are also actors' categories, used to understand changes from the ordering of populations to the rise of scientific periodicals. Like these other concepts, too, seriality points to bureaucratic and institutional transformations that promise to shed light on a fundamental paradox of the nineteenth century: how did the places and practices of the sciences appear increasingly distant and specialized, at the precise moment that they became central to everyday life?

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REFERENCES

1. Lewis Campbell and William Garnett, *The life of James Clerk Maxwell, with selections from his correspondence and occasional writings*, new edn (London, 1884), 354.
2. Arthur O. Lovejoy, *The great chain of being: A study of the history of an idea* (Cambridge, MA, 1964), 242–87; William F. Bynum, "The great chain of being after 40 years: An appraisal", *History of science*, xiii (1975), 1–28.
3. E.g., Joseph O'Connell, "Metrology: The creation of universality by the circulation of particulars", *Social studies of science*, xxiii (1993), 129–73; M. Norton Wise (ed.), *The values of precision* (Princeton, 1995); Theodore M. Porter, *Trust in numbers: The pursuit of objectivity in science and public life* (Princeton, 1995); Bruce J. Hunt, "Doing science in a global empire: Cable telegraphy and electrical physics in Victorian Britain", in Bernard Lightman (ed.), *Victorian science in context* (Chicago, 1997), 312–33; Simon Schaffer, "Metrology, metrication, and Victorian values", *ibid.*, 438–74; Volker Hess (ed.), *Normierung der Gesundheit: Messende Verfahren der Medizin als kulturelle Praktik um 1900* (Husum, 1997); Graeme J. N. Gooday, *The morals of measurement: Accuracy, irony and trust in late Victorian electrical practice* (Cambridge, 2004); and (for literature reviews) Arne Hessenbruch, "Metrology" and "Standardization", in *idem* (ed.), *Reader's guide to the history of science* (London, 2000), 477–80 and 704–6.
4. *Oxford English dictionary*, s.v. "series"; Emile Littré, *Dictionnaire de la langue française* (4 vols, Paris, 1877), s.v. "série"; Jacob Grimm and Wilhelm Grimm, *Deutsches Wörterbuch*, viii (Leipzig, 1893), cols 636–55.
5. Lovejoy, *op. cit.* (ref. 2), 236. On missing links in nineteenth-century culture see Gillian Beer, *Open fields: Science in cultural encounter* (Oxford, 1996), 115–45; and James W. Cook, *The arts of deception: Playing with fraud in the age of Barnum* (Cambridge, MA, 2001).
6. Lovejoy, *op. cit.* (ref. 2), 332.
7. Michel Foucault, *The order of things: An archaeology of the human sciences* (London, 1970), 150, 138, 275. See also Henri Daudin, *Cuvier et Lamarck: Les classes zoologiques et l'idée de série animale (1790–1830)* (Paris, 1926); François Jacob, *The logic of life: A history of heredity* (New York, 1982); and Wolf Lepenies, *Das Ende der Naturgeschichte* (Frankfurt am Main, 1976).
8. Carl Friedrich Kielmeyer, *Ueber die Verhältniße der organischen Kräfte unter einander in der Reihe der verschiedenen Organisationen, die Geseze und Folgen dieser Verhältniße* (Stuttgart, 1793), 38–9; Timothy Lenoir, *The strategy of life: Teleology and mechanics in nineteenth-century German biology* (Chicago, 1982), 43.

