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KLAUS HENTSCHEL

Visual Cultures in Science and Technology

A Comparative History

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Great Clarendon Street, Oxford, OX2 6DP,
United Kingdom

Oxford University Press is a department of the University of Oxford.
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First Edition published in 2014
Impression: 1

Published in the United States of America by Oxford University Press
198 Madison Avenue, New York, NY 10016, United States of America

British Library Cataloguing in Publication Data
Data available

Library of Congress Control Number: 2014938233

ISBN 978–0–19–871787–4

Printed and bound by
CPI Group (UK) Ltd, Croydon, CR0 4YY

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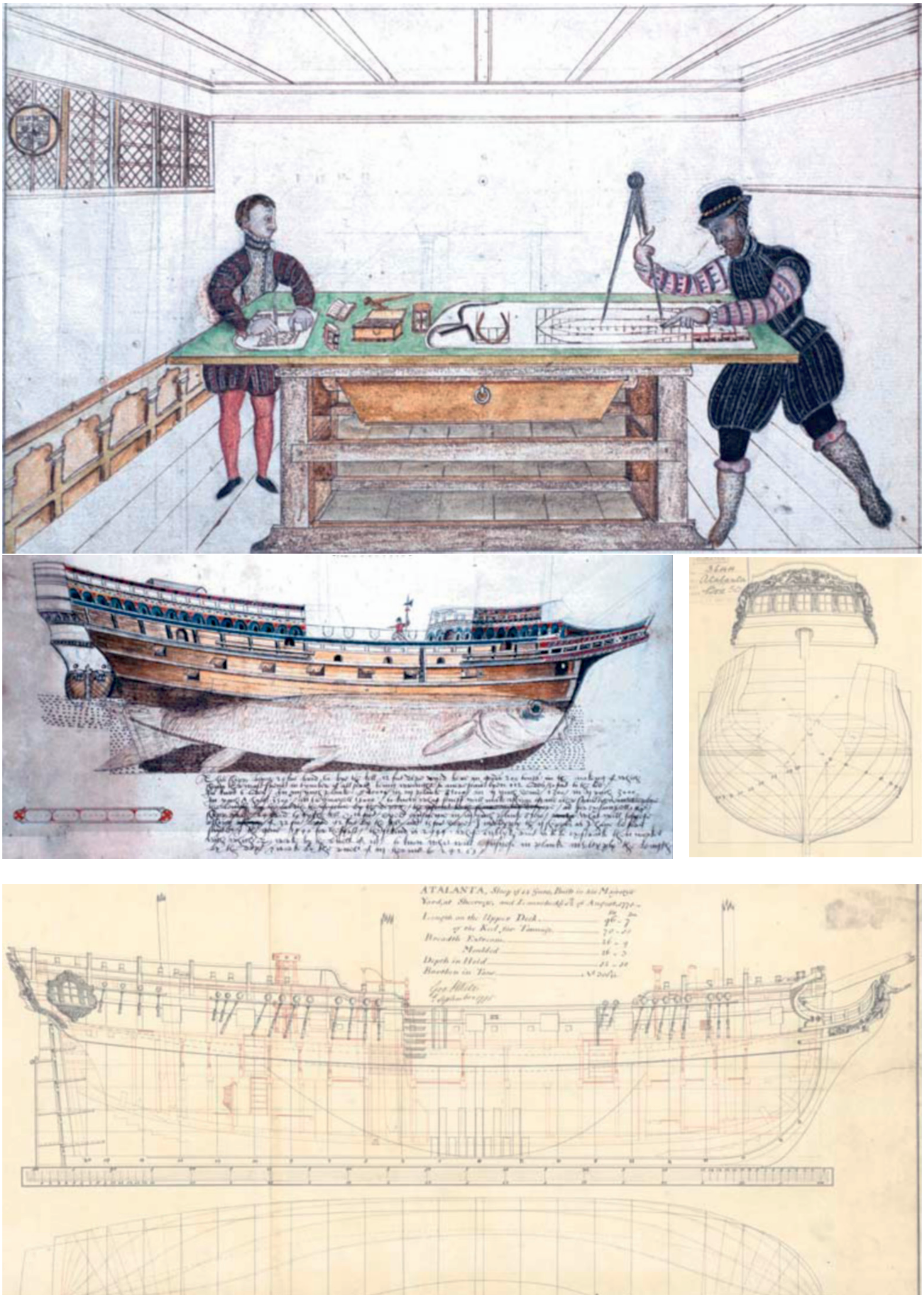

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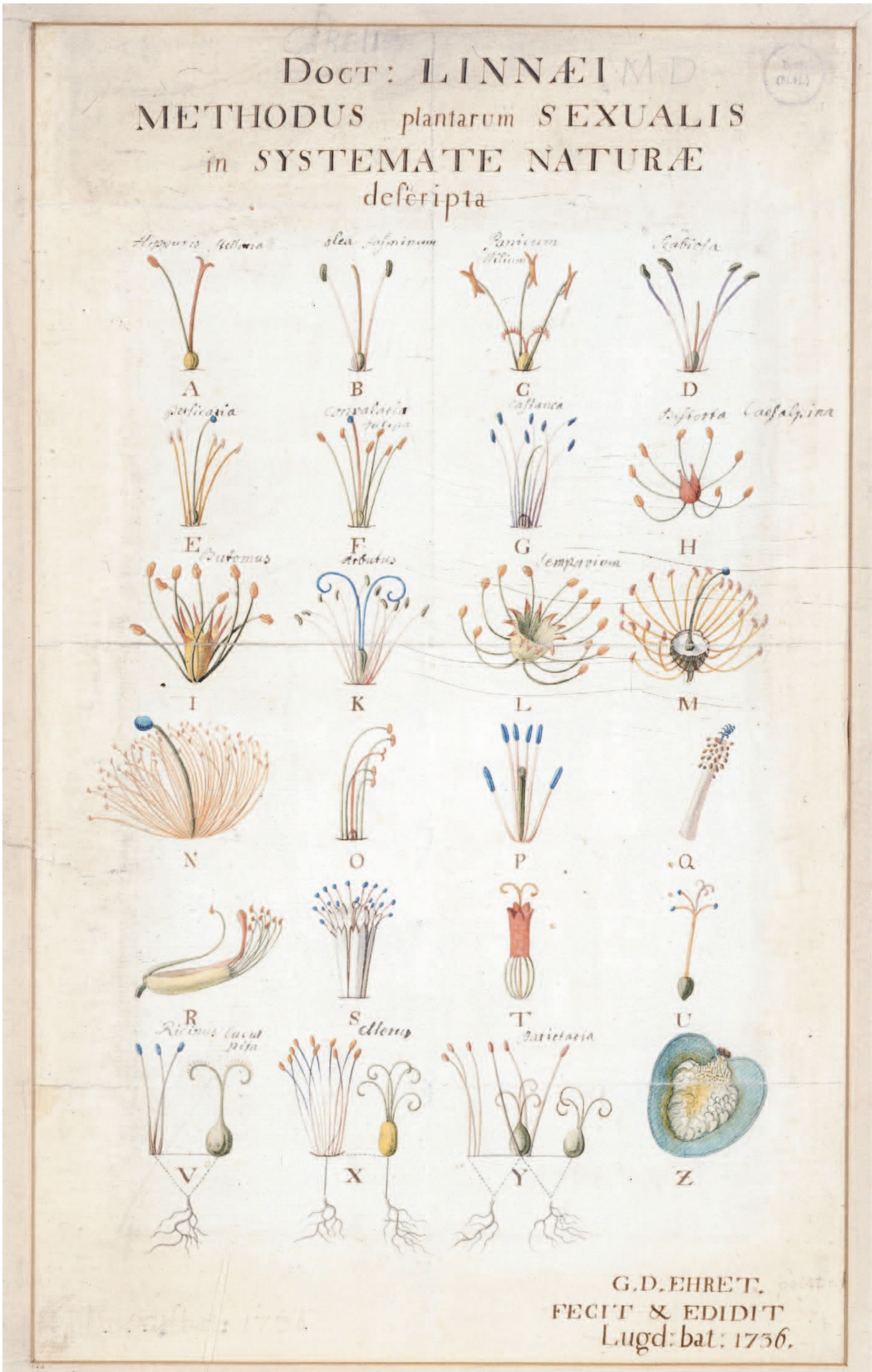

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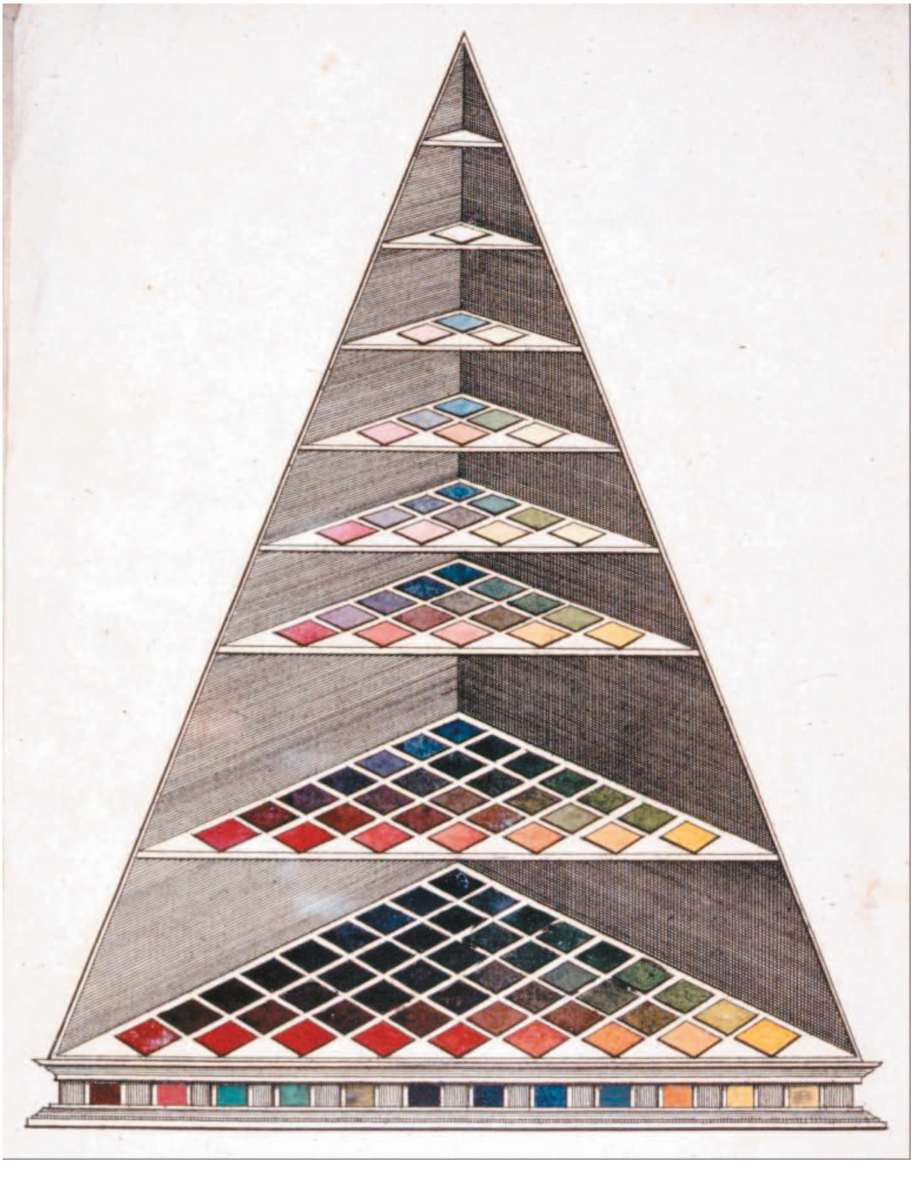

