CHAPTER TWELVE

Photography and the Making of Modern Science

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The term "scientific photography" often invokes a familiar list: dazzling iconic photographs of scientific phenomena—stars, X-rays, bacteria, the moon. Scratch beneath the surface, however, and a more complex picture emerges of the subjects for the study of science and photograph. The subject is quite as likely to include photographs of unfamiliar science experiments, visual documents of scientific expeditions, portraits of scientific teachers and students, series of slides used for projection for the purpose of scientific education, photographs of specimens in museums and police departments, scientific photographs used in social and political activism, and images (such as spirit photographs) that circulated for a time as part of counter-science movements, challenging scientific heterodoxies. Their study has, in turn, helped to broaden historical perspectives about the sciences and their integration within a variety of different professional and everyday settings.

This chapter considers some of the critical questions that have been most visible since the 1970s in the study of photographic practices in the history of the natural sciences. Today, the domain of study on photography and science incorporates several distinct but overlapping fields, from the technological histories of photography, to the role of photography in scientific exploration, to the employment of scientific imagery in other sociocultural contexts, to the wide range of subject-specific scholarly debates that surround virtually all such visual conventions and practices. The material and social traces of photographs made in the scientific quest to document the world may be found today partly in "the historical and disciplinary dynamics that surrounded their production; the collecting practices of librarians, archivists, and corporations; and the archives they inhabit" (Mitman and Wilder 2016: 2). Taken as a whole, this body of work has generated innovative understandings about how scientific meanings are generated through photographic production, circulation, interpretation and, above all, debate (Kelsey 2007; Wilder 2009; Helmreich 2016; Mitman and Wilder 2016). Where once scientific and technical photography were marginalized in histories of nineteenth- and twentieth-century photography and science, studies over the past two decades have provided strong empirical foundations and critical frameworks for renewed histories of the role of photography in scientific investigation, from the early nineteenth century to the present.

What were the historical conditions of production and circulation? How were photographs used, interpreted, and, later, reinterpreted by others? What epistemologies authorized (or undermined) photography's uses? What sorts of meanings did photography

compel, for which viewing audiences, and with what results? What is a "scientific" photograph? What counts as "science" in any given historical time or place? After a brief survey of some leading studies in this field, the chapter sketches current and future directions for research.

MATERIAL AND SOCIAL TRACES OF PHOTOGRAPHY IN SCIENCE

From the start of their entanglements, photography and science were united through their common roots in the physical and natural sciences: photography was both an art *and* a science (Snyder and Allen 1975; Jenkins 1987; Schaaf 1996; Thomas 1997; Barger and White 2000; Elkins 2008; Wilder 2009; Pinson 2012; Helmreich 2016; Pichel 2016). The very representation of scientific objects in pictures, the use of photography to detect and measure phenomena, and the development of photography as a science drew upon material and intellectual forms of knowledge, from chemistry to optics to physics. Furthermore, contemporary artists have long addressed science as a focal point for their art, through their incorporation of scientific photographs into art institutions or art market; the investigation of scientific iconography in art; and the use of scientific concepts, such as observation experiment and archiving) in their making of art (Geimer 2002; Elkins 2008; Wilder 2009: 102).

Yet from its earliest days, the reckoning of the importance of photography to society was also reckoned in terms of its *contribution* (not merely its indebtedness) to science. In 1839, for example the astronomer François Arago, director of the Paris Observatory, predicted astronomical applications for Daguerre's new process, and advocated its use to obtain an improved map of the moon (Tresch 2007). The French chemist J. L. Gay-Lussac echoed Arago's enthusiasm, declaring boldly that same year that photography promised to lead to scientific progress:

> [T]hrough Monsieur Daguerre's invention physics is today in possession of a reagent extraordinarily sensitive to the influence of light a new instrument which will be to the study of the intensity of light and of luminous phenomena what the microscope is in the study of minute objects, and it will furnish the nucleus around which new researches and new discoveries will be made. (Quoted in Darius 1984: 11)

As the acute and prescient lithograph, *La Daguerréotypomanie*, by the French painter and lithographer Théodore Maurisset, highlights (Figure 12.1), warnings about the potential for social disorder and upheaval also stressed the new medium's potential for revolutionizing the very foundations of knowledge.

By 1860, British photographer F. F. Statham wrote that "To give a just and accurate idea of all that photography has done for science would be to write anew the whole history of the art" (quoted in Darius 1984: 11). Editors of photographic trade journals, because they were exposed to a broad cross-section of early users of photography, recognized the complexity of networks of technology and the arts. In 1864, a review proclaimed that despite the camera's impact on art, "It is to science … that photography, the child of science, renders, and will unceasingly render, the most valuable aid," adding that:

> There is scarcely one in the whole list of sciences which is not largely indebted to it. Astronomy and microscopic observations have benefited singularly from the increased accuracy that has been secured. It is a boon of enormous value to be able in any instance

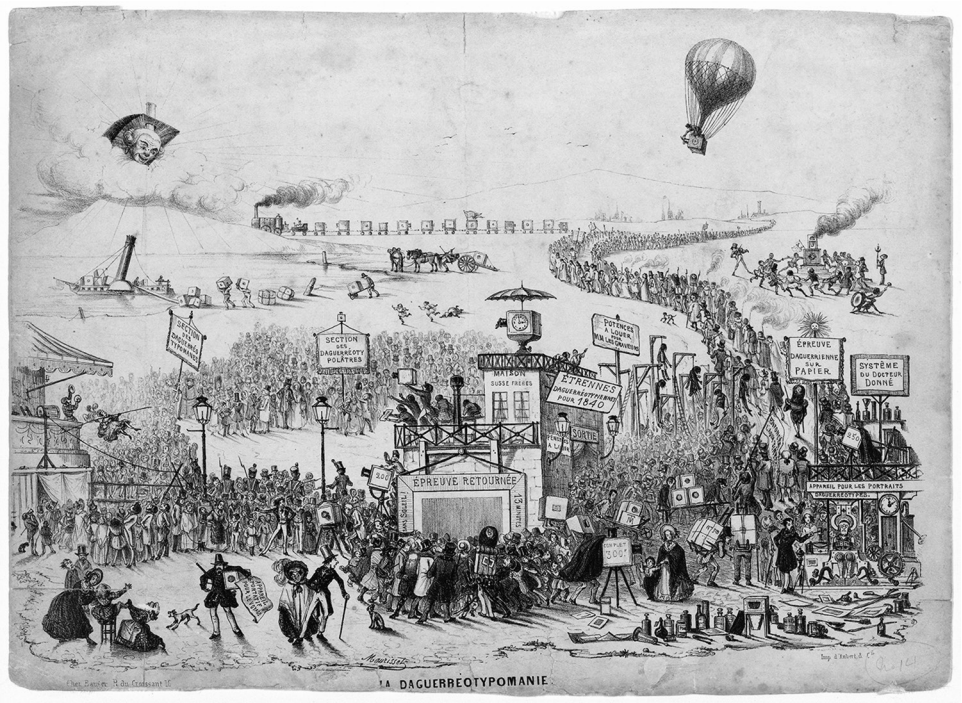

FIGURE 12.1: Théodore Maurisset, *La Daguerreotypomanie*, lithograph, 26 × 35.7 cm, December 1839. J. Paul Getty Museum.