9. Karl Ernst v. Baer, “Beiträge zur Kenntniss der niedern Thiere. VII. Die Verwandtschafts-Verhältnisse unter den niedern Thierformen”, *Verhandlungen der Kaiserlichen Leopoldinisch-Carolinischen Akademie der Naturforscher*, xiii (1827), 731–62, p. 740, translated according to “Fragments relating to philosophical zoology: Selected from the works of K. E. von Baer”, in *Scientific memoirs, selected from the transactions of foreign academies of science and from foreign journals: Natural history*, ed. by Arthur Henfrey and Thomas Henry Huxley (London, 1853), 176–238, p. 179; Foucault, *op. cit.* (ref. 7), 271.
10. Toby A. Appel, “Henri de Blainville and the animal series: A nineteenth-century chain of being”, *Journal of the history of biology*, xiii (1980), 291–319.
11. “Observations on the nature and importance of geology”, *Edinburgh new philosophical journal*, i (1826), 292–302, p. 300. The author of this article is uncertain, but it is certainly not Robert Edmond Grant and may even be Jameson himself: James A. Secord, “Edinburgh Lamarckians: Robert Jameson and Robert E. Grant”, *Journal of the history of biology*, xxiv (1991), 1–18; and, for discussion of contemporary ‘ultraserialism’, Adrian Desmond, *The politics of evolution: Morphology, medicine and reform in radical London* (Chicago, 1989), 5 n. 11, 45, 311.
12. Desmond, *op. cit.* (ref. 11), 263–4.
13. William Herschel, “Astronomical observations relating to the sidereal part of the heavens”, *Philosophical transactions of the Royal Society*, civ (1814), 248–84, p. 248.
14. John Herschel, “Account of some observations made with a 20-feet reflecting telescope”, *Memoirs of the Astronomical Society*, ii (1826), 459–97, p. 488; [John Pringle Nichol], “State of discovery and speculation concerning the nebulae”, *Westminster review*, xxv (1836), 390–409, pp. 404–5n; Michael Hoskin, “John Herschel’s cosmology”, *Journal for the history of astronomy*, xviii (1987), 1–34, p. 8; Stephen G. Brush, *Nebulous Earth: The origin of the solar system and the core of the Earth from Laplace to Jeffreys* (Cambridge, 1996), 40–2.
15. Simon Schaffer, “The nebular hypothesis and the science of progress”, in James R. Moore (ed.), *History, humanity and evolution: Essays for John C. Greene* (Cambridge, 1989), 131–64, pp. 150–1.
16. Giulio Barsanti, *La scala, la mappa, l’albero: Immagini e classificazioni della natura tra Sei e Ottocento* (Florence, 1992).
17. On the transformation of maps, see Rachel Laudan, *From mineralogy to geology: The foundations of a science, 1650–1830* (Chicago, 1987), 168–9; Martin J. S. Rudwick, *Bursting the limits of time: The reconstruction of geohistory in the age of revolution* (Chicago, 2005); *idem*, “The emergence of a visual language for geological science, 1760–1840”, *History of science*, xiv (1976), 149–95.
18. Esther Fischer-Homberger, *Medizin vor Gericht: Gerichtsmedizin von der Renaissance bis zur Aufklärung* (Bern, 1983), 249–50; Barbara Duden, “Zwischen ‘wahrem Wissen’ und Prophetie: Konzeptionen des Ungeborenen”, in Duden, Jürgen Schlumbohm and Patrice Veit (eds), *Geschichte des Ungeborenen: Zur Erfahrungs- und Wissenschaftsgeschichte der Schwangerschaft, 17.–20. Jahrhundert* (Göttingen, 2002), 11–48; Tatjana Buklijas and Nick Hopwood, “Development”, in *Making visible embryos* (2008; http://www.hps.cam.ac.uk/visibleembryos/s2.html). See further Michael Hagner, “Enlightened monsters”, in William Clark, Jan Golinski and Simon Schaffer (eds), *The sciences in enlightened Europe* (Chicago, 1999), 175–217; Janina Wellmann, “Keine Ikone der Entwicklung: Die *Icones embryonum humanorum* von Samuel Thomas Soemmerring”, in Ulrich Johannes Schneider (ed.), *Kulturen des Wissens im 18. Jahrhundert* (Göttingen, 2008), 585–94; and *idem*, “Die Metamorphose der Bilder: Die Verwandlung der Insekten und ihre Darstellung vom Ende des 17. bis zum Anfang des 19. Jahrhunderts”, *N. T. M.*, xvi (2008), 183–211.
19. David Gooding, “Experiment and concept formation in electromagnetic science and technology in England in the 1820s”, *History and technology*, ii (1985), 151–76; Michael Faraday, *Experimental researches in electricity* (London, 1839), pp. iii–iv; Iwan Morus, *Frankenstein’s children: Electricity, exhibition and experiment in early nineteenth-century London* (Princeton, 1998),

23–41.

20. Nick Hopwood, "Visual standards and disciplinary change: Normal plates, tables and stages in embryology", *History of science*, xliii (2005), 239–303.

21. Gowan Dawson is currently completing work on forms of publication in Victorian palaeontology. On Cuvier and Laplace, see Dorinda Outram, *Georges Cuvier: Vocation, science and authority in post-Revolutionary France* (Manchester, 1984); and Charles Coulston Gillispie (with the collaboration of Robert Fox and Ivor Grattan-Guinness), *Pierre-Simon Laplace, 1749–1827: A life in exact science* (Princeton, 1997). For serial publication of novels see Linda K. Hughes and Michael Lund, *The Victorian serial* (Charlottesville, VA, 1991); Mary Poovey, *Uneven developments: The ideological work of gender in mid-Victorian England* (Chicago, 1988); Norman N. Feltes, *Modes of production of Victorian novels* (Chicago, 1986); and several of the essays in John O. Jordan and Robert L. Patten (eds), *Literature in the marketplace: Nineteenth-century British publishing and reading practices* (Cambridge, 1995).