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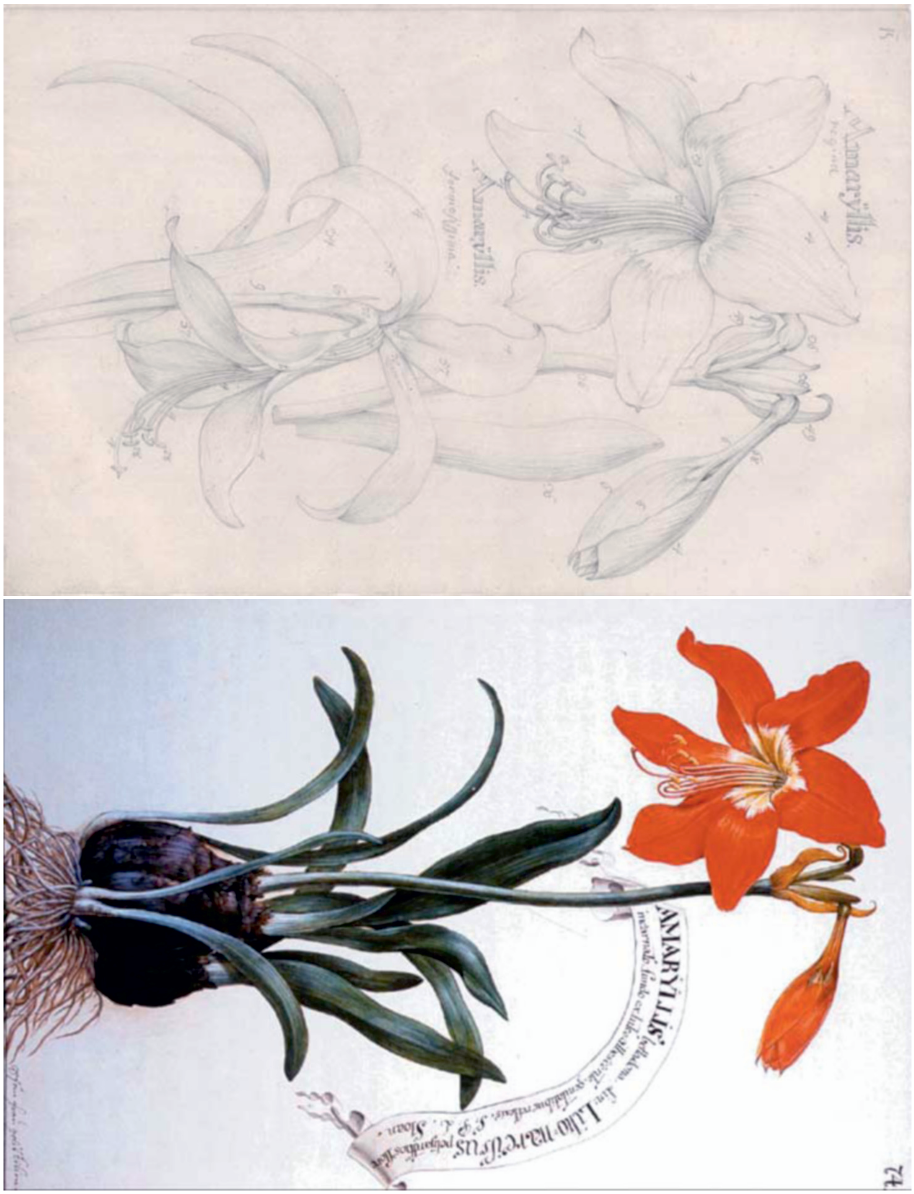

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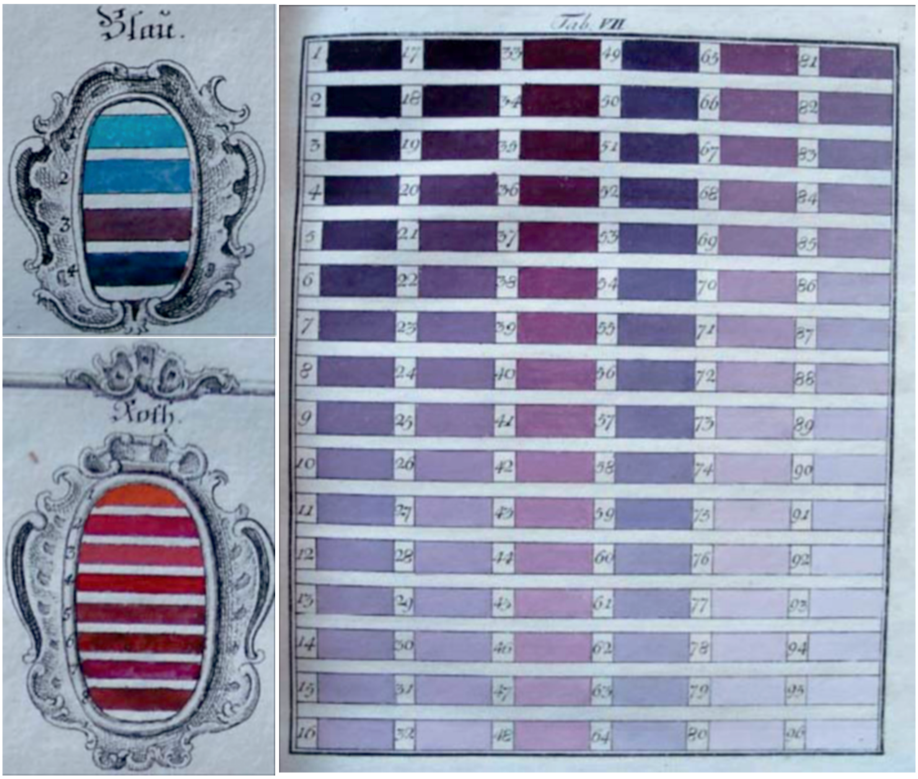

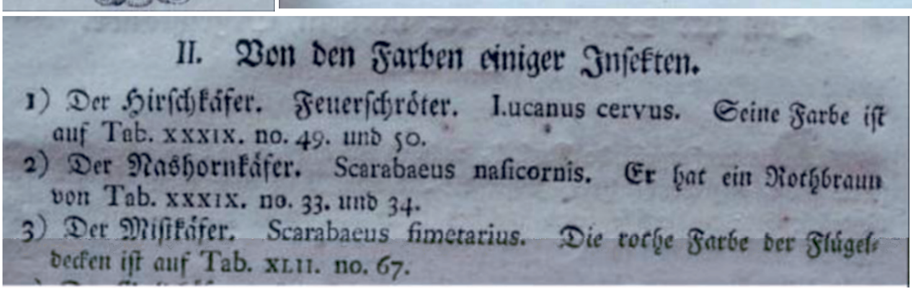
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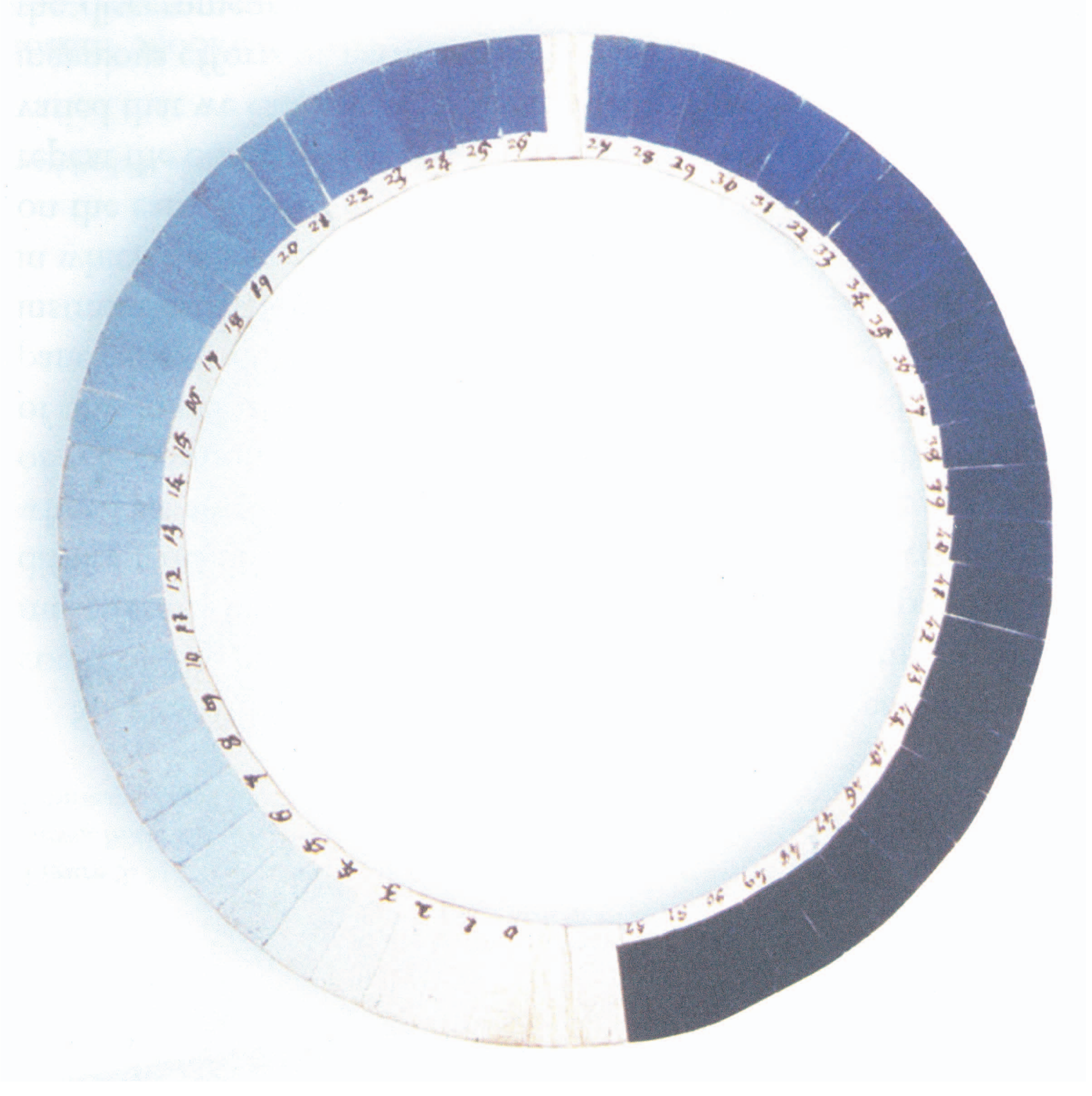