> to eliminate that fruitful source of error, the fallibility of the observer. Photography is never imaginative, and is never in any danger of arranging records by the light of a preconceived theory. (Quoted in Darius 1984: 11)

The French astronomer, P. J. C. Janssen argued in an 1888 speech that photography was useful to science not only because it promised (in theory, at least) a neutral, mechanically objective record, but also because it was able to conserve and propagate images for many other viewers—a point that the critic Walter Benjamin would later develop in his 1936 essay "The Work of Art in the Age of Mechanical Reproduction." Janssen wrote:

> The sensitive photographic film is the *true retina of the scientist* … for it possesses all the properties which Science could want; it faithfully preserves the images which depict themselves upon it, and reproduces and multiplies them indefinitely on request; in the radiative spectrum it covers a range more than double that which the eye can perceive and soon perhaps will cover it all; finally, it takes advantage of that admirable property which allows the accumulation of events, and whereas our retina erases all impressions more than a tenth of a second old, the photographic retina preserves them and accumulates them over a practically limitless time. (Quoted in Hannavy 2007: 1255, italics added)

Furthermore, almost immediately after its invention, the camera was being described as a "servant" of science, in part because it could perform such a wide variety of different tasks within the natural sciences. The author of "The Art Question" in *Photographic News*,

published in 1872, described photography as "handmaid of the visible world," while in an essay titled "What Photography Does for Science," published in 1882 in the British journal the *Photographic News*, a photographic correspondent narrated the evolution of photography's role, from tool of discovery to routinized instrument of everyday science, explaining the transition as one from "upper-servant" to "handmaiden" (terminology of domestic service with which many of its middle- and upper-class readers were familiar): "Fifteen years ago she [photography] was a species of upper-servant performing valuable services enough, but rather of a light order. To-day she is a maid-of-all-work, put upon, on every occasion, to discharge all sorts of functions, whether manual or high-class." Where nature had once been "fugitive," wrote Joseph Auguste Belloc in the *Photographic News* in 1858, it was now "subservient to our will."

Scientific and medical atlases, illustrated with photographs and other images, were a prominent means for disciplines to educate the next generations of practitioners and present a consolidated (if limited) picture of their objects of empirical study (e.g., stars, bones, fossils). As Daston and Galison (2007) explain, scientific atlases were vitally important in defining historically changing regimes of epistemic virtues to which scientists were encouraged to aspire (see Figure 12.2 for example). Yet in practice, photographers

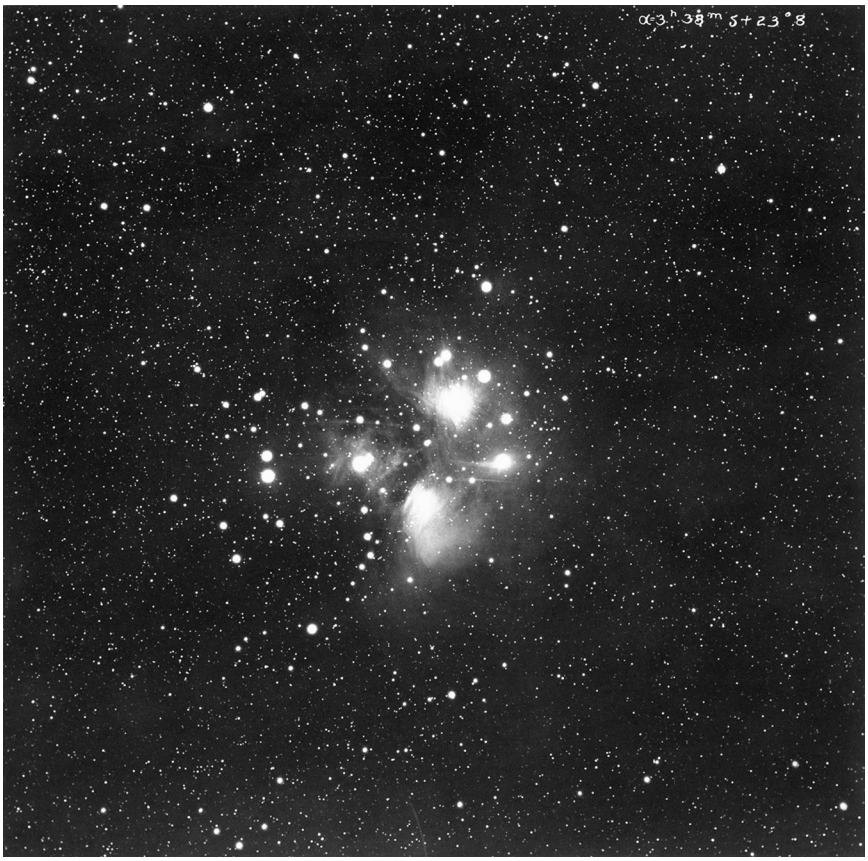

FIGURE 12.2: Edward Emerson Barnard, *A Photographic Atlas of Selected Regions of the Milky Way* (Washington, DC.: Carnegie Institution of Washington), 1927. Plate 4.

and scientists also negotiated and, importantly, contested—the prescriptive meanings of photography through other, less expensive media, such as correspondence and conversations, and even in the burgeoning technical literature aimed at amateur and professional photographers.

Not only were inventors and scientific experimenters among the shapers of photographic processes, they were among the very first individuals to create historical narratives about scientific photography. Eager to situate the new medium in relation to longer artistic and technological traditions, the earliest histories of photography quickly acquired a set of historical narratives. These, and other, scientific experimenters promoted an image of the new medium of photography as a scientific tool, an aspiration that carried with the new medium as photographic technologies and processes spread quickly around the world (Elkins 1995; Pinney 1997; Peterson and Pinney 2003; Thompson 2012). Nineteenth-century journals such as the *Photographic News* frequently published reports of the use of photography in various domains of scientific exploration as photography became a large outlet for artistic and scientific works of all kinds, across a range of social backgrounds and creative settings. Technical journals, too, informed members of scientific communities about possible uses of photography in research or teaching, giving suggestions for scientific applications, such as high-speed photography (Lawrence 1941). Scientific publications are, therefore, an important and often neglected source for early historical accounts of photography.

These and other studies reveal the existence of extensive historical sources for the study of the relationship between science and photography. Primary sources for the study of photography and science include a rich and in many ways barely explored range of laboratory and field books, material apparatus, correspondence, patents, and scientific publications.

CRITICAL APPRAISALS OF SCIENCE AND PHOTOGRAPHY

The 1970s and 1980s were pivotal decades for new theoretical and historical approaches to the study of visual representations in the natural sciences more generally. These years saw the publication of several new historical books about photography's role in science. Biographies and books focused on the work of individual photographers began to appear, many of them revealing photographers as "men of science," with intellectual interests in the natural sciences which spurred their photographic work (Arnold 1977; Schaaf 1996). At the same time, histories of photography frequently included chapters about scientific work (which, however, sometimes also had the effect of leaving unexplained and unquestioned the categories of "scientific" and "unscientific" practices).

The beginnings of major collections of scientific photographs for preservation, exhibition, and historical analysis, often in museums, also date from around this time. One of the first new exhibitions about photography in the sciences opened to the public at the Science Museum in London in 1984 under the name *Beyond Vision*. As its curator, Jon Darius explained (1984: 6), "It was the inauguration of a new museum—the National Museum of Photography, Film, and Television—which lit the fuse leading to *Beyond Vision*." Darius added that the book and the corresponding exhibition

> can claim with some justice to be the first of their kind … Of course scientific photographs have been collected in books and displays on many previous occasions for

> the edification, amusement, even bewilderment of the public. The images are usually selected either to illustrate the range and power of a tool or technique wielded by the scientific photographer (electron microscopy, for instance) or else to dazzle the viewer with aesthetically pleasing shots of balloons at burstpoint, heat maps of the body supernova remnants in blazing colour and so forth. (1984: 6)

"It is high time," Darius added (1984: 6), "[that] we expand our narrow vision of photography to allow for the incursion of more recent technologies"—especially the rise of new digital photographic technologies, which began around 1957, when the first digital image was produced on a computer and a rotating drum device was created allowing images to be scanned. Darius further explained that his book was about photography that was "scientific" in that it provided information inaccessible to the naked eye. *Beyond Vision* therefore began to push the boundaries of what was considered reliably to be a proper "photograph" (which Darius left open for interpretation)—foreshadowing debates today over what is truly considered "photography" in an era witnessing the multiplication of new reproductive digital media.