22. John Herschel, "Sound", *Encyclopaedia metropolitana*, iv (London, 1830), 763–824; and Susan Faye Cannon, *Science in culture: The early Victorian period* (New York, 1978), 180–1. On the debates about transmutation, see Pietro Corsi, "The importance of French transformist ideas for the second volume of Lyell's *Principles of geology*", *The British journal for the history of science*, xi (1978), 221–44, pp. 227–9.

23. On periodicals, see Maurice Crosland, *In the shadow of Lavoisier: The* Annales de chimie *and the establishment of a new science* (Oxford, 1994); W. H. Brock, "The development of commercial science journals in Victorian Britain", in A. J. Meadows (ed.), *Development of science publishing in Europe* (Amsterdam, 1980), 95–122; Thomas H. Broman, "Periodical literature", in Marina Frasca-Spada and Nick Jardine (eds), *Books and the sciences in history* (Cambridge, 2000), 225–38; James A. Secord, "Science, technology and mathematics", in David McKitterick (ed.), *The Cambridge history of the book in Britain*, vi: *1830–1914* (Cambridge, 2009), 443–74, pp. 451–9; and W. F. Bynum, Stephen Lock and Roy Porter (eds), *Medical journals and medical knowledge: Historical essays* (London, 1992). The significance of general periodicals for the sciences is brought out in the work of the SciPer Project at Leeds and Sheffield, especially Gowan Dawson, Richard Noakes and Jonathan R. Topham, "Introduction" to Geoffrey Cantor *et al.* (eds), *Science in the nineteenth-century periodical: Reading the magazine of nature* (Cambridge, 2004), 1–34.

24. Simon Schaffer, "Scientific discoveries and the end of natural philosophy", *Social studies of science,* xvi (1986), 387–420. On the 'spirit of the age', see James Chandler, *England in 1819: The politics of literary culture and the case of Romantic historicism* (Chicago, 1998).

25. James A. Secord, "How scientific conversation became shop talk", in Aileen Fyfe and Bernard Lightman (eds), *Science in the marketplace: Nineteenth-century sites and experiences* (Chicago, 2007), 23–59. For aspects of the French case, Dorinda Outram, "Before objectivity: Wives, patronage, and cultural reproduction in early nineteenth-century French science", in Pnina G. Abir-Am and Dorinda Outram (eds), *Uneasy careers and intimate lives: Women in science, 1789–1979* (New Brunswick, NJ, 1987), 1–30.

26. These issues have recently been extensively discussed, e.g., in C. A. Bayly, *The birth of the modern world, 1780–1914* (Oxford, 2004); Dwayne R. Winseck and Robert M. Pike, *Communication and empire: Media, markets, and globalization, 1860–1930* (Durham, NC, 2007); and the focus section edited by Sujit Sivasundaram, "Global histories of science", *Isis,* ci (2010), 95–158.

27. Paul Greenhalgh, *Ephemeral vistas: The expositions universelles, great exhibitions and world's fairs, 1851–1939* (Manchester, 1991); Robert W. Rydell and Nancy Gwinn (eds), *Fair representations: World's fairs and the modern world* (Amsterdam, 1994); Chantal Georgel (ed.), *La jeunesse des musées: Les musées de France au XIXe siècle* (Paris, 1994); Eckhardt Fuchs (ed.), *Weltausstellungen im 19. Jahrhundert* (Leipzig, 1999); Carla Yanni, *Nature's museums: Victorian*

science and the architecture of display (London, 1999).