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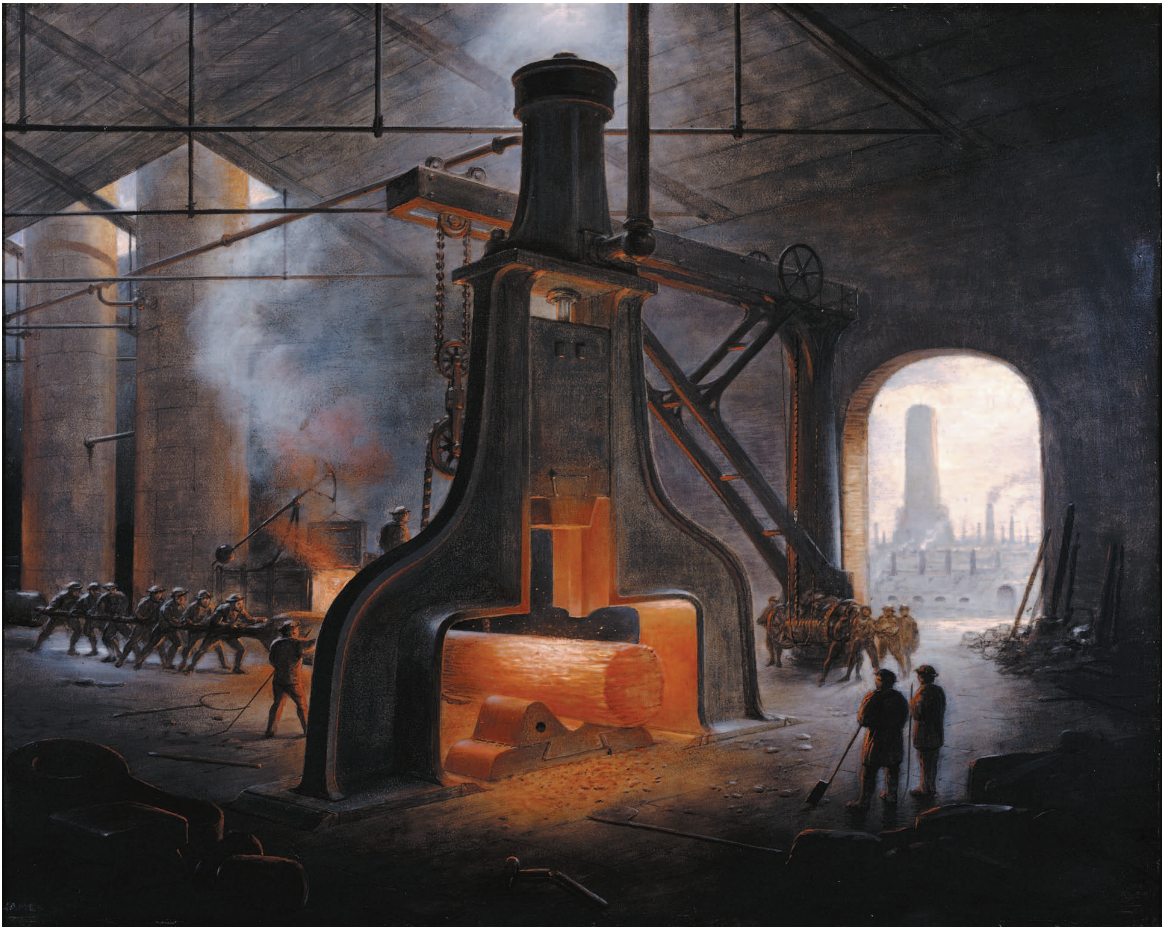

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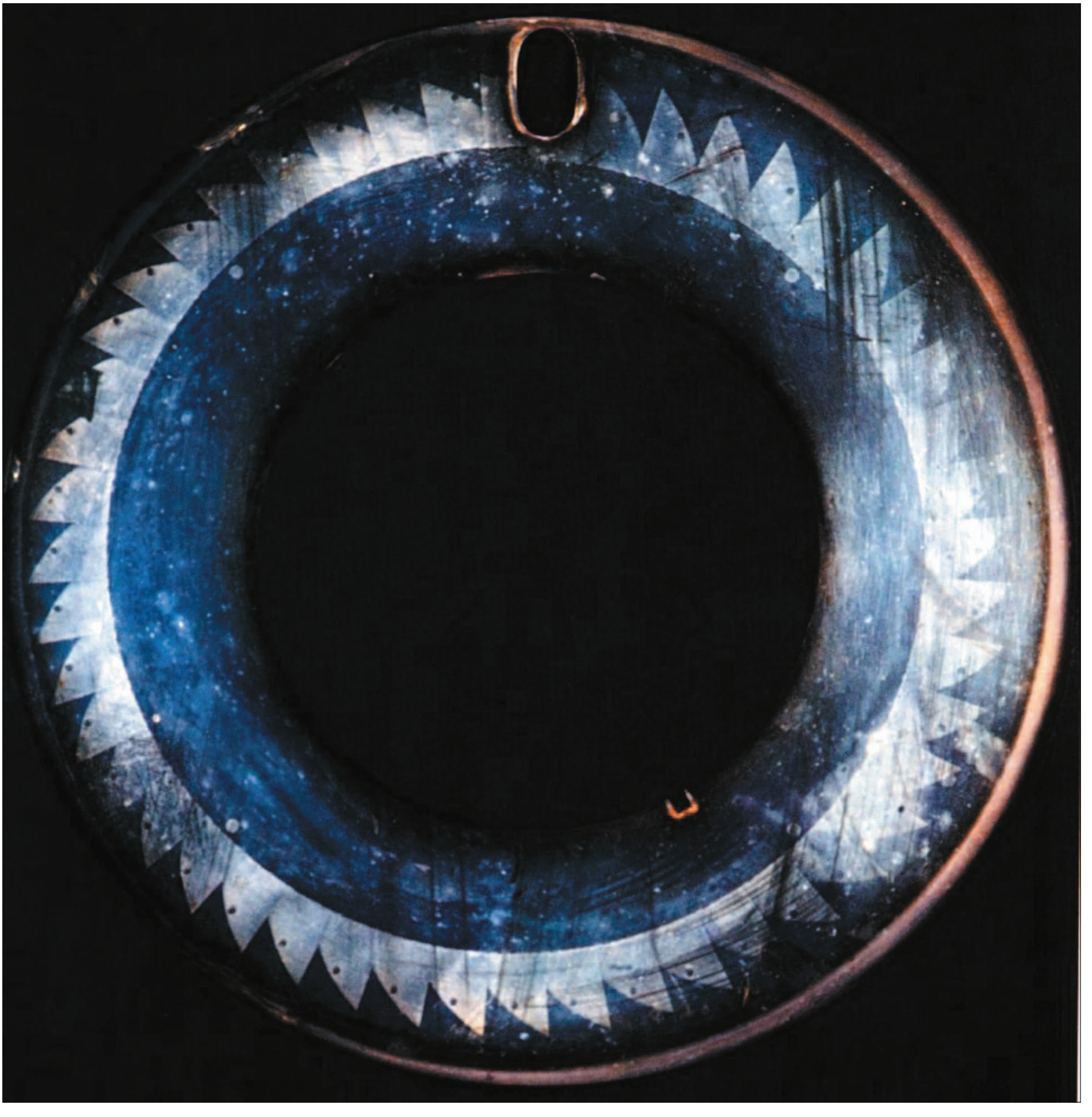

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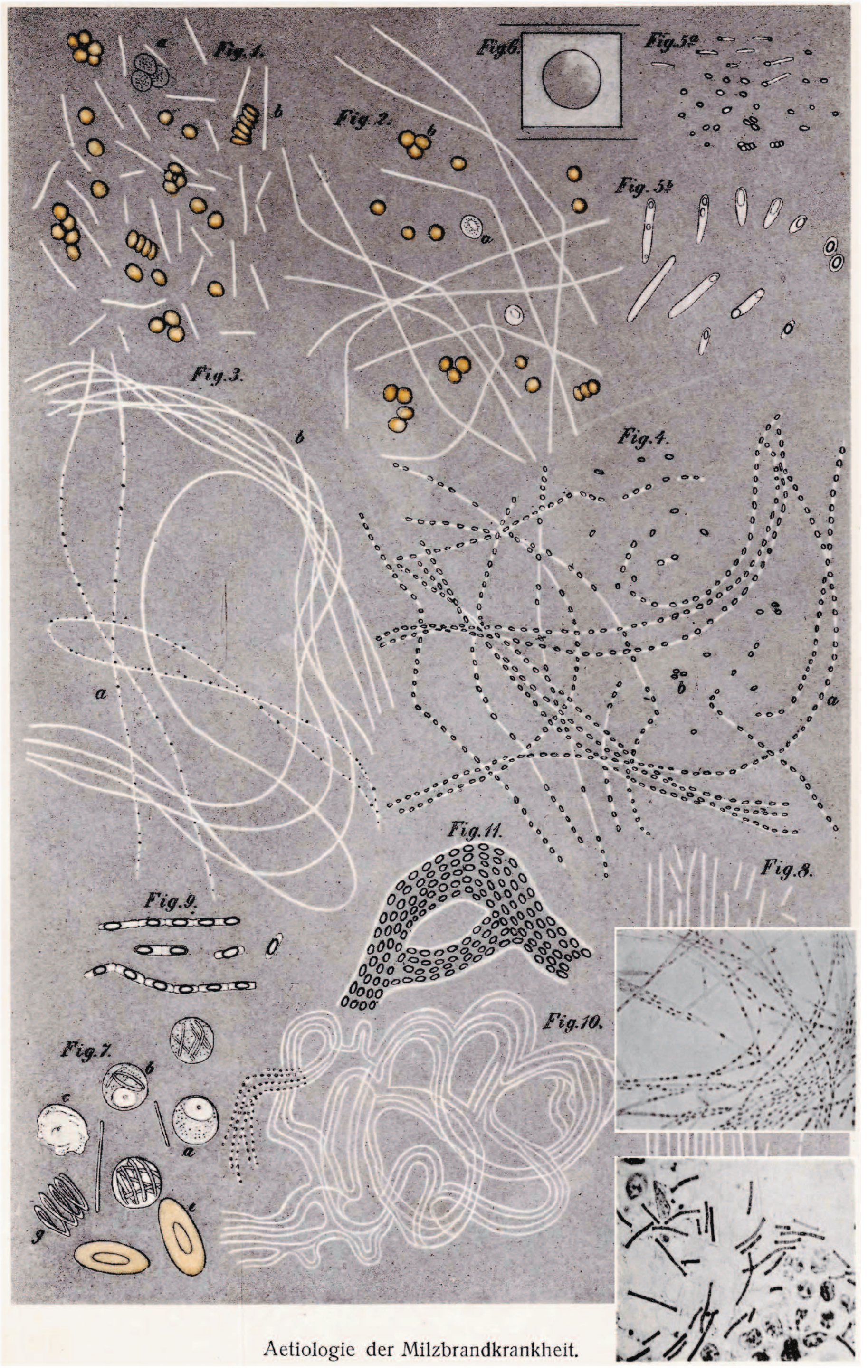

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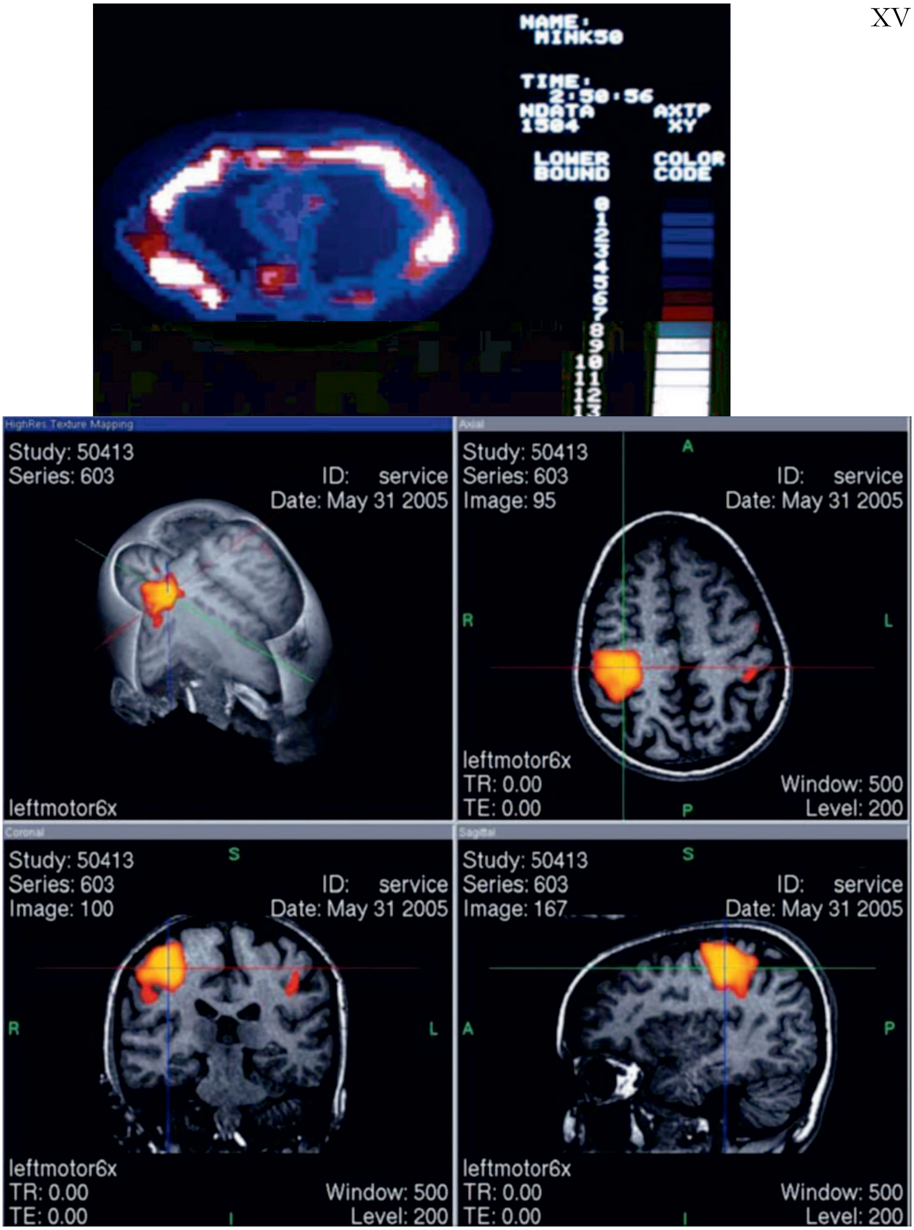