Some of the early work on the complex relations of photography, science, and vision drew strongly on Foucauldian themes (Foucault [1966] 1994, 1975). Foucault's work, and its reinterpretation by subsequent historians, influenced studies of the role of imaging techniques in science and their theoretical underpinnings in a number of ways. The idea that the coupling of evidence and photography was bound up with the emergence of new institutions and novel practices of observation and record-keeping (in modern factories, prisons, the police, schools, public health departments, for example) resonated with scholarship in the history of science that was focused increasingly on the disciplinary practices of field and laboratory ways of seeing. In contrast to previous studies that had tended to define science in universal terms, often focused on a linked series of great individual discoveries, historians of science began to see science as a phenomenon that was best understood as the site of historically specific material and social practices (Hacking 1986; Haraway 1988; Tagg 1988: 5; Schaffer 1998). Foucault's "field of vectors" and "interplay of exchanges" as well as Latour's imaging of "matrices, networks, and loops" were concepts that underpinned new studies about the conditions of science (how, for example, communication and exchanges in science worked; who participated, and what terms, etc.)—how, specifically, the authority of scientific explanations entered the arena of debate. Photography was seen as part of how institutions' local cultures facilitated the emergence of robust facts and instruments from fragile experiments (Daston and Galison 1992; Rothermel 1993; Pang 2002; Tucker 2005). These and other studies were generally developed, furthermore, not as specific contributions to the advancement of knowledge about the history of photography per se, but instead as part of a larger project in the study of science *as* culture. By at least the 1980s and 1990s, then, science was being seen by many historians as a cultural form, that is, as enacted in spaces that were largely co-extensive with other forms of activity. The concept of "contact zones" (Pratt 1992) and "open fields" (Beer 1996), for example, were helpful for framing scientific work and the material and cultural exchanges that it required. Photography and science were, furthermore, both implicated in what Foucault called the "constitution of subjects" (the making up of the subject): "We should try to discover how it is that subjects are gradually, progressively, really and materially constituted through a multiplicity of organisms, forces, energies, materials, desires, thoughts, etc." (Foucault 1980: 97). Nineteenth-century modernity was increasingly seen by historians as being "inseparable from the way in which dispersed mechanisms of power coincide with new modes of

subjectivity," wrote Jonathan Crary (1992: 15), "detailing a range of pervasive and local techniques for controlling, maintaining, and making useful new multiplicities of individuals." Photography (and also cinema) were part of a broader tendency in society toward the technological surveillance, management, and physical transformation of the individual body and the social body, leading to new ways of looking at the everyday practices of scientific and medical imaging that people encounter in clinics and hospitals (Cartwright 1995). The extension of human powers of observation through the agencies of technologies such as photography had contributed to the collapse of classical models of vision, or "a transformation from classical theories of vision as something mechanical and capable of abstraction from the body (exemplified by the camera obscura), to modernist notions of perception as a process characterized by temporal flux and embedded in a physical body" (Jones and Galison 1998: 20). Yet to a greater degree, perhaps, than in many other historical specializations (including photography studies), historians of science tended not to focus, in particular (or exclusively) on Foucault's interest in state power as it related to science; on the contrary, there was interest in how scientific institutions produced new paradigms, identities, and forms of authority.

Historians of science generally agree that the problem of visualization lies at the heart of the scientific enterprise and its public perception. With the rise of science and technology studies, scholars began studying material practices (including photography) as part of the transduction of scientific meaning—a move which had far-reaching effects for the history of photography and the way that histories of science were written. In contrast to the way that photographic and other visual representation are sometimes glossed over by other kinds of historians, historians of science and technology generally embraced the study of photography and other visual practices as offering insight into "science-in-action" (Latour 1988), even as they disagreed over how photographs were to be approached: they agreed that photographs *mattered*. One of the important contributions of the history and philosophy of science to the study of photography was in its insistence on the importance of studying material and social practices, and not merely abstract scientific theories separated from practices. In many studies, the power of the language of images was scrutinized as part of the study of practice.

Key terms and focal points of interest surrounded the uses of photography as a "witness" in science, with all the issues that raised for understanding the cultural meanings of objectivity and subjectivity and the construction of scientific authority more generally. This work was partly stimulated in the context of debates that were generated by physicist Thomas Kuhn's influential work, *The Structure of Scientific Revolutions* (1962), which challenged the prevailing view of so-called "normal science," and called for an epistemic model which helped account for how radical changes occurred in the sciences. Observation, experiment, and issues of authority were points of critical analysis that anticipated later trends as historians of science sought to understand historically how scientists communicated with each other using visual technologies of all kinds (Rudwick 1976; Cartwright 1983; Hacking 1983; Lynch 1985). Theoretical and conceptual debates over problems of objectivity, precision, and accuracy powerfully informed critical examinations of photography's seeming capacity to serve as an impartial extension to (and even as a surrogate for) the human scientific eye. Visualization could not, on this analysis, be reduced to perceptual processes because they are always and inevitably bound up with material culture and inscriptions.

At the heart of the so-called "science wars" were contrasting understandings of scientific image practices: in the context of a vigorous debate over whether scientific

knowledge proceeded through a linear increase in truth and understanding, "objectivity" became a fighting word (Daston and Galison 1992). Scientific photographs moved to the center of this wider debate: were images of pure intellectual discovery, or artifacts of socially constructed knowledge? (Shapin and Schaffer 1985; Lynch 2005; Coopmans et al. 2014). A field-defining set of essays about science and visual language published in 1992 both historicized cultural meanings of objectivity and emphasized the importance of scientific images as objects of study in the humanities (Cartwright 1992; Daston and Galison 1992).

The very definition of objectivity was shown to be historically changing and associated with different formulations of knowledge, vision, and the scientific self, with "mechanical objectivity" a scientific ideal borne out in practices only in the mid-nineteenth century (Daston and Galison 1992, 2007). Atlases and the images reproduced within them became seen as a particularly salient source of evidence because, Daston and Galison argued (2007: 48, 10), they registered new epistemic fears and virtues "more explicitly and forcefully" than many other visual sources, and served as descriptive guides to idealized scientific identities or personae. Photography's role in science, in this methodology, is approached by studying epistemic virtues and prohibitions in the moral economy of scientific representation. The virtue of mechanical objectivity emerged hand-in-hand with the appearance of a "certain kind of willful self" that was prone to impose hypotheses on data; photography, in this account, was ushered in partly because it seemed to embody the distinctive brand of late nineteenth-century pictorial objectivism to which many natural scientists increasingly aspired (Daston and Galison 2007: 37, 174). Porter (2008) and Tucker (2008) extend and critique this discussion.

Works on vision thus consolidated an approach of integrating an analysis of bodies, technologies, and vision still evident in photographic studies today. The new focus on notions of objectivity and the ideal of scientific selfhood opened new ways of seeing the work of scientific communication. In exploring these, and other, questions, scholars demonstrated how the effort to find objective, mechanical measures of social difference proliferated in the period of mechanical objectivity: the same period that saw the formulation by scientists of new concepts of sex, class, and "race," as Western science and medicine analyzed, configured, and regulated the human body (Haraway 1990; Jordanova 1993; Cartwright 1995; Tobing Rony 1996; Poole 1997; Smith 1999, 2004; Hamilton and Hargreaves 2001; Tucker 2006). The role of photography in the self-fashioning of the scientist as a public figure also has been shown to be an important and often neglected part of the story of the rise of contemporary science (Fox and Lawrence 1988; Jordanova 1993; Shapin and Schaffer 1985; Browne 2009; White 2011; Belknap and Defrance 2015).

Above all, the findings of this research led to the recognition (now accepted among historians of science) that visualization within the sciences is *not a single kind of practice* or practices. The concept of the "black box"—a metaphor borrowed from cybernetics denoting a piece of machinery that "runs by itself"—became widely used in science and technology studies of photography after Latour used photography as a leading case in ~~his 1990 essay, "Drawing Things Together,"~~ in which he cited Reese Jenkins, the author of the 1987 ~~publication~~ *Images and Enterprises: Technology and the American Photographic Industry, 1839–1925*. Latour ~~(1990)~~ and Jenkins's ~~example~~ of the simultaneous invention of the Kodak camera and the mass market for amateur photography in trying to explain why technology is such an enigma for social theory—showing that the domination of the Eastman company was visible only at the *end* of the process (see also ~~Latour~~ 1987).

The concept of "boundary object" was introduced to describe information such as specimens, field notes, drawings, photographs, and maps that were used in different ways by different communities. While objects might have "different meanings in different social worlds," their structure is "common enough to more than one world to make them recognizable, a means of translation" (Starr and Griesemer 1989: 387).