28. For Salter: James A. Secord, "The Geological Survey of Great Britain as a research school, 1839–1855", *History of science*, xxiv (1986), 223–75, p. 260; for Neumayr: Martin J. S. Rudwick, *The meaning of fossils: Episodes in the history of palaeontology* (Chicago, 1985), 255.
29. Rudwick, *op. cit.* (ref. 28), 252–4; Adrian Desmond, *Huxley: From devil's disciple to evolution's high priest* (London, 1998), 471–3; Constance Areson Clark, *God — or gorilla: Images of evolution in the jazz age* (Baltimore, 2008).
30. Nick Hopwood, "Pictures of evolution and charges of fraud: Ernst Haeckel's embryological illustrations", *Isis*, xcvii (2006), 260–301; Julia Voss, *Darwins Bilder: Ansichten der Evolutionstheorie 1837–1874* (Frankfurt am Main, 2007), 190–7.
31. E.g., Bert Theunissen, *Eugène Dubois and the ape-man from Java: The history of the first missing link and its discoverer* (Dordrecht, 1989).
32. Thomas Henry Huxley, *Lay sermons, addresses and reviews* (London, 1870), 117; Desmond, *op. cit.* (ref. 29), 367–8.
33. E. A. Davis and I. J. Falconer, *J. J. Thomson and the discovery of the electron* (London, 1997), 47–52, 73–6.
34. William R. Everdell, *The first moderns: Profiles in the origins of twentieth-century thought* (Chicago, 1997), 75–6.
35. David K. van Keuren, "Museums and ideology: Augustus Pitt-Rivers, anthropological museums and social change in later Victorian Britain", in Patrick Brantlinger (ed.), *Energy and entropy: Science and culture in Victorian Britain* (Bloomington, 1989), 270–88, p. 277; A. Lane Fox [Pitt Rivers], "On the principles of classification adopted in the arrangement of his anthropological collection", *Journal of the Anthropological Institute of Great Britain and Ireland*, iv (1874), 1–16, p. 3; William Ryan Chapman, "Arranging ethnology: A. H. L. F. Pitt Rivers and the typological tradition", in George W. Stocking, Jr (ed.), *Objects and others: Essays on museums and material culture* (Madison, 1985), 15–48, p. 41.
36. Andrew Zimmerman, *Anthropology and antihumanism in Imperial Germany* (Chicago, 2001), 172–98; H. Glenn Penny, *Objects of culture: Ethnology and ethnographic museums in Imperial Germany* (Chapel Hill, 2002).
37. See also Clark, *God — or gorilla* (ref. 29).
38. J. R. R. Christie and J. V. Golinski, "The spreading of the word: New directions in the historiography of chemistry, 1600–1800", *History of science*, xx (1982), 235–66; Benjamin R. Cohen, "The element of the table: Visual discourse and the preperiodic representation of chemical classification", *Configurations*, xii (2004), 41–75.
39. André-Marie Ampère, "Essay towards a natural classification of simple bodies", *Philosophical magazine*, xlvii (1816), 438–46, p. 444. For chemists and the chain of being see David M. Knight, *The transcendental part of chemistry* (Folkestone, 1978), 248–54.
40. Michael D. Gordin, *A well-ordered thing: Dmitrii Mendeleev and the shadow of the periodic table* (New York, 2004), 26.
41. Eric R. Scerri, *The periodic table: Its story and its significance* (Oxford, 2007), 251.
42. Simon Eliot, *Some patterns and trends in British publishing, 1800–1919* (London, 1994); Gary Bryan Magee, *Productivity and performance in the paper industry: Labour, capital, and technology in Britain and America, 1860–1914* (Cambridge, 1997).
43. Staffan Müller-Wille, "Early Mendelism and the subversion of taxonomy: Epistemological obstacles as institutions", *Studies in history and philosophy of biological and biomedical sciences*, xxxvi (2005), 465–87; Hans-Jörg Rheinberger and Müller-Wille, *Vererbung: Geschichte und Kultur eines biologischen Konzepts* (Frankfurt am Main, 2009), 160–5, 175–81.
44. Michel Foucault, *Security, territory, population: Lectures at the Collège de France, 1977–1978*, ed.

by Michel Senellart (Basingstoke, 2007), 315.