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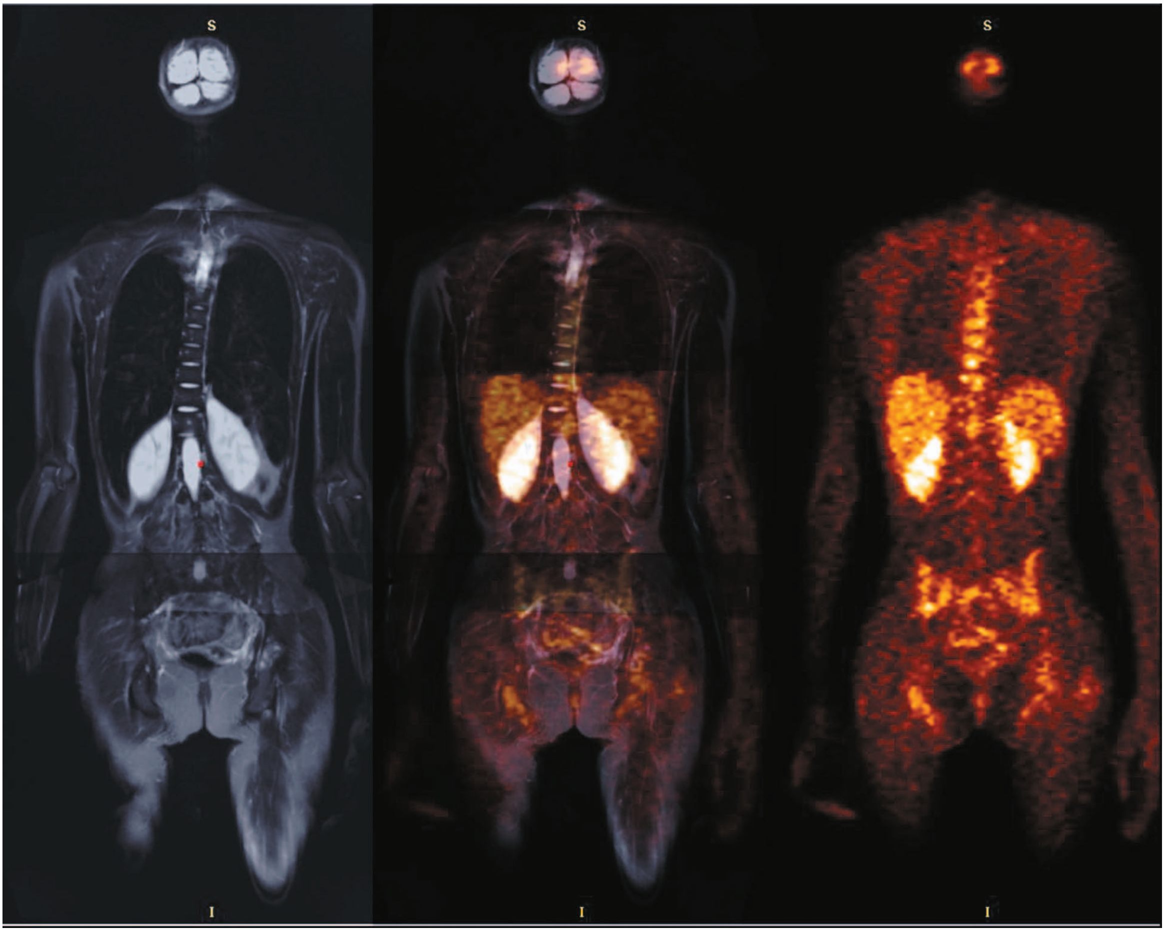

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Preface and acknowledgments

This book attempts a synthesis. I decided to make this study differ from most of my other books in the history of science. Rather than working on primary material in dusty archives, I delve deeply into the rich reservoir of case studies that have been amassed over the past couple of decades by historians, sociologists and philosophers of science on visual representations in scientific and technological practice. This book's goals are thus located on a meta-level. First and foremost, I aim at an integrative view on recurrently noted general features of visual cultures in science and technology, something that has hitherto been unachieved and has been believed by many to be a mission impossible. Furthermore, I have broadened the view from myopic microanalysis to a search for overriding patterns extracted from a comparison of many such case studies, again something that many of my colleagues have given up on doing. Readers already somewhat familiar with the broad field of visual studies will undoubtedly recognize some of these cases, but I am quite certain that not all will be known to any one of them, since I touch upon many different disciplines and research areas ranging from mathematics to technology, from natural history to medicine, and from the geosciences to astronomy, chemistry and physics. At the same time, this book should also be perfectly readable to beginners still looking for basic orientation in the maze of pertinent analyses published during the last two or three decades. I hope to have produced a text of potential interest to both audiences. Given this agenda, the bibliography necessarily grew to rather lengthy proportions. It cannot claim completeness, though, but is – I hope – a fair and broad selection. References to specially pertinent primary literature are included along with indications of where further sources on each of these many and very diverse topics can be found. I would like to acknowledge a special debt to the following colleagues and scholars whose work on specific case studies was most helpful to me. In alphabetical order, they are: Svetlana Alpers, Kirsti Andersen, Rudolf Arnheim†, Charlotte Bigg, Horst Bredekamp, Olaf Breidbach, Jimena Canales, Jordi Cat, Lorraine Daston, Margaret Dikovitskaya, Meghan Doherty, Monika Dommann, Samuel Edgerton, James Elkins, Eugene Ferguson†, Peter Galison, David Gooding†, Jochen Hennig, Ludmilla Jordanova, Bruno Latour, Michael Lynch, Omar W. Nasim, Kärin Nickelsen, Alex Soojung-Kim Pang, Nicolas Rasmussen, Frances Robertson, Tim Otto Roth, Martin Rudwick, Simon Schaffer and Aaron Wright.

The notes to the main narrative always make clear from whom I took which example and where (and how) I agree with or perhaps differ from their interpretation. Most of them have not seen a draft of my text, so I alone am responsible for any errors. In my comparative approach, I have tried to be as comprehensive and all-inclusive as possible, but of course there will be gaps and missed opportunities for further references. I apologize to all scholars whose pertinent work was not referred to – given the enormous size to which literature on visual culture(s) has grown in recent years, I could not go beyond the explicit inclusion of c. 2000 entries listed at the end of this book. In the brief section preceding my detailed bibliography, I give some personal recommendations on where to start excursions into the thicket of existing literature on visual cultures in science and technology.

I would like to point out, though, that this selection of examples was not based purely on personal taste but also on a more hidden agenda of establishing fruitful interconnections. There are surprisingly many cross-linkages throughout this book, which evidence a high degree of interconnectivity between science cultures otherwise not brought into association. In my opinion, this is exactly one of the strengths of a comparative approach. I hope the reader will appreciate this effort of weaving together many strands, so far only discussed in isolation. My aim is to provide the reader with just the right number of primary and secondary references so as not to overtax him or her with material, yet without omitting essential hints for further study. Each of the hundreds of historical case-studies touched upon in this book is so complex and interesting that they urge further work, especially where they venture beyond the necessarily limited pool of examples here. You will notice that these examples, picked from different periods, typically even from different centuries within each chapter, also make a fair attempt at representing all the natural sciences, medicine and technology. My main emphasis and expertise is in the physical sciences, though.

It is indicative that representatives of many fields have claimed their discipline to be "by nature" most particularly visual. Thus, for instance, the lead-in to a 10-line announcement about a recent workshop on the history of astronomical imaging: "Of all the sciences it is arguable that images have played the greatest role in astronomy, both for the professional and for the interested public."[1] Similar claims could be made of anatomy, botany or zoology, microscopy, mineralogy and crystallography, perspectival theory, technical drawing or the designing of bridges. All these fields, and many more besides, feature prominently in this book.

[1] Quoted from the public announcement by the RAS about a special discussion meeting in London, January 13, 2012, distributed via MERSENNE.

Given the strong interest by art and science historians, sociologists, and philosophers in issues of visual representation for several decades now, it is surprising how few studies have attempted a comparative approach. By this I mean more than a mere compilation of impressive and/or famous images as found in anthologies such as Baynes & Pugh's *The Art of the Engineer* (1981), Brian Ford's *Images of Science* (1992) or Harry Robin's *The Scientific Image* (1992) including some 150 selections "from cave to computer." In my opinion, the most convincing attempts at a truly comparative approach have been made in relatively specific fields. An *intra*disciplinary comparison is drawn within a given field encompassing various actors and possibly larger spans of time. Examples would be Robert Brain's doctoral dissertation, which documents and analyzes the emergence and diffusion of the graphic method within ballistics and physiology, or Eda Kranakis's comparative exploration of French and American cultures of civil engineering in the 19th century. The latter was partly prompted by the German historian of technology Ulrich Wengenroth's call for comparative studies,[2] as "a panacea against technological determinism" and – more positively speaking – as a convenient and methodologically satisfactory pathway toward recognizing "general patterns in the interlocking of [science,] technology and society" or "social and material components in the construction of a technology" – or science, I would add.[3] Further calls for a comparative history of science and technology mostly sought to transcend the fixation on national contexts by explicitly addressing international comparisons, for example, of education, research or innovation systems.[4] Even broader, intercultural comparisons – e.g., between Western and far-Eastern cultures – are even rarer.[5] Within the context of this book, I have refrained from such far-comparisons. I stick to the Western hemisphere, but choose my examples from very many different national, regional and disciplinary contexts from the early-modern era until the 20th century – a field already extremely broad.[6]

[2]See Wengenroth (1993); cf. Kranakis (1997) and Nikolow & Bluma (2002/2008b) p. 44 for similar calls.

[3]See Brain (1996) and Kranakis (1997), with all previous quotes from the latter, p. 6. My own books on spectroscopy as a visual culture (Hentschel, 2000*a*) and on astronomy (Hentschel & Wittmann, eds. 2000) follow a similar agenda.

[4]See, e.g., Pyenson (2002a) on comparative history of science, (2000b) about "an end to national science," Emmerson (1973), König (1997) & Olesko (2009) on technical education, or Simon (ed. 2012, 2013) on cross-cultural and comparative history of science education.

[5]See, e.g., Lloyd & Sivin (2003) for one such daring and impressive attempt.

[6]For synchronic studies and comparisons within the early-modern period, see, e.g., Baldasso (2006), P. H. Smith (2006), Kusukawa & MacLean (2006), Kusukawa (2012); on the 18th c.: Stafford (1994); on the 19th c.: Schwartz & Przyblyski (eds. 2004), Lightman (2000, ed. 2007), Morus (2006);

A similarly broadly ranging, but – in my opinion – only partly successful attempt at an *inter*disciplinary comparison was made in a paper that appeared in *Representations*, one of the key journals for the new field of 'visual studies.' Lorraine Daston and Peter Galison's work on the history of objectivity, first appearing in 1992, was later expanded into a book-length study (Daston & Galison, 2007). These widely noted and discussed publications focus on visual sources, such as atlases; they study the historical development in the making, intentions and usage of scientific atlases. Their claim is that three distinct phases of development exist:

1. The search for the typical or representative exemplar that is chosen for depiction in an atlas, for example, of natural history. This homotype is carefully crafted to bring out the features deemed essential or characteristic, and to suppress other features deemed unimportant, irrelevant or idiosyncratic. Such atlases were prevalent in the 18th and early 19th centuries.
2. The goal of so-called 'mechanical objectivity,' i.e., self-registration of scientific objects. New technologies such as photography, allegedly obviating intervention by the observer, dominated the second half of the 19th century.
3. The constructive use of and work with the observer's subjectivity during the 20th century.

The courage and energy motivating these two top-notch historians of science to search for patterns in the broadly scattered material of atlases in anatomy, astronomy, botany and radiology is impressive. Yet their resulting claims are not quite so convincing.[7] These differences of opinion nevertheless motivated me to likewise step beyond the myriad of details in a micro-historical case study and search for deeper historical patterns holding true and telling more than in a single instance. The following are the results of this decade-long search in material ranging from the late Middle Ages throughout the early-modern period into the 20th century and touching on all kinds of disciplines and research fields in science, technology and medicine.

The following features characterize my comparative approach to the history of science and technology:[8]

- avoidance of the pitfalls of a local microstudy;
- parallel analysis of many comparable cases;

on the 20th c., e.g., Galison (1997), etc. and a myriad of further references in each of these.

[7] See, e.g., Hentschel (2008*b*) for a detailed and critical review of Daston & Galison (2007).

[8] For a deeper methodological reflection on historical comparisons, see Hentschel (2003*a*) and further methodological literature on comparative analysis cited there.

- no forced analysis, but category choices motivated by the sources (actor's categories wherever available);
- a bottom-up approach, starting out from the material;
- intentional generalizability beyond the pool of selected cases; and
- context-sensitive, cautious structural description of historical processes.

Following this methodology, history of science can produce results of relevance to neighboring fields and not exhaust itself in internal dialogue within a narrow niche of specialists. I fully agree with H. Floris Cohen, professor of comparative history of science at the University of Utrecht, who described the proper way to make historical comparisons:

> Rather than importing a conceptual apparatus from the outside, a better approach is to develop it from the inside. Such a procedure allows us to avoid current categories as much as an a priori limitation to actors' categories. [...] In the writing of history patterns must be discerned, not imposed.[9]

This is what Clifford Geertz (1926–2006) meant when he urged us "not to generalize across cases but to generalize within them." Generalizable patterns are most likely to be found on the medium scale of time and level of abstraction. Alluding to the same phenomenon, the famous *Annales* historian Fernand Braudel (1902–85) remarked that "history does not repeat itself, but it has its habits."[10]

Acknowledgments

The considerations set forth in this volume had time to mature over the course of a decade. The plan for such a work was originally conceived since completion of my studies on spectroscopy in 2002, but teaching duties and other vagaries of academic life hindered its execution to now. I thank all the students participating in my Stuttgart lecture cycle on visual cultures of science and technology in the summer term of 2009 and the participants of the Sixth European Spring Academy on Visual Science Cultures in Menorca in May 2011 for intense and fruitful discussions of these ideas. This feedback helped very much to fine-tune my claims and at the same time to broaden my empirical basis.

[9] Cohen (2007) p. 496.

[10] Cf. Geertz (1973) §6, Hentschel (2003*a*) p. 257, and Jürgen Kocka (1989) p. 27: "Comparing means arguing, with sharply defined concepts and a willingness to abstract at the medium level."

Writing a book of this scope and breadth requires access to a very broad spectrum of publications, many of them quite inaccessible. My cordial thanks to the interlibrary office of our Stuttgart University library for the excellent and prompt service concerning roughly 300 interlibrary loans. I also thank the staff of the *Württembergische Landesbibliothek Stuttgart*, especially the staff in the manuscripts and rare books reading room. Reproduction permissions have been granted by courtesy of the following copyright holders:

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Publishers:

Cambridge University Press, Cambridge, England; Elsevier Limited, Oxford, England; John Wiley & Sons, Inc.; Maney Publishing; MIT Press, Cambridge, Massachusetts; Oxford University Press, Oxford, England; Pacific Press, New York; SAGE Publications, Ltd, London; Sinauer Associates, Inc., Sunderland Massachusetts, Springer Science + Business Media, BV.

The following individuals have also generously granted permissions:

Prof. Dr Reto Bale, MD, University of Innsbruck, Austria; Ms Dee Breger, Micrographic Arts, Saratoga Springs, New York; Prof. Derek E. G. Briggs, New Haven, Connecticut; Dr Raymond V. Damadian, president, FONAR Corp., Melville, New York; Prof. Christoph Gerber, Basel; Prof. Jürgen Klaus Hennig, Freiburg; David Jasmin, Institut National de Recherche Pédagogique, Paris; Prof. Hans-Holger Jend, MD, Hamburg; Prof. Dr Willi A. Kalender, Institut für Medizinische Physik, University of Erlangen; Prof. Thierry Lefebvre, Université Paris-Diderot; Prof. Charles W. Misner, University of Maryland; Prof. Kärin Nickelsen, University of Munich; Mr Joe Orman, Chandler, Arizona; Mr Mike Peyton, Essex; Prof. Martin J. S. Rudwick, Cambridge University; Prof. Bradley E. Schaefer, Louisiana State University, Baton Rouge; Prof. Günter Schnitzler, University of Freiburg; Prof. Roger N. Shepard, Stanford University; Prof. Klaus Staeck, Heidelberg; Prof. Kip S. Thorne, Caltech, Pasadena, California; Mr Simon Weber-Unger, Vienna, Austria; Mr John Wetzel, WikiPremed; Prof. John White; Dr Martijn Zegel, Haarlem.

Furthermore, I am very grateful for the kind assistance of Prof. Kenneth W. Ford, Philadelphia; Johanna Norborg, Volvo Car Corp., Gothenburg, Sweden; Mrs Kathleen M. Peyton, Essex; Prof. James E. Wheeler, MD, executor of the John Wheeler Estate, Philadelphia; and Ms Lauren Amundson, Lowell Observatory, Flagstaff, Arizona. It was a great pleasure to cooperate with the team at Oxford University Press. I would like to thank in particular Sonke Adlung and Jessica White as well as Saravanan Omakesaven of Integra Co. My wife Ann kindly checked the style, translated some quotes from German, French and Spanish originals and helped to obtain copyrights of images. Hearty thanks to all of the above and – needless to say – all remaining errors are mine.

A quick guide through this book

In the following introductory chap. 1, I give a concise survey of the vast literature on visual representations in science and on visual cultures more generally. I define fundamental terms (in sec. 1.1), discuss basic polarities such as visual versus textual, iconophile vs. iconophobe (in sec. 1.2), and thematize their interplay (sec. 1.3). Visual rhetorics and visual argumentation are analyzed (in sec. 1.4) with respect to 2D images and 3D models alike. In sec. 1.7, which is a must even for those readers already familiar with the literature, I summarize roughly two dozen deep insights from early visual studies. The work of Svetlana Alpers on the Dutch connection and its mapping impulse is singled out and identified as a useful point of departure (in sec. 1.5), whereas many later works are criticized by me as "wrong turns of the visual turn" (in sec. 1.8).

In chap. 2, I develop my own notion of 10 historiographic layers of visual science cultures. My claim is that their historical analysis should delve into all 10 of these layers, not just focus on a few of them as is normally done. Only then can we hope to get a 'thick description' of visual cultures in science, medicine and technology. Chapter 3 discusses how visual science cultures are formed. It starts with a summary of Martin Rudwick's paradigmatic analysis of geology, then switches to stereochemistry (in sec. 3.2), metallography (sec. 3.3) and geometrodynamics (sec. 3.4). A few carefully selected pioneers of visual cultures are portrayed in chap. 4. After four biographical case-studies in sec. 4.1, I offer a more systematic prosopography of 30 spectroscopists from the 19th and early 20th centuries, which already aims at the identification of common features. Section 4.4 continues to search for a generalizability of these claims and is another must for all readers.

The transfer of visual techniques is exemplified with the complex shifts back and forth between arts, architecture, mathematics, optics in the history of perspectival drawing (in sec. 5.1). Indicator diagrams mark a point of transition between secret industrial practice of steam-engine development and the new science of thermodynamics established in the middle of the 19th century (in sec. 5.2). The trajectory from NMR to MRI, i.e., from physics and chemistry to medicine, is studied in sec. 5.3, with CT and PET scanners as a late 20th-century endpoint (in sec. 5.4). Chap. 6 traces the role of images and their makers in the business of science and chap. 7 explores their evolutive histories.

Among the 10 historiographic layers expounded in chap. 2, quite a few are treated in chapters of their own: the methods of practical training in visual skills (in chap. 8); the embuing mastery of pattern recognition (in chap. 9), of visual thinking in scientific and technological practice (in chap. 10), the aesthetic fascination of practitioners (in chap. 12) and issues of visual perception (in chap. 13). Recurrent color taxonomies are also given their own chapter (11). A concise summary of my main results is attempted in the final chap. 14 about visuality through and through. This should also be compulsory reading for all who might otherwise suit their reading to their own fields of interest or follow the many cross-references in the text that also trace the complex interconnections. Before the c. 2000 item bibliography and the name index I give personal recommendations of where to start further reading.

1

INTRODUCTION

1.1 Cultures, scopic regimes and visual domains

Whole libraries have been written on the meaning and connotation of the term 'culture' or 'cultures,' without any agreement being reached on its precise definition. I should therefore begin this systematic introduction by saying a few words about it, as it figures so prominently not only in this book's title but also in the field called 'visual culture,' to which the present work aims to contribute. This is by no means an easy proposition.[1] The term 'culture' derives from the Latin *cultura*, initially denoting husbandry, i.e., the practice of "cultivating" land and soil, and tending plants or crops.[2] Since the 16th century, and increasingly since the 18th century, this term was also in use metaphorically in the sense of cultivating or developing the human mind, faculties or manners. 'Culture' was then understood as the result of such development, training or refinement. During the Enlightenment, the concept of culture and especially its French companion *civilisation* became loaded with the notion of progress and unidirectional development away from supposed barbarism or "savagery," in which process all tribes and nations undergo many steps of mental cultivation. Against this Eurocentric and ethnocentric ideology, Johann Gottfried Herder (1744–1803) defended the idea of a plurality of cultures, each with its own way of life, its own traditions and its own artistic and intellectual achievements. In the 19th century, culture increasingly came to be seen in material and social terms, and thus in reference to the products of communal activity. Twentieth-century 'cultural studies' began as a revolt against the self-imposed limitation by academic disciplines like art history or the philologies to analyze only select products of "high" culture such as the fine arts, poetry or tragedy. The material culture of the populace was sought, the vernacular imagery in children's books and popular media, along with all kinds of

[1]On the historiography of 'culture' see the early but still useful literature survey by Kroeber & Kluckhohn (1952). Exemplary for current approaches, but by no means exhaustive, are Geertz (1973), Hall (1980, 1990), Storey (ed. 1996), Hardtwig & Wehler (ed. 1996) and Fried & Stolleis (eds. 2009), each with further references. Finally, see the "What's culture" webpage: www.wsu.edu/gened/learn-modules/top_culture/culture-index.html (last accessed April 29, 2011) with links to key texts in this debate.

[2]See *Oxford English Dictionary*, 2nd ed., vol. 4 (1989) pp. 121ff.; cf. also Rampley (2005) chap. 1.

practices found in everyday life. Nowadays, culture is understood as encompassing "anything that is meaningful to more than one person" or "everyday objects and practices of a group of people, or of an entire way of life."[3] The singular, with which the concept of culture had once been mobilized as a banner against barbarism (or what was rhetorically demarcated as such), has given way to a plurality of cultures, sometimes explicitly defined as a "patchwork of situated, disparate, locally organized practices, in which knowledge is constituted through a variety of social and political processes."[4]

The concept of culture historically comprehends both a process and material artifacts. Throughout this book, both these meaning variants are applied. Our understanding of culture will not be limited to denoting skills or products of "high" culture but responds to the impulse from 20th-century cultural studies and social history to broaden the concept.[5] Not only will the elitist products of top-notch science and technology be looked at, but an attempt will also be made to find a level of description that fits typical examples of "normal" science (in Thomas S. Kuhn's sense) from the everyday lives of scientists and engineers.

From the ethnologist Clifford Geertz, in particular, we learned that human cultures are complex systems of knowledge in which the members converse about and among themselves in a partly self-referential mode. Visual representations of all kinds play a vital, but not isolated, part in these 'autopoietic' systems of communication. Since many layers of meaning are superimposed in all cultural objects and processes, ethnologists and historians alike need a 'thick description' to unpack the various layers of signification. Cultural objects carry a high degree of symbolic content. Consequently, Geertz has defined 'culture' as the "self-spun webs of significance" that humans inhabit, as "a system of inherited conceptions expressed in symbolic forms by means of which people communicate, perpetuate, and develop their knowledge about and attitudes toward life."[6] Seen from this perspective, visual elements in science and technology are "efflorescences of informational images in general."[7] Barbara Stafford's portrayal of the Enlightenment

[3] On these definitions by Raymond Williams 1958 and Malcolm Barnard 1998, see, e.g., Storey (ed. 1996), Schwartz & Przyblyski (eds. 2004) pp. 6ff., as well as W. J. T. Mitchell and Brian Goldfarb in Dikovitskaya (2005) pp. 1, 33, 57, 79f., 164, 245, 288.

[4] Thus, for instance, the anthropologist Charles Goodwin (1994) p. 608, in a study about professional vision and encoding schemes.

[5] For a good survey of cultural studies methodology, see Storey (ed. 1996). Cf. also Dikovitskaya (2005) pp. 16f., and Rampley (2005) for further references.

[6] See Geertz (1973) pp. 5 and 89, respectively.

[7] Elkins (1999) p. 5. The distinction between informational and artistic (or expressive) images is by no means a dichotomic one for art historian James Elkins: see here p. 16.

as a period of "artful science" and as the "eclipse of a visual education" can be understood as an example of this kind of multifaceted approach. Associatively spun cross-connections are aimed at between spectators at a market fair or diorama, between instrument-makers of gadgetry for visual entertainment and children's books and between museums, collections and what remained of the *Wunderkabinett*, soon to disappear forever in the much more rigid textual classification and institutionalization of the new sciences in the 19th century.[8] Methodologically, these heroic efforts at a thick description of a whole cultural period are riddled with problems, since they presume a unity of experience and visuality throughout this period despite many (often conflicting) cultural strata, domains of knowledge and practices. Impressionistic case studies and mostly associative linkages between these domains and practices[9] don't suffice to prove the relevance, say, of an artist's visuality to that of a tradesman, a naturalist or an engineer. Therefore I choose not to pursue my own analyses in this broad Staffordian approach of looking at *all* strata of a population at once, rather I limit my reference groups to people somehow contributing to a systematic study of nature or technological artifacts. This is by no means restricted to the elite, but also includes mechanics and assistants, etc., and hence it still constitutes a very large group. Following the lessons of a 'materialized epistemology,' we will rather base our comparisons on "in-depth studies of the people and practices involved in making particular sorts of images and of the ways in which those images form both what and how we know."[10] As will become evident throughout this book, there are already plenty of cultural studies in this vein, which I take to be richer in insight than would be a broad cleavage of whole strata of epistemes in a Foucaultian manner.

The close interplay between 'culture' and 'practice' makes 'cultural studies' of all aspects of human societies go hand in hand with 'practice studies' – both these trends having intensified since the 1970s. For the purposes of history of science and technology, a special branch of these cultural studies has proven to be of special relevance, namely those dealing with 'knowledge cultures,' i.e., cultures more broadly conceived than cultures of science, but still directed toward an increase

[8]See Stafford (1994) and the review symposium in *Metascience* 1994, issue no. 6, pp. 46–60. On the radical restructuring of natural history since the Sattelzeit of 1770–1830, see, e.g., Lepenies (1994), Stichweh (1984) and Rudwick (2007).

[9]Such as are practiced by Stafford. In all her publications, she likes to play the "game of back and forth." This is a quote from Stafford (1999) p. 1 in a (to me unbearable) book on visual analogy.

[10]Norton Wise (2006) p. 82 in a focus section on science and visual culture. Cf. also Dupré (2010) p. 621 and Elkins (2007) for many examples of "visual practices across the university."

in knowledge of some sort, whether theoretical or practical.[11] The sociologist Nico Stehr (*1942) noted the growing importance of canonized knowledge in modern societies, as contained in the term 'knowledge society' (*Wissensgesellschaft*) to denote this concentration of highly skilled and well-informed labor in the modern and postmodern world.[12] Specialists and experts gain central importance in modern societies; and generating, stabilizing and transmitting such knowledge from one generation to the next becomes of vital importance to their survival in an increasingly global market of expanding systems of expertise. Science and technology are, of course, special cases in point. The American historian of science Peter Galison (*1955) has shown, for instance, how 20th-century high-energy physics can be fruitfully studied as a "material culture of microphysics." His British colleague Andrew Warwick has demonstrated how to transfer this approach to "cultures of theory." The American historians Kathryn Olesko and David Kaiser as well as the Spanish historian Josep Simon have broadened this further to integrate science pedagogy into this science–culture package.[13] From the technological angle, there are portrayals of material cultures as well as technological training.[14] The German historian of technology Wolfgang König (*1949) has published a nice documentation comparing different traditions of education in machine building and construction between 1850 and 1930. France and Germany are both characterized as "school cultures" and contrasted against a "production culture" typical of the USA; the British "practice culture" trains more engineers on the job, in industry.[15] Wolfgang König and the American engineer and historian of technology Eugene S. Ferguson (1916–2004), as well as several historians of education, have pointed out how very important practical exercises in free and technical drawing as well as in 3D model-making were in the curricula of (poly)technical schools of the time.[16] At the general, prosopographic level,

[11] In German: *Wissenskultur(en)* as opposed to cultures of science; see, e.g., Knorr-Cetina (1999*a*), who prefers to speak of 'epistemic cultures.'

[12] See Stehr (1994) and further sources cited therein.

[13] See Galison (1997), Warwick (2003) and the special issue of *Studies in the History and Philosophy of Modern Physics* 29B,3 (1998), Olesko (1991, 2006), Kaiser (1998, 2005*a*, *b*), Kaiser (ed. 2005) and Simon (ed. 2012).

[14] See, e.g., Booker (1963), Hindle (1983) on the US context, both examples for the latter, comparatively organized, and comprising examples from the USA, Great Britain, Germany, France and Switzerland. Cf. Dalby (1903), Emmerson (1973), Ferguson (1992), König (1997), Olesko (2009) and A. J. Angulo in Simon (ed. 2012).

[15] See again König (1997) p. 11 for the quotes, and part II for his international comparison.

[16] See König (1997) pp. 81f. and Ferguson (1992); also Ulrich (1958), Feldhaus (1959), Booker (1963) and Lipsmeier (1971) for general histories of technical drawing; cf. here secs. 5.1 and 8.1.

technical education is already densely documented. It becomes more impressive still by zooming in on individual biographies including these kinds of visual training. For instance, it is still not very widely known that the young Ludwig Wittgenstein (1889–1951), later to become one of the foremost philosophers of the 20th century, underwent thorough training in descriptive geometry at the Berlin Polytechnic in Charlottenburg, where he was receiving his undergraduate training in architecture in 1906/07 after having passed his school-leaving exams at the Linz *Oberrealschule*, a high school placing heavy emphasis on applied geometry and drawing instruction.[17]

Like language, mentality and habitus, visual representations are shaped by cultural factors: globally by the distinctive culture of scientific disciplines, and more locally by subcultures and local clusters.[18] In chapter 6 we will see in detail how fruitful it is to look beyond the higher echelons of leading scientists or engineers and view them embedded within a broader context of other carriers of culture. These include illustrators, photographers and image technicians. Many of them might not have received any 'scientific' or 'academic' training, having rather acquired their skills at an artisanal workshop or polytechnic institution, or by private tuition from a practicing master in their field.[19] Since the Renaissance, the hitherto strictly separated social milieus of craftsmen, scholars and naturalists became increasingly intercalated: a) Ambitious craftsmen and artist-engineers such as Leonardo da Vinci, Francesco di Giorgio Martini and Lorenzo Ghiberti became interested in acquiring higher knowledge such as in anatomy, alchemy, perspectival theory or optical theory, either for their own purposes or to raise the social status of their work.[20] b) Systematic observers of nature, such as Galileo or Hooke, Agricola or Huygens, concentrated on the fine arts in order to improve their own drawing and observing skills.[21] Cultures of science and technology, the center of attention in this book, will always be understood here as embedded within these broader cultures of knowledge.

[17] On Wittgenstein's technical training, see Hamilton (2001) pp. 56ff., who claims that this training also left its mark on his *Bild* conception in the philosophy of science; cf. Consentius (1872), Müller (1872), Hindle (1983) pp. 13f. and Vincenti (1993) for other examples.

[18] See, e.g., Knorr-Cetina (1991, 1999), Pickering (ed. 1992) or Galison & Stump (1996) for exemplary studies on these local cultures of science and technology.

[19] See Hentschel (ed. 2008) and further references listed there on 'invisible hands,' furthermore Gotz & Gotz (1979) and Stenstrom (1991) for a statistical analysis of their typical family background.

[20] On artisanal skills and traditions in the early-modern period, see, e.g., Findlen (1994) and Pamela H. Smith (2004).

[21] On the plurality of motifs and functions of drawings in the late Middle Ages and early-modern period, see, e.g., Lefèvre (ed. 2004) and Dupré (2008).

Attentive readers will notice that I tend to speak of cultures and sciences in the plural, avoiding the singular that philosophy of science had started out with at the beginning of the 20th century. Logical empiricists, who dominated philosophy of science from the 1930s to the 1970s, had always insisted on the notion of a unity of science, guaranteed by a purported unity of method and by collective submission to the dictate of truth as the only legitimate authority. All components of this belief have come under heavy fire; but I will refrain from going into these debates, which would lead us far astray.[22] What is necessary for the broadly comparative approach practiced here is an acceptance of the great variety of scientific and technological practices rather than the presupposition of any common denominator under which all can be subsumed. I sympathize with art theorist James Elkins (*1954), who demands that "we need to let individual image-making practices exist in all their splendid particulate detail" and "simply listening to the exact and often technical ways in which images are discussed."[23] This plurality of image practices does not imply boundless heterogeneity, though. We will watch out for patterns and spell them out wherever we spy them, but we won't hypothesize them before they have been traced down in a sufficiently broad array of analyzed cases. Thus a log must also be kept of the differences and specificities of each case. Our starting point will be the plural of both sciences and cultures – emphatically so, for all its messiness and exasperating variety.

Logical empiricists also tried to demarcate their singular science, which they contrasted to its obverse: despised 'metaphysical,' i.e., unproven and unprovable pseudo-science. By limiting our object of study in the title of this book to "cultures of science and technology," we implicitly also seem to fall prey to this charge of drawing a simplistic and narrow-minded distinction that cannot be upheld if one looks carefully enough at scientific and technological practice. I would retort to this charge that this title only implies a set focus, not a sharp demarcation line. This point will be corroborated in the further discussion of many cases trespassing this imaginary borderline between science and technology. In particular, we will notice that their fringes and skills in visual cultures clearly extend beyond both, into artisanal workshops and deep into the everyday life-worlds of our actors.

A similar demarcation problem has haunted the history of art, incidentally, with the traditional distinction drawn between 'high art' and 'low art.' Even within the

[22] Book titles are indicative, such as *A Social History of Truth* by Shapin (1994), *The Disunity of Science* by Galison & Stump (1996), and the three editions of the *Handbook of Science and Technology Studies*, Cambridge, Mass.: MIT Press 1977, 1995, 2007.

[23] Elkins (2007) p. 8; he then presents more than 30 different examples across academe; cf. also Hentschel (2011*b*) for a survey of other recent studies of image practices.

first category, lines are drawn between first-rate artists, second-raters and no-names at the very fringes of what was considered worthy of study by a well-educated art historian. These strong qualitative judgments of connoisseurship have been under fire for a long while now. Aby Warburg's and Erwin Panofsky's pioneering efforts to broaden the subject of art history date back to the first half of the 20th century. Renewed attacks came with Ernst Gombrich's, Samuel Edgerton's and Martin Kemp's persistence within the history of perspectival seeing. To this day, controversies continue to rage over the issue of perspectival representation. On the one hand, there are those who argue (like Panofsky and the neo-Kantian philosopher Ernst Cassirer) that cultural preconditions determine what and how objects are seen and represented, or (like the cultural relativist Nelson Goodman) that all forms of representation are heavily overloaded with conventionality. On the other hand, there are those who see linear perspective as the only "true" form of representation, "corresponding to a high degree of approximation to the way we actually see the world around us."[24] Maurice Henri Pirenne (1912–78) had a point when he declared that "the strange fascination which perspective had for the Renaissance mind was the fascination of truth" or perfection of perspectival representations.[25] It is important to keep in mind that this fascination was not limited to a few "great" minds but was fairly broadly disseminated down to the level of architects and surveyors, painters and draftsmen, goldsmiths, carpenters and stone masons.

The demarcation between art and non-art was also openly combatted since the 1990s by James Elkins at the Department of Art History, Theory and Criticism of the *School of the Art Institute of Chicago*. He points out that the overwhelming number of images around primarily convey information and thus are not images of art, created with the aim to please (or displease) aesthetically. These 'utility graphics' include musical scores, floor plans, money, bond certificates, seals and stamps, pictographic signs indicating one-way streets or escalators, etc., as well as geometric diagrams, astronomical charts and engineering drafts. Earlier generations of historians of art tended to dismiss the latter as "intrinsically less interesting than paintings," engravings or sculptures. Consequently such profane images were ignored as mere "half-pictures or hobbled versions of full pictures, bound by the necessity of performing some utilitarian function and therefore unable to mean more freely, [...] as incapable of the expressive eloquence that

[24]See, e.g., Panofsky (1927), Cassirer (1955), Goodman (1976), Veltman (1980*b*) or Moxey (2001) vs. Derksen (2005), Gombrich (1960, 1982), Krieger (1984), Turner (1992) or Pirenne (1952), with the last quote from p. 170. On Kemp's publications, see also Dupré (2010).

[25]Pirenne (1952) p. 185. See here sec. 5.1 and further references there.

is associated with painting and drawing."[26] Illustrators were only included in biographical dictionaries compiled by historians of art if they had succeeded in transcending the busy world of commerce and everyday life, having thus striven for acceptance as "real" artists, not as lowly artisans. Consequently, only a few scientific illustrators are found in handbooks and dictionaries of the fine arts (for more on this prosopographic point, see chap. 6). Precisely in order to fill this historiographic gap, I instituted the compilation of a *Database of Scientific Illustrators* (DSI) at the University of Stuttgart. DSI covers five centuries from 1450 to 1950, thus excluding illuminators of medieval books and professionally still active illustrators. Its 20 search fields, ranging from name to region of activity, education and patronage, allow the user to search for illustrators (many of them not listed anywhere else), their clients and relatives, their techniques and their regions of activity.[27]

A small minority of historians of art countered these prejudices against the applied arts. They argued in favor of many apparently dry, mundane "informational" and "utility" representations: "far from being inexpressive, they are fully expressive, and capable of as great and nuanced a range of meaning as any work of fine art."[28] A first move proving this point would be to show how often they are actually inspired by the fine arts. Andreas Vesalius's (1514–64) famous skeleton figures and muscle-men in *De humani corporis fabrica* (1543) become allusions to older Italian compositions; medical illustrations more generally become the "shadow of fine-art depictions of the body." Likewise, "computer software developers recapitulate the history of art in various particulars" such as the adoption of perspectival space construction and quasi-mylar layering.[29] A next step could be to show how scientific motifs enter the fine arts, such as cartographic maps adorning the interiors of some of Jan Vermeer's (1632–75) famous paintings. They were depicted in such detail that the original prints could be traced down by

[26] All preceding quotes are from James Elkins (1995) p. 553 (also republished as chap. 1 of Elkins 1999), who then proceeds to refute each of these quotes. A good analysis of the full breadth of images with an effort towards their taxonomy is provided by Gottfried Boehm (1994).

[27] Currently (as of December 2013) the database contains over 6,200 entries, with more to come in the next months and years. See www.uni-stuttgart.de/hi/gnt/dsi and its subpages, online since April 2011, and Hentschel (2012) for a brief introduction on how to work with this database.

[28] Elkins (1995) p. 554. Cf. also Elkins (1999) pp. 6, 10f. and Schwartz & Przyblyski (eds. 2004) pp. 4f. on the social history of art. Boehm (1994) tries to retain some distinctions and emphasizes the limits of utility graphics.

[29] All preceding quotes are from Elkins (1995) p. 556. On Vesalius and his illustrators, see, e.g., Kemp (1970), O'Malley (1964), Harcourt (1987), P. H. Smith (2006) pp. 86f. and the interestingly annotated online version of Vesalius's main oeuvre of 1543 at http://vesalius.northwestern.edu.

specialists. Whether and how scientific devices like the *camera obscura* might have been used by the same artist would be another avenue.[30] The final move along these lines would be to concede to the very occasional scientific image a strong enough impact and symbolic weight to leave its mark in works of art. Well-known examples of this feedback loop between the sciences and the arts include James Watson (*1928) and Francis Crick's (1916–2004) double-helix DNA, photographs of an atomic bomb mushroom cloud or some portraits of Einstein.[31]

None of these three argumentative strategies does away with the hierarchic distinction between art and non-art though. They all work with it and just proudly present some point of contact, overlap or a limited transfer from one realm into another. Edgerton's, Elkins's and Kemp's critique aims at this very dualism, however. They see it as categorically misplaced. It simply does not make sense to keep apart Leonardo da Vinci (1452–1519) the acute observer and proto-scientist from Leonardo the artist. Any effort at such a distinction is artificial and useless.[32]

How do I position myself in these debates? On one hand, I sympathize with those who warn against arbitrary distinctions in continuous fields. I do not want to throw out the baby with the bathwater, though, and dispense with all disciplinary borders, especially not for periods from the 19th century onward where these borders were very much in place, both cognitively and socially.[33]

In focusing on what is loosely termed "visual cultures of science and technology" in the title of this book, I do not want to fail to define the latter differently from how they were considered during the period involved. The boundaries become sharper the more modern our examples become. But even during the 17th century there is already a difference between speaking about a workshop for the painter Vermeer or one for the microscopist Leeuwenhoek, although both were embedded in the broader context of early-modern Dutch culture.[34] To continue within this example – our focus will clearly remain on the Leeuwenhoek side of

[30] See, e.g., Steadman (2001). Cf. here sec. 1.6, note 184 suggesting Vermeer used a *camera obscura*.

[31] On the preconditions for this to happen, see Bredekamp in Ullrich (2003*a*) pp. 18f. On Watson and Crick's DNA model as an icon, see Nelkin & Lindee (1995). Van Dijck (1998) coined the term 'imagenation' with respect to popular images of genetics. See Kemp (2000) pp. 254ff. and Soraya de Chadarevian's paper on Watson & Crick's model in Chadarevian & Hopwood (eds. 2004). On atomic bomb images, see part III of Bigg & Hennig (eds. 2009), as well as here p. 61 on the Einstein iconography and processes of idolization.

[32] See, e.g., Kemp (1990, 2004, 2007) and further Leonardo literature listed there in making this point. Cf. also Fehrenbach (1997, 2002), Dupré (2010) and here p. 242 on Leonardo's ingenious efforts to capture motion.

[33] On this process of disciplinary differentiation, see Stichweh (1984).

[34] For more on the latter, see Alpers (1983), commented upon in greater detail here in sec. 1.5.

the argument. Nevertheless, obvious links to his artist contemporaries will not be ignored, such as his role as the official executor of Vermeer's last will and testament. Nor will the broader cultural strata in which both these masters were embedded. The plural in 'visual cultures' is very important to me. There is always more than just one 'culture' even during one and the same period, and one and the same place; here Delft around, say, 1670.[35]

In order to distinguish specific spheres of activities performed by small groups of specialists in particular ways of seeing, representing and recognizing patterns, I have introduced the concept of visual or scopic domains.[36] In my book on spectroscopy, for instance, I distinguished at least 14 different 'spectro-scopic domains,' all having to do with spectra, their recording and interpretation, but differing in minor details about the instrumentation, spectral resolution and range, sensitivity, goals and tacit knowledge not easily transferable from one domain to the next.[37] Viewed from this angle, the visual culture of spectroscopy becomes "contested terrain" over which instrumentation linked to specific observing and measuring practices should compete. Within each visual domain, there exist stages of familiarity and immersion, from novices in a discipline (i.e., beginner students), or apprentices and journeymen (roughly corresponding to the academic undergraduate or postdoc stages), to the final stage of expert in a visual culture.

A similar idea lies behind Jonathan Crary's study on *Techniques of the Observer*. Taking examples mainly from the 19th century, Crary presents a plethora of modes of vision, created by means of various optical devices ranging from the *camera obscura* (known since the 17th century) to the stereoscope, kaleidoscope and phenakistoscope.[38] Taken as a historical progression, each of these gadgets increasingly distances the observer from his object of observation, yielding increasingly artificial and synthetic views embedded in increasingly complex systems of conventions of representation and limitations of seeing. Each of these gadgets creates another view of the world and its parts. Each of them plays on human perception with a sequence of deconstruction (or analysis) and reconstruction (or synthesis).[39] Each of them is bound to a different user group, fascinated with very

[35]See, e.g., Mitchell (1995) p. 543 on this issue of the singular vs. plural of culture.

[36]See Hentschel (2002*a*) pp. 434ff. This concept incorporates both Martin Jay's concept of 'scopic regimes' (see below on p. 27 and James Elkins' (1999) 'domain of images' (see here p. 16).

[37]See Hentschel (2002*a*) pp. 434–6 for a survey summary; and Elkins (2007) pp. 50f. on "families of visual technologies" within which such transfers are relatively easy to perform.

[38]See Crary (1988, 1995); cf. Liesegang (1920) pp. 53ff., Füsslin (1993); cf. Lenoir (1997) p. 164 for von Helmholtz's 'spectrascope' for determining complementary colors, and Brücke's variant of it, the 'schistoscope.'

[39]On this feature, see esp. Timby (2005), who parallels 19th-century stereoscopy and color

special features and goals of the various instruments. The thaumatrope is a simple disk, with two printed images, one on each of its faces. They appear to merge when the disk is rapidly spun around itself. The phenakistoscope ('spindle viewer,' also metaphorically called a 'fantascope' or 'wheel of life,' *Lebensrad*) gives the illusion of seeing objects in motion by watching a rapid succession of images printed or mounted on the circumference of a disk (see fig. 1 middle). The observer looks at these images through a second disk with as many thin slits as there are images on the other disk. Because both disks are mechanically coupled and thus rotate at the same speed, the observer's eye held fixed sees only the image sequence and is not disturbed by the white spaces in between the images, which are blocked by the black intervals between the slits of the second disk.[40] The zoetrope (also called *daedaleum* or in German *Wundertrommel*; fig. 1 right) has the image sequence inside a rotating drum; the observer looks through thin slits along its circumference. Both gadgets are early examples of stroboscopic viewing instruments that – when rotated fast enough – generate the impression of continuous motion.[41]

The stereograph gave the closest 3D impression obtainable by 2D representations throughout the 19th century. Two images (usually photographs) taken from slightly different angles (for an example, see fig. 3) are viewed with a special binocular device at the appropriate distance such that each eye looks only at one of the two photographs. In the viewer's mind, these two pictures are superimposed and create a nearly perfect 3D impression of the depicted objects. Stereo-viewing under controlled conditions creates a sense of depth that simulates normal human perception of objects in space. This technique was invented in the 1830s by the English scientist Charles Wheatstone (1802–75) in the context of his studies on binocular vision.[42] Since Wheatstone published the first part of his findings in June 1838, which was roughly half a year before Daguerreotypes and Talbotypes became publicly known, his illustrations were simple line drawings. The technique would have remained an obscure, odd invention and soon been forgotten if photographic processes had not allowed relatively simple produc-

photography. A variant of stereoscopy, anaglyphs, use two images taken with different filters from slightly differing perspectives in conjunction with color-tinted viewing binoculars (cf. here p. 23).

[40]For photographs of historical phenakistoscopes, see Füsslin (1993); cf. also Rocke (2010) p. 213 on Kekulé's use of this device to visualize the motions of atoms in molecules.

[41]See Plateau (1831, 1832, 1833) and Horner (1834). The terms 'stroboscope' and 'stroboscopic' were introduced by Stampfer (1833). On these two and various other related devices, cf. Liesegang (1920) pp. 54ff., Crary (1995) chap. 4, Füsslin (1993) and the website courses.ncssm.edu/gallery/collections/toys/opticaltoys.htm . Cf. here sec. 7.4 on the long history of efforts to depict motion. On Plateau's biographical background and strong visuality, see here p. 156.

[42]See Wheatstone (1838/52), Brewster (1856), Gill (1969) and Wade (1983).

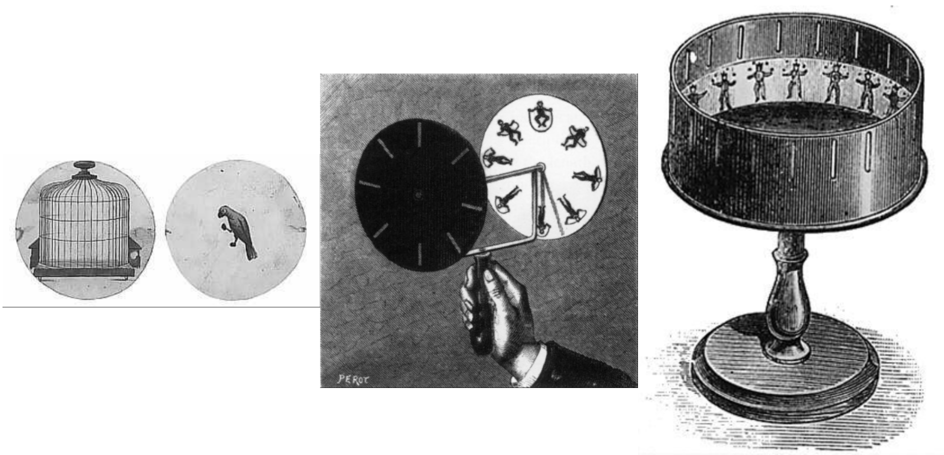

Fig. 1: Left: A thaumatrope. Middle: A simple phenakistoscope of Joseph Plateau. Right: William G. Horner's zoetrope. All from the mid-1830s. From Liesegang (1920) pp. 55, 57.

tion of such stereo-images. In the late 1840s, substantially improved versions of stereoscopes were developed by the Scottish physicist and spectroscopist David Brewster (1781–1868). He replaced Wheatstone's double mirror with a pair of adjacent half-lenses that allowed direct viewing of the two stereophotographs, side by side, which considerably facilitated their mounting. Around 1850, the Parisian opticians and instrument-makers Duboscq and Soleil started to market these gadgets, which became quite popular in the second half of the 19th century.[43]

The first stereophotographs were advertised at the 1851 Crystal Palace Exhibition in London. They were perceived as providing a "truthful, yet wondrous experience for the at-home viewer."[44] The professor of anatomy and art critic Oliver Wendell Holmes (1809–94) was one of the most outspoken and enthusiastic advocates of the new viewing device. He developed a particularly light and cheap variant of it that became known as the 'American stereoscope.' Holmes was fascinated by how much stereoscopes made flat surfaces look "solid," or, as we would rather put it, three-dimensional:

> The first effect of looking at a good photograph through the stereoscope is a surprise such as no painting ever produced. The mind feels its way into the very depths of the picture. The scraggy branches of a tree in the foreground run out at us as if they would scratch our eyes out. The elbow of a figure stands forth so as to make us almost uncomfortable. Then there is such a frightful amount of detail, that we have the same sense of

[43] On the history of stereoscopes, see Reynaud et al. (eds. 2000), esp. Pellerin (2000) and Timby (2000, 2005) and Halsband (2008). On Brewster's visual culture, see here p. 144.

[44] See Halsband (2008), quoting early enthusiastic commentaries, most notably by Queen Victoria.

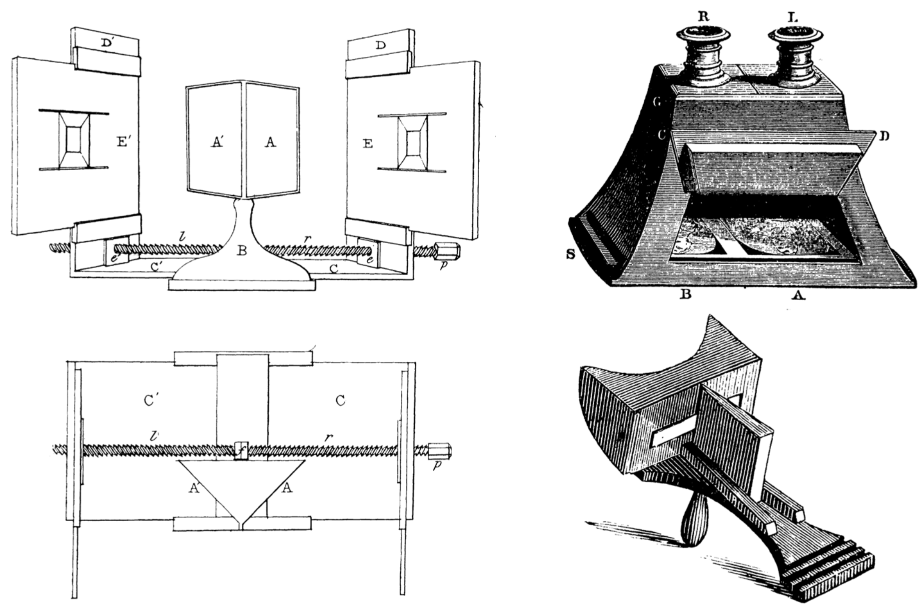

Fig. 2: Left: Wheatstone's reflecting stereoscope (1838). Right top and bottom: Brewster's lenticular (1849) and Holmes's handheld American stereoscope (1861), respectively. From Wheatstone (1838/52) p. 10, figs. 8 and 9; Brewster (1856) p. 67 and Holmes (1869) p. 24.

> infinite complexity which Nature gives us. A painter shows us masses; the stereoscopic figure spares us nothing – all must be there, every stick, straw, scratch, as faithfully as the dome of St. Peter's, or the summit of Mont Blanc, or the ever-moving stillness of Niagara. The sun is no respecter of persons or of things.[45]

Stereoscopes were used intensively. They were certainly not limited to the realm of popular images. Being an expert in prosthetics, Holmes made use of stereographs to depict people performing various motions, in order to improve the design of his artificial limbs, which were in high demand as a consequence of the American Civil War (1861–65).[46] During the era of professional stereoscopy (1852–69), when this art was practiced by just a few specialists, Charles Piazzi Smyth's account of *An Astronomer's Experiment* was the very first book worldwide with reproductions of select stereographs, taken on the Canary Islands in 1858 (see fig. 3). They were simply glued into the volume as adjacent prints on albumen paper. The book documents the intricate fauna and flora as well as Smyth's expedition as Astronomer Royal of Scotland to the mountain tops of Tenerife, where he made geological, topographic, spectroscopic and astronomical observations.

[45] Holmes (1859) p. 744.
[46] On this application of stereography, see Albrecht Hoffmann (1990) p. 32.

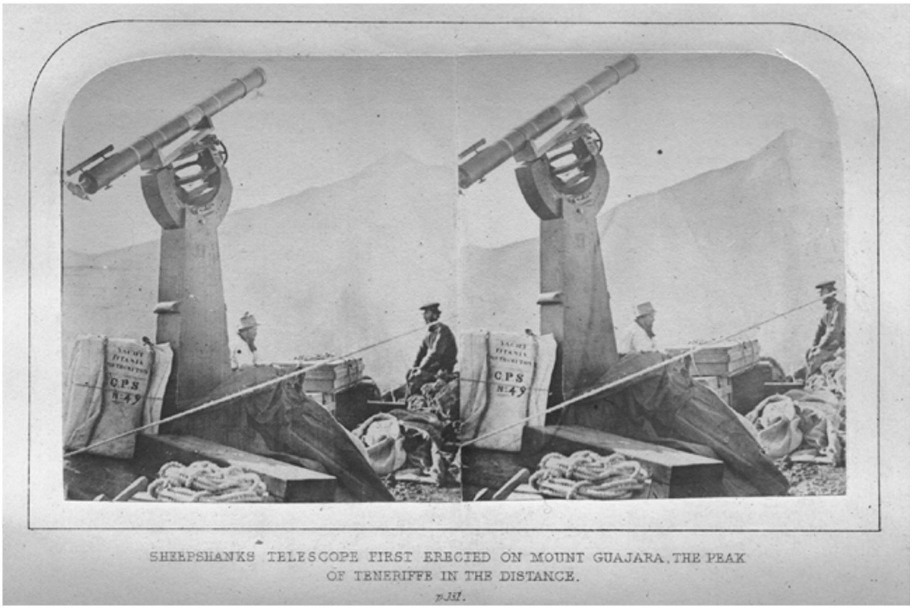

Fig. 3: Stereograph taken on Tenerife by C. P. Smyth, albumen print, 6 cm × 7 cm 1858. Courtesy of George Eastman House, International Museum of Photography and Film, no. 1995:0152:0005. See pp. 142ff. below on Smyth's other visually oriented activities.

In the late 1850s and early 1860s, the British astronomer, chemist and print expert Warren de la Rue (1815–89) and the American amateur astronomer and expert photographer Lewis Morris Rutherford (1816–92) obtained the first successful stereographs of the Moon. The large distance of this object precludes the usual procedure of choosing two different perspectives for the left and right photographs. Instead, they took photographs at different times, making use of the Moon's libration. Improved versions of such lunar stereographs were made by Henry Draper (1837–82) in New York and by John Adams Whipple (1822–91) at the *Harvard College Observatory* in Cambridge, Massachusetts. Around the turn of the century, lunar stereographs were commercially mass-marketed just as were topographic and other motifs by companies such as *E. & H.T. Anthony* or *Underwood & Underwood* in New York.[47]

In this case, 3D perception in the human mind went beyond mere mimicry. It in fact amplified the image. Holmes wrote enthusiastically: "the [Moon's] sphere rounds itself out so perfectly to the eye that it seems as if we could grasp

[47] See A. Hoffmann (1990) p. 35; for examples see www.londonstereo.com/modern_stereos_moons.html and www.geh.org/ne/mismi2/moon_sum00003.html

Fig. 4: Lunar stereograph by Warren de la Rue. Left: on February 27, 1858 at 13:50 at a lunar age of 14.2 days; right: on September 11, 1859, 11:20 at 14.8 days. The lunar libration led to a difference of c. 6° latitude and 2.5° longitude