Works like these, focusing as they do on the complex historical meanings of social practices surrounding the making, viewing, and circulation of images, have great potential for future studies of photography and science. They promise to advance the subject of scientific photography beyond the previous focus on individual photos and their discoverers, and to lay groundwork for future work on scientific photography.

The rise of anthropological, sociological, postcolonial, feminist, and critical race studies approaches to photography has also shaped the historical and contemporary study of photography and science (Rose 2012, 2016). Donna Haraway's book, *Primate Visions*, for example, examined the way in which wildlife photography was an integral part of systems of scientific knowledge, gender, and race (1990: 41–6). Focusing on the American biologist and conservationist Carl Akeley, Haraway (1990: 42) suggested that he perfected the narrative tool of photography, advising that his practice of photography "was suspended between the manual touch of sculpture, which produced knowledge of life in the fraternal discourses of organicist biology and realist art, and the virtual touch of the camera, which has dominated our understanding of nature since World War II."

Critical studies of colonial photography offered breakthroughs in photographic criticism and theory, showing the need to study the circulation of photographs around the world, and in various colonial and postcolonial contexts of scientific exploration (Coombes and Edwards 1989; Edwards 1994, 2001; Pang 1994, 2002; Tobing Rony 1996; Pinney 1997; Ryan 1997; Peterson and Pinney 2003; Belknap 2014, Hall 2017). Elizabeth Edwards (2014: 173–4) challenged the way that many studies of colonialism and photography uncritically aligned photography and the rise of the nation-state, often even assuming, rather than demonstrating, a causal relationship between photography, collecting, and state and colonial power. Within colonial systems, she pointed out, modes of governance were "messy" and often indeterminate; moreover, photographs were not just simply "representations" but sets of material practices which were "entangled with the practices of governance through complex and sometimes ambiguous demands made of them to 'perform' information in ways that inflect larger governmental practices" (Edwards 2014: 174).

The expansion of interdisciplinary work in this field means that important findings are found in works that do not announce themselves as studies of photography but rather, are part of scientific biographies, institutional histories, or historical studies of scientific controversy, among other topics. A new body of interdisciplinary work on science and photography has arisen, for example, that continues to address enduring topics of interest among historians of science, such as instrumentation, art and artifact, evidence, objectivity, trust, material practice and circulation, and institutional practices. This view of photography (as messy and entangled in practices of institutions and governments) is also one that was increasingly shared by many historians of science after the 1990s (Pang 1994; Tucker 2005; Coopmans et al. 2014). Local studies of material exchange, exhibition and display, and the politics of seeing are now a primary focus in new studies of scientific photography. Studies have considered, among other topics: how photography was used to record movement that revolutionized our way of visualizing time and motion (Braun 1992); the impact of Fox Talbot's pioneering

work in myriad scientific fields (Brusius, Dean, and Ramalingam 2013; Klamm 2016); the significance of Alphonse Bertillon, Francis Galton, and Etienne-Jules Marey in problematizing photography's orientation to what the human eye sees (Ellenbrogen 2013). New work on Eadweard Muybridge, who photographed animals and nudes for scientific study, offers a new way of looking both at the linkages between photography and modernity in the context of the rise of university-based scientific patronage (Gordon 2015), while the role of photography in the naturalist Charles Darwin's work, meanwhile, has been explored in works that yield new insights into the history of the emotions (Browne 2009; Prodger 2009; White 2011). Such studies have informed and, in some cases, transformed how we traditionally think about the sciences as entangled with developments in the history of photography.

PHOTOGRAPHY AND THE SCIENTIFIC DISCIPLINES

Studies of scientific photography continue to have a strong focus on individual scientific disciplines, particularly in the fields of medicine, astronomy, geology, and anthropology. Stimulated perhaps by the rise of interest in environmental history, the study of photography in geology, meteorology, and natural history is a particularly fast-growing field for research, extending studies of photography from the laboratory to the field and incorporating insights from the discipline of art history, with its longstanding interest in landscape painting and photography (Thomas 1997; Keller 2008: 19–35).

Studies of astronomical photography have traditionally been—and remain—a leading site for work on scientific photography (Vaucouleurs 1961; Warner 1967; Schaffer 1988; Rothermel 1993; Pang 1994, 2002; Bigg 2008, 2011, 2015; Becker 2011; Kessler 2012; Vertesi 2015). These and other works have explored the making, use, and exhibition of photographs as historical records of the sky and celestial phenomena, challenging the idea that images were simply traces of nature in any simple or straightforward way. Their work offered new frameworks for understanding the ways that photographs were used in conjunction with drawings and other representational tools. As Pang suggested (2002: 92), "Victorian astronomers worked in a period in which printing technologies flourished, debates over the merits of drawings versus photography were rampant, and the standards by which originals and reproductions were judged were in flux." They and others also innovated in the way that they pursued the importance of situating scientific photography in print culture more generally. Good reproductions had to be realistic, detailed, and made in a fashion that was trustworthy (Schaffer 1992). Producing pictures for one's colleagues required deciding how field-produced drawings and photographs should be copied, negotiating access to originals with astronomers and expedition sponsors, and making the process subject to public testimonial and approval. Pictures, on this account, had to be "built up," and photographers (no less than other image-crafters) went into the field with ideas about constructing practices that would let them get around the constraints of their technology (Pang 2002: 92–120).

Medical photography has benefited from new archival findings and digital repositories making more medical photographs available for study than before (Fox and Lawrence 1988; Gilman 1988; Lalvani 1996; Kemp 1997; Naruyama and Ishida 2004). Histories of X-ray photography, for example, have long delved into issues of scientific controversy, evidence, practice, and professionalism (Knight 1986; Howell 1991). There has been a growing interest too, over the past couple of decades, in works that explore the nature and significance of so-called photography of the "invisible" or "subvisual" across different

disciplines, from physics to meteorology to spiritualism (Darius 1984; Gunning 1995; Tucker 2005; Barger 2015).

Studies of photography and science are not merely situated in the history of science, however; they have also made important potential contributions to examinations of art, evidence, documentary traditions, legal affairs, national and international institutions, business history, animal studies, studies of religion, gender and sexuality studies, and critical race studies, among others. Exciting new research directions in science and photography are being sketched out, for example, in works that focus on digital photography (Halpern 2015; Vertesi 2015) and environmental history (Mitman 1999; Dunaway 2015) among others. Photography has become a site for critical reflections on scientific "styles" (Pauwels 2005; Kelsey 2007; Coopmans et al. 2014; Bredekamp, Dunkel, and Schneider 2015; Mitchell 2015). Portraiture has been a fruitful site for exciting new work in the field of science and photography that sheds light on the question of scientific identity of practitioners (Jordanova 1993; Knight 1996; Browne 2009; White 2011). The critical study of photography's role in surveillance and information society is a subject of interest (Gross, Katz, and Ruby 1988; Weil and Snapper 1989; Finn 2001), as is the study of photographs as scientific evidence in the practice of law (Mnookin 1998; Feigenson and Spiesel 2011; Tucker 2016).

SCIENCES AND PHOTOGRAPHS IN EVERYDAY LIFE

To return to the opening reflections, one often thinks of science photography in the context of the lab, exploration, discovery, and so on. Yet scientific photographs were also deployed, circulated, and consumed (and disputed) in popular culture. Moving forward, therefore, future studies of the relationships between photography and the sciences must continue to forge new understandings of the relationships between photography and science beyond the laboratory, in the myriad settings beyond the field and the laboratory where scientific photographs were made to do work: for example, in forensics, advertising, teaching, and communication and investigation activities. By forging new understandings about the historical conditions and processes through which new forms of knowledge arise and are legitimatized in the first place, such approaches can lead to new ways of thinking about science and photography (Tucker 2012b, 2014; Heiferman 2016; Mitman and Wilder 2016).

Among the variety of rising topics that are currently being studied that may be included in this category are investigations of the use of lantern slides for scientific gatherings and instructional settings, as scientific education expanded and often stressed direct study of objects over "book knowledge" (Thomas 1997; Lightman 2000). Figure 12.3 is one example. Periodicals have been studied for knowledge of how photography of natural phenomena was deployed for mass readerships (Lutz and Collins 1993: 11; Ryan 1997, 2013; Belknap 2016). Studies of metaphors of science and medicine in photography highlight the cross-fertilization of language and technologies (Sheehan 2012), and studies of science as a business puts the analysis of capital and labor at the center (Tucker 2012a).

Relevant here, too, are studies that build upon, and extend, explorations of the "biographies of scientific objects," which question "how a heretofore unknown, ignored, or dispersed set of phenomena is transformed into a scientific object that can be observed and manipulated" (Daston 2000: 5). Historians of science and photography may also make new findings by investigating how and why photographs "travel" in the company

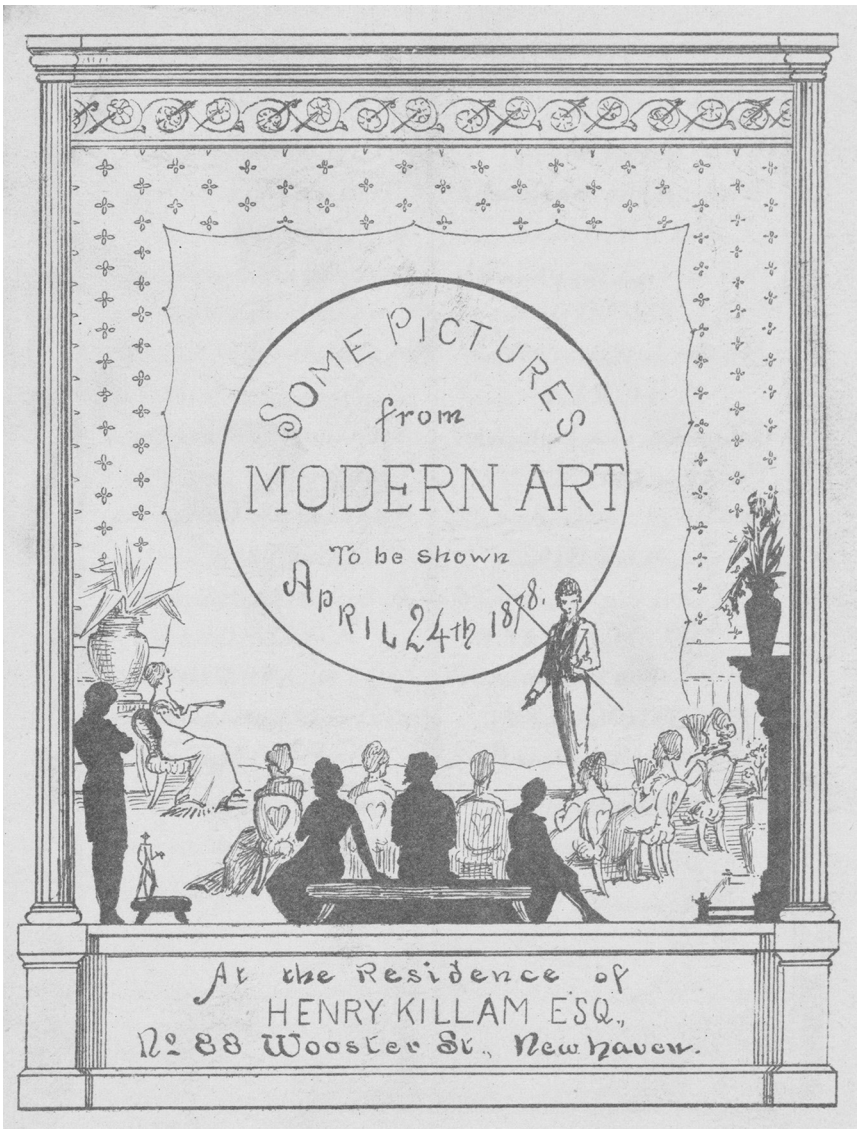

FIGURE 12.3: *Program for a tableaux or lantern-slides entertainment* (front cover), 1878, lithograph printed in brick red ink on wove paper. Davison Art Museum, Wesleyan University (CT).

of other images; for, by studying the way photographs circulate, we may learn about many new aspects of their "character and means of production" (Howlett and Morgan 2010: 28).

The photograph shown in Figure 12.4, for example, draws our attention to the myriad creative uses of scientific photography. The greatly reduced illustrations, made for an advertising pamphlet around 1935, show the use of photomicrographs in promoting national commercial products in the United States. Made by the American scientific photographer Philip O. Gravelle, who worked with national advertising campaigns during

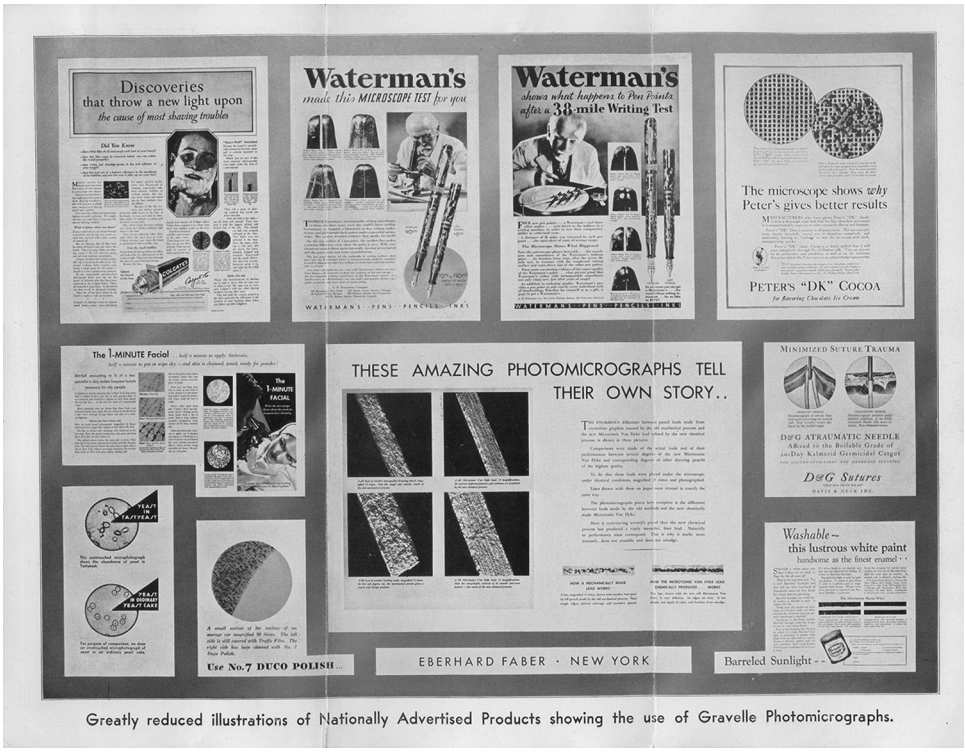

FIGURE 12.4: Photomicrographs by Gravelle in a printed promotional pamphlet showing nationally advertised products (Eberhard Faber), *c*. 1935. Staten Island Historical Society, New York.

the early decades of the twentieth century, they bring into focus the intricate links that connected microscopic optics, scientific realism, photography, amateur nature study, and the worlds of commercial advertising and manufacturing interests in the 1920s and 1930s. Gravelle was a popular scientific celebrity whose innovations with camera and microscope received wide coverage both by police departments and in the popular press. A pioneer in the use of magnification, dyes in negatives, and polarized light to make photographs of microscopic phenomena, he was also a prominent nature photographer and the first non-English scientist to win, in 1923, the prestigious Barnard medal from the London Photographic Society: the highest achievable honor in photomicrography at the time. Gravelle's photographs of microscopic phenomena, which graced hundreds of glossy corporate print advertisements during the late 1920s and 1930s, pioneered new modalities of photography in American advertising. They help us see how photographs may be construed as scientific, not merely by how they are deployed in scientific investigation, but also because of the specific ways in which they are circulated and consumed within popular culture (Tucker 2012b).

Generally speaking, photographic studies have a long way to go to address the persisting problem that historians too often make, of assuming, or taking for granted, that the boundaries of science in the past were clear to practitioners when, in fact, what has counted as properly scientific knowledge is continually negotiated and evolving

as new fields emerge and rival forms of knowledge are disputed. Photographs were not merely used *in* science; their employment helped demarcate, and sometimes confuse, the very meaning of "science" in a given place and historical period. In fact, the majority of leading histories of science today argue that the forms, demarcations, and contours of knowledge were shifting and continually contested and reformed. As photographic studies and historical studies of science travel together more, we can expect many more studies than heretofore about alternative and contested forms of scientific knowledge.

NEED FOR HISTORICAL CONSERVATION

Innovative methods and topics promise both to advance empirical research and to extend our understanding about the relations between science and photography. There is an especially strong and compelling need for more work on photography and the historical development of scientific cultures across the globe beyond the US and Europe.

Moving forward, however, one of the biggest challenges facing scholarship about science and photography will be collecting and conserving sources. Historical scientific photographs face a dual stigma when it comes to conservation: they are neither "fine art" (worthy of collection in art museums), yet neither are, in most cases, exemplary science (e.g., iconic forms). For instance, "the vestiges of the documentary impulse are still found everywhere: in storage freezers of scientific laboratories and natural history museums, in the attics and basements of private homes, in the archives of libraries and museums, and on websites, ranging from Archive.org to Youtube.com" (Mitman and Wilder 2016: 1–2). But even once they are preserved, the vast majority of scientific photographs—to the extent that they survive at all—are often organized in ways that make them hidden to the researcher, for photographs made for scientific purposes often are unattributed or attributed in ways whose context has been lost. Individual photographers in the sciences did not establish their authorship of the images in some of the conventional ways that are familiar to fine art photographs that had a commercial market. There is a tendency to view individual scientific images or their collections as exemplifying "old" (and, therefore, irrelevant) science—and not worth preserving.

Museums continue to be an important site for collection, preservation, and circulation and public interpretation of materials—and much important critical work on photography and scientific archives emerges from this site (Thomas 1997; Keller 2008; Morton and Edwards 2012). These have looked at a variety of uses of photography in science, "from the official announcements of the medium's invention in 1839 to its maturation as an industrialized process by the end of the nineteenth century" and considered "what it meant to 'see' photographically" (Keller 2008: 20). Keller (2008: 20) urged that, "It is crucial to point out that neither science nor photography can be considered a fixed or monolithic category during this formative period. In order to fully understand these pictures and the issues that surrounded them, we must not only attempt to recover the vast conceptual distance between ourselves and the nineteenth century, but also acknowledge the important changes that occurred between the early 1800s and its later decades."

Historical research on scientific photography also could benefit greatly from greater collaboration among archivists and academic scholars. More collaboration and partnership among scholars and curators are necessary to ensure that photographic collecting does not occur in the field of fine arts, alone (or primarily). Historical research on scientific photography may also benefit from the development of studies that focus not so much on individuals or particular photographs, but on the use of photography and photographs

by institutional cultures such as the Royal Society, the American Association for the Advancement of Science, and the like.

CONCLUSIONS

Over one hundred and fifty years after its invention, the practices of science and photography still afford an excellent vantage point from which to consider more generally the historical uses of photography. From a comparatively small field of study focused on a small handful of inventors and applications in the laboratory and field, the study of the changing historical relations between science and photography has grown into a rich body of work about the forms that scientific images take, what they reveal, how they transform the disciplines they serve, and the lives they influence. Extensive new research has also been done on the epistemological underpinnings of photographic practices in science; how scientists as cultural figures are represented in the news, within the sciences and the arts, and in commercial imagery, for example (Thomas 1997; Keller 2008: 19–35; Browne 2009). Given that most common ways for photographs to circulate among scientists, however, was through correspondence and lectures (and, over time, in specialized research journals), studies of local knowledge production turned to actual material practices, including photography. Furthermore, while the analysis of scientific photographs is often set apart from other subjects in photographic studies, the wide range of subject-specific scholarly debates that surround virtually all such (visual) conventions and practices is also relevant to its study.

REFERENCES

Arnold, H. J. P. (1977), *William Henry Fox Talbot, Pioneer of Photography and Man of Science*, London: Hutchinson Benham.

Barger, J. A. B. (2015), *Beyond the Dark Veil: Post Mortem and Mourning Photography from the Thanatos Archive*, San Francisco, CA: Last Gasp.

Barger, S. M., and W. B. White (2000), *The Daguerreotype: Nineteenth-Century Technology and Modern Science*, Baltimore, MD: Johns Hopkins University.

Becker, B. J. (2011), *Unravelling Starlight: William and Margaret Huggins and the Rise of the New Astronomy*, Cambridge: Cambridge University Press.

Beer, G. (1996), *Open Fields: Science in Cultural Encounter*, Oxford: Oxford University Press.

Belknap, G. (2014), "Through the Looking Glass: Photography, Science and Imperial Motivations in John Thomson's Photographic Expeditions," *History of Science*, 52 (1): 73–97.

Belknap, G. (2016), *From a Photograph: Authenticity, Science and the Periodical Press, 1870–1890*, London: Bloomsbury Academic Press.

Belknap, G., and S. Defrance (2015), "Photographs as Scientific and Social Objects in the Correspondence of Charles Darwin," in E. Edwards and C. Morton (eds), *Photographs, Museums, Collections: Between Art and Information*, 139–56, London: Bloomsbury Academic Press.

Belloc, J. A., "The Future of Photographic News," *Photographic News* (September 17, 1858): 13.

Benjamin, W. ([1936] 1968), "The Work of Art in the Age of Mechanical Reproduction," in Hannah Arendt (ed.), *Illuminations*, 214–18, London: Fontana.

Bigg, C. (2008), "La Carte du Ciel vue de Potsdam," in J. Lamy (ed.), *La Carte du Ciel, Histoire et actualité d'un Projet scientifique international*, 129–53, Paris: EDP Sciences/Observatoire de Paris.

Bigg, C. (2011), "A Visual History of Jean Perrin's Brownian Motion Curves," in L. Daston and E. Lunbeck (eds.), *Histories of Scientific Observation*, 156–79, Chicago, IL: Chicago University Press.

Bigg, C. (2015), "Sciences du portrait céleste," in B. Le Maitre and B. N. Aboudrar (eds.), *Tout ce que le ciel permet, en cinéma, peinture, photograhie et vidéo*, 119–26, Paris: Presses de la Sorbonne Nouvelle.

Braun, M. (1992), *Picturing Time: The Work of Etienne-Jules Marey, 1830–1904*, Chicago, IL: University of Chicago Press.

Bredekamp, H., V. Dunkel, and B. Schneider, eds. (2015), *The Technical Image: A History of Styles in Scientific Imagery*, Chicago, IL: University of Chicago Press.

Browne, J. (2009), "Looking at Darwin: Portraits and the Making of an Icon," *Isis*, 100 (3): 542–70.

Brusius, M., K. Dean, and C. Ramalingam, eds. (2013), *William Henry Fox Talbot: Beyond Photography*, New Haven, CT: Yale University Press.

Cartwright, L. (1992), "Experiments of Destruction," *Representations*, 40: 129–52.

Cartwright, L. (1995), *Screening the Body: Tracing Medicine's Visual Culture*, Minneapolis, MN: University of Minnesota Press.

Cartwright, N. (1983), *How the Laws of Physics Lie*, Oxford: Oxford University Press.

Coombes, A. E., and S. Edwards (1989), "Site Unseen: Photography in the Colonial Empire: Images of a Subsconscious Eroticism," *Art History* 12 (4): 510–16.

Coopmans, C., J. Vertesi, M. Lynch, and S. Woolgar, eds. (2014), *Representation in Scientific Practice Revisited*, Cambridge, MA: MIT Press.

Crary, J. (1992), *Techniques of the Observer: On Vision and Modernity in the Nineteenth Century*, Cambridge, MA: MIT Press.

Darius, J. (1984), *Beyond Vision: One Hundred Historic Scientific Photographs*, Oxford: Oxford University Press.

Daston, L. J. (2000), *Biographies of Scientific Objects*, Chicago, IL: University of Chicago Press.

Daston, L. J., and P. Galison (1992), "The Image of Objectivity" Special Issue, *Representations: Seeing Science*, 40, 81–128.

Daston, L. J., and P. Galison (2007), *Objectivity*, Cambridge, MA: MIT Press.

Dunaway, F. (2015), *Seeing Green: The Use and Abuse of American Environmental Images*, Chicago, IL: University of Chicago Press.

Edwards, E., ed. (1994), *Anthropology and Photography, 1860–1920*, New Haven, CT: Yale University Press.

Edwards, E. (2001), *Raw Histories: Photographs, Anthropology and Museums*, London: Bloomsbury Academic Press.

Edwards, E. (2014), "Photographic Uncertainties: Between Evidence and Reassurance," *History and Anthropology*, 25 (2): 171–88.

Elkins, J. (December 1995), "Art History and Images that are not Art," *Art Bulletin*, 77: 553–71.

Elkins, J. (2008), *Six Stories from the End of Representation: Images in Painting, Photography, Astronomy, Microscopy, Particle Physics, and Quantum Mechanics, 1980–2000*, Stanford, CA: Stanford University Press.

Ellenbrogen, J. (2013), *Reasoned and Unreasoned Images: The Photography of Bertillon, Galton and Marey*, London: Eurospan.

Feigenson, N., and C. Spiesel (2011), *Law on Display: The Digital Transformation of Legal Persuasion and Judgment*, New York: New York University Press.
Finn, J. (2001), *Capturing the Criminal Image: From Mug Shot to Surveillance Society*, Minneapolis, MD: University of Minnesota Press.
Foucault, M. (1975), *Discipline or Punish: The Birth of the Prison*, New York: Random House.
Foucault, M. (1980), *Power/Knowledge*, ed. C. Gordon, London: The Harvester Press.
Foucault, M. ([1966] 1994), *The Order of Things: An Archaeology of the Human Sciences*, London: Routledge.
Fox, D. M., and C. Lawrence (1988), *Photographing Medicine: Images and Power in Britain and America since 1840*, New York: Greenwood Press.
Geimer, P. (2002), *Ordnungen der Sichtbarkeit. Fotografie in Wissenschaft, Technologie und Kunst*, Frankfurt am Main: Suhrkamp.
Gilman, S. L. (1988), *Disease and Representation: Images of Illness from Madness to AIDS*, Ithaca, NY: Cornell University Press.
Gordon, S. (2015), *Indecent Exposures: Eadweard Muybridge's Animal Locomotion*, New Haven, CT: Yale University Press.
Gross, L., J. S. Katz, and J. Ruby, eds. (1988), *Image Ethics: The Moral Rights of Subjects in Photographs, Film, and Television*, Oxford: Oxford University Press.
Gunning, T. (1995), "Phantom Images and Modern Manifestations: Spirit Photography, Magic Theater, Trick Films, and Photography's Uncanny," in P. Petro (ed.), *Fugitive Images: From Photography to Video*, 42–71, Bloomington, IN: Indiana University Press.
Hacking, I. (1983), *Representing and Intervening: Introductory Topics in the Philosophy of Natural Science*, Cambridge: Cambridge University Press.
Hacking, I. (1986), "Making up People," in T. C. Heller, M. Sosna, and D. E. Wellberry (eds.) *Reconstructing Individualism: Autonomy, Individuality, and the Self in Western Thought*, Stanford, CA: Stanford University Press, 222–36.
Hall, Amy Cox (2017), *Framing a Lost City: Science, Photography, and the Making of Machu Picchu*, Austin, TX: University of Texas Press.
Halpern, O. (2015), *Beautiful Data: A History of Vision and Reason since 1945*, Durham, NC: Duke University Press.
Hamilton, P., and R. Hargreaves (2001), *The Beautiful and the Damned: The Creation of Identity in Nineteenth Century Photography*, Aldershot: Lund Humphries.
Hannavy, J., ed. (2007), *Encyclopedia of Nineteenth-Century Photography*, London: Routledge.
Haraway, D. (1988), "Situated Knowledges: The Science Question in Feminism and the Privilege of Partial Perspective," *Feminist Studies*, 14 (3): 575–600.
Haraway, D. (1990), *Primate Visions: Gender, Race, and Nature in the World of Modern Science*, London: Routledge.
Heiferman, M. (2016), "Seeing Science." http://seeingscience.umbc.edu
Helmreich, A. (2016), *Nature's Truth: Photography, Painting, and Science*, University Park, PA: Pennsylvania State University Press.
Howell, J. (1991), "Diagnostic Technologies: X Rays, Electrocardiograms, and CAT Scans," *Southern California Law Review*, 65: 529–64.
Howlett, P., and M. Morgan, eds. (2010), *How Well Do Facts Travel? The Dissemination of Reliable Knowledge*, Cambridge: Cambridge University Press.
Jenkins, R. (1987), *Images and Enterprises: Technology and the American Photographic Industry, 1839–1925*, Baltimore, MD: Johns Hopkins University Press.
Jones, C. A., and P. Galison, eds. (1998), *Picturing Science, Producing Art*, New York: Routledge.

Jordanova, L. (1993), *Sexual Visions: Images of Gender in Science and Medicine between the Eighteenth and Twentieth Centuries*, Madison, WI: University of Wisconsin Press.
Keller, C., ed. (2008), *Brought to Light: Photography and the Invisible, 1840–1900*, New Haven, CT: San Francisco Museum of Modern Art with the Yale University Press.
Kelsey, R. (2007), *Archive Style: Photographs and Illustrations for U.S. Surveys, 1850–1890*, Berkeley, CA: University of California Press.
Kemp, M. (1997), "'A Perfect and Faithful Record': Mind and Body in Medical Photography before 1900," in A. Thomas (ed.), *Beauty of Another Order: Photography in Science*, 120–49, New Haven, CT: Yale University Press.
Kessler, E. (2012), *Picturing the Cosmos: Hubble Space Telescope Images and the Astronomical Sublime*, Minneapolis, MN: University of Minnesota Press.
Klamm, S. (2016), "Reverse—Cardboard—Print: The Materiality of the Photographic Archive and Its Function," in G. Mitman and K. Wilder (eds), *Documenting the World*, 166–99, Chicago, IL: University of Chicago Press.
Knight, D. (1996), "Illustrating Chemistry," in B. S. Baigrie (ed.), *Picturing Knowledge: Historical and Philosophical Problems Concerning the Use of Art in Science*, 148–53, Toronto: University of Toronto Press.
Knight, N. (1986), "The New Light: X Rays and Medical Futurism," in J. Corn (ed.) *Imagining Tomorrow: History, Technology, and the American Future*, 10–34, Cambridge, MA: MIT Press.
Kuhn, T. (1962), *Structure of Scientific Revolution*, Chicago, IL: University of Chicago Press.
Lalvani, S. (1996), *Photography, Vision, and the Production of Modern Bodies*, Albany, NY: State University of New York.
Latour, B. (1987), *Science in Action: How to Follow Scientists and Engineers Through Society*, Cambridge, MA: Harvard University Press.
Latour, B. (1988), *Science in Action: How to Follow Scientists and Engineers Through Society*, Cambridge, MA: Harvard University Press.
Latour, B. (1990), "Drawing Things Together," in M. Lynch and S. Woolgar (eds), *Representation in Scientific Practice*, 19–60, Cambridge, MA: MIT Press.
Lawrence, A. S. C. (1941), *The Scientific Photographer*, Cambridge: Cambridge University Press.
Lightman, B. (2000), "The Visual Theology of Victorian Popularizers of Science: From Reverent Eye to Chemical Retina," *Isis*, 91: 651–681.
Lutz, C., and J. Collins (1993), *Reading National Geographic*, Chicago, IL: University of Chicago.
Lynch, M. (1985), "Discipline and the Material Form of Images: An Analysis of Scientific Visibility," *Social Studies of Science*, 15 (1): 37–66.
Lynch, M. (2005), "The Production of Scientific Images: Vision and Re-Vision in the History, Philosophy, and Sociology of Science," in L. Pauwel (ed.) *Visual Cultures of Science: Rethinking Representational Practices in Knowledge Building and Science Communication*, 26–40, Hanover, NH: Dartmouth University Press.
Mitchell, W. J. T. (2015), *Image Science: Iconology, Visual Culture, and Media Aesthetics*, Chicago, IL: University of Chicago Press.
Mitman, G. (1999), *Reel Nature*, Cambridge, MA: Harvard University Press.
Mitman, G., and K. Wilder, eds (2016), *Documenting the World: Film, Photography, and the Scientific Record*, Chicago, IL: University of Chicago Press.
Mnookin, J. (1998), "The Image of Truth: Photographic Evidence and the Power of Analogy," *Yale Journal of Law and the Humanities*, 10: 1–74.
Morton, C., and E. Edwards, eds (2012), *Photography, Anthropology, and History*, New York: Routledge.

Naruyama, A., and S. Ishida, eds. (2004), *The Dr. Ikkaku Ochi Collection: Medical Photographs from Japan around 1900*, Zurich: Scalo.
Pang, A. S.-K. (1994), "Victorian Observing Practices, Printing Technology, and the Representation of the Solar Corona (II): The Age of Photomechanical Reproduction," *Journal for the History of Astronomy*, 26: 249–74.
Pang, A. S.-K. (2002), *Empire and the Sun: Victorian Solar Eclipse Expeditions*, Stanford, CA: Stanford University Press.
Pauwels, L. ed. (2005), *Visual Cultures of Science: Rethinking Representational Practices in Knowledge Building and Science Communication*, Lebanon, NH: Dartmouth College Press.
Peterson, N., and C. Pinney, eds. (2003), *Photography's Other Histories*, Durham, NC: Duke University Press.
Pichel, B. (2016), "From Facial Expressions to Bodily Gestures: Passions, Photography and Movement in French Nineteenth-century Sciences," *History of the Human Sciences*, 29 (1): 27–48.
Pinney, C. (1997), *Camera Indica: The Social Life of Indian Photographs*, Chicago, IL: Chicago University Press.
Pinson, S. (2012), *Speculating Daguerre: Art and Enterprise in the Work of L. J.M. Daguerre*, Chicago, IL: University of Chicago Press.
Poole, D. (1997), *Vision, Race and Modernity: A Visual Economy of the Andean Image World*, Princeton, NJ: Princeton University Press.
Porter, T. (2008), "The Objective Self," *Victorian Studies*, 50 (4): 641–48.
Pratt, M. L. (1992), *Imperial Eyes: Travel Writing and Transculturation*, London: Routledge.
Prodger, P. (2009), *Darwin's Camera: Art and Photography in the Theory of Evolution*, New York: Oxford University Press.
Rony, F. Tobing (1996), *The Third Eye: Race, Cinema, and Ethnographic Spectacle*, Durham, NC: Duke University Press.
Rose, G. (2012), "The Question of Method: Practice, Reflexivity and Critique in Visual Culture Studies," in I. Heywood and B. Sandywell (eds.) *The Visual Culture Handbook*, 542–58, Oxford: Berg.
Rose, G. (2016), *Visual Methodologies*, London: Sage.
Rothermel, H. (1993), "Images of the Sun: Warren de la Rue, George Biddel Airy and Celestial Photography," *British Journal for the History of Science*, 26 (2): 137–69.
Rudwick, M. (1976), "The Emergence of a Visual Language for Geological Science 1760–1840," *History of Science*, 14: 149–95.
Ryan, J. (1997), *Picturing Empire: Photography and the Visualisation of the British Empire*, Chicago, IL: University of Chicago Press.
Ryan, J. (2013), *Photography and Exploration*, London: Reaktion.
Schaaf, L. (1996), *Records of the Dawn of Photography: Talbot's Notebooks*, Cambridge: Cambridge University Press.
Schaffer, S. (1988), "Astronomers Mark Time: Discipline and the Personal Equation," *Science in Context*, 2: 115–45.
Schaffer, S. (1992), "Late Victorian Metrology and Its Instrumentation: A Manufactory of Ohms," in R. Bud and S. E. Cozzans (eds.), *Invisible Connections: Instruments, Institutions, and Science*, 23–56, Bellingham: SPIE Press.
Schaffer, Simon (1998), "The Leviathan of Parsonstown: Literary Technology and Scientific Representation," in Timothy Lenoir (ed.), *Inscribing Science: Scientific Texts and the Materiality of Communication*, 182-222. Stanford: Stanford University Press.
Shapin, S., and S. Schaffer (1985), *Leviathan and the Air Pump: Hobbes, Boyle, and the Experimental Life*, Princeton, NJ: Princeton University Press.

Sheehan, T. (2012), *Doctored: The Medicine of Photography in Nineteenth-Century America*, College Park, PA: Pennsylvania State University Press.
Smith, S. M. (1999), *American Archives: Gender, Race and Class in Visual Culture*, Princeton, NJ: Princeton University Press.
Smith, S. M. (2004), *Photography on the Color Line: W.E. B. Du Bois, Race, and Visual Culture*, Durham, NC: Duke University Press.
Snyder, J., and N. W. Allen (1975), "Photography, Vision and Representation," *Critical Inquiry*, 2/1 (1975): 143–69.
Starr, S. L., and J. R. Griesemer (1989), "Institutional Ecology, 'Translations,' and Boundary Objects: Amateurs and Professionals in Berkeley's Museum of Vertebrate Zoology, 1907–1939," *Social Studies of Science*, 19 (3): 387–420.
Tagg, J. (1988), *The Burden of Representation: Essays on Photographies and Histories*, Minnesota, MN: University of Minnesota Press.
Thomas, A., ed. (1997), *Beauty of Another Order: Photography in Science*, New Haven, CN: Yale University Press.
Thompson, T. J. (2012), *Light on Darkness? Missionary Photography of Africa in the Nineteenth and Early Twentieth Centuries*, Cambridge: Eerdman.
Tresch, J. (2007), "The Daguerreotype's First Frame: François Arago's Moral Economy of Instruments," *Studies in History and Philosophy of Science*, 38: 445–76.
Tucker, J. (2005), *Nature Exposed: Photography as Eye Witness in Victorian Science*, Baltimore, MD: Johns Hopkins University Press.
Tucker, J. (2006), "Gender and Genre in Scientific Photography," in A. Shteir and B. Lightman (eds.), *Figuring It Out: Visual Languages of Gender in Science*, 140–63, Lebanon, NH: University of New England Press.
Tucker, J. (2008), "Objectivity, Collective Sight, and Scientific Personae," *Victorian Studies*, 50 (4): 648–57.
Tucker, J. (2012a), "The Hidden World of Science: Nature as Art in 1930s American Print Advertising," *Spontaneous Generations*, 6/1: 90–105.
Tucker, J. (2012b), "'Let the Microscope Tell Your Story': Philip Gravelle and the Neglected Industrial and Advertising Contexts of Ultra-Microphotography, 1920–1940," *PhotoResearcher*, 17: 19–32.
Tucker, J. (2014), "Science Institutions in Modern British Visual Culture: The British Association for the Advancement of Science, 1831–1940," *Historia Scientiarum: International Journal of the History of Science Society of Japan*, 23 (3): 191–213.
Tucker, J. (2016), "Moving Pictures: Photographs on Trial in the Sir Roger Tichborne Affair," in G. Mitman and K. Wilder (eds.), *Documenting the World: Film, Photography and the Scientific Record*, 23–44, Chicago, IL: University of Chicago Press.
Vaucouleurs, G. de (1961), *Astronomical Photography: From the Daguerreotype to the Electron Camera*, London: Faber and Faber.
Vertesi, J. (2015), *Seeing Like a Rover: How Robots, Teams, and Images Craft Knowledge of Mars*, Chicago, IL: University of Chicago Press.
Warner, D. J. (1967), "The American Photographical Society and the Early History of Astronomical Photography in America," *Photographic Science and Engineering*, 11: 342–7.
Weil, V., and J. W. Snapper (1989), *Owning Science and Technical Information*, New Brunswick, NJ: Rutgers University Press.
White, P. (2011), "'Darwin Wept'; Science and the Sentimental Subject," *Journal of Victorian Culture*, 16 (2): 195–213.
Wilder, K. (2009), *Photography and Science*, London: Reaktion.