45. Ian Hacking, *The taming of chance* (Cambridge, 1990), 35–6, 123; Theodore M. Porter, *The rise of statistical thinking, 1820–1900* (Princeton, 1986), 86.
46. Charles Lyell, *Principles of geology* (London, 1833), iii, 31; M. J. S. Rudwick, "Charles Lyell's dream of a statistical palaeontology", *Palaeontology*, xxi (1978), 225–44; and *idem*, "Transposed concepts from the human sciences in the early work of Charles Lyell", in Ludmilla Jordanova and Roy Porter (eds), *Images of the Earth: Essays in the history of the environmental sciences* (Chalfont St Giles, 1979), 67–83.
47. Secord, *op. cit.* (ref. 28), 250; *idem*, *Controversy in Victorian geology: The Cambrian–Silurian dispute* (Princeton, 1986), 243.
48. Maureen Perkins, *Visions of the future: Almanacs, time, and cultural change, 1775–1870* (Oxford, 1996), chap. 6; Theresa Levitt, *The shadow of enlightenment: Optical and political transparency in France, 1789–1848* (Oxford, 2009), 91–8, 101.
49. Katharine Anderson, *Predicting the weather: Victorians and the science of meteorology* (Chicago, 2005), 58–63.
50. *Ibid*., 207–8.
51. Andrew Ure, *The philosophy of manufactures; or, an exposition of the scientific, moral and commercial economy of the factory system of Great Britain* (London, 1835), 13; W. V. Farrar, "Andrew Ure and the philosophy of manufactures", *Notes and records of the Royal Society*, xxvii (1973), 299–324; Maxine Berg, *The machinery question and the making of political economy, 1815–1848* (Cambridge, 1980), 199.
52. Berg, *op. cit.* (ref. 51), 282, cites a socialist journal of 1836; Kufahl (1844) is cited in Richard Biernacki, *The fabrication of labor: Germany and Britain, 1640–1914* (Berkeley, 1997), 139. For rival systems of serial factory layouts see Thomas A. Markus, *Buildings and power: Freedom and control in the origin of modern building types* (London, 1993), 261–70.
53. Karl Marx, *Capital: A critique of political economy*, i (London, 1976), 463–5, 500–2, 544–5. Compare Siegfried Giedion, *Mechanization takes command: A contribution to anonymous history* (New York, 1969), 99–100; Thomas P. Hughes, "The order of the technological world", *History of technology*, v (1980), 1–16, pp. 5–7; and Raniero Panzieri, "The capitalist use of machinery: Marx versus the 'objectivists'", in Phil Slater (ed.), *Outlines of a critique of technology* (London, 1980), 44–68.
54. Charles Babbage, *The ninth Bridgewater treatise: A fragment*, 2nd edn (London, 1838), 41–42, 66; *idem*, *Passages from the life of a philosopher* (London, 1864), 387; Simon Schaffer, "Babbage's intelligence: Calculating engines and the factory system", *Critical inquiry*, xxi (1994), 203–27; Brian P. Dolan, "Representing novelty: Charles Babbage, Charles Lyell, and experiments in early Victorian geology", *History of science*, xxxvi (1998), 299–327.
55. For serial production and artful variation in commodity culture see Asa Briggs, *Victorian things* (Harmondsworth, 1990), 20–4, 370–4; Thomas Richards, *The commodity culture of Victorian England: Advertising and spectacle, 1851–1914* (Stanford, 1990); Lara Kriegel, *Grand designs: Labor, empire and the museum in Victorian culture* (Durham, NC, 2007). These debates about standards and adaptations in serial production had major scientific and moral aspects. Natural theology often used the minute adaptations of natural entities to argue for their divine origin. But in the 1870s, for example, Clerk Maxwell and his colleagues used magazines, encyclopaedia articles and sermons to debate whether molecules' uniformity made them resemble "manufactured articles" like mass-produced screws or shoes, and whether this uniformity was better evidence of molecules' divine manufacture than was ingenious adaptation. See Campbell and Garnett, *op. cit.* (ref. 1), 300–2; Paul Theerman, "James Clerk Maxwell and religion", *American journal of physics*, liv (1986), 312–17.

56. Giedion, *op. cit.* (ref. 53), 17–30, 101–13; Dolf Sternberger, *Panorama of the nineteenth century* (New York, 1977), 39–40; Wolfgang Schivelbusch, *The railway journey: The industrialization of time and space in the 19th century* (Berkeley, 1986), 61–4. For panoramic vision in nineteenth-century sciences, see Charlotte Bigg, "The panorama, or *la nature à coup d'oeil*", in Erna Fiorentini (ed.), *Observing nature — representing experience: The osmotic dynamics of Romanticism, 1800–1850* (Berlin, 2007), 73–95.
57. Grace Seiberling, *Monet's series* (New York, 1981), 29–35.
58. Anson Rabinbach, *The human motor: Energy, fatigue and the origins of modernity* (Berkeley, 1992), 103, 116. Compare Robert M. Brain, "Representation on the line: Graphic recording instruments and scientific modernism", in Bruce Clark and Linda Dalrymple Henderson (eds), *From energy to information: Representation in science and technology, art, and literature* (Stanford, 2002), 155–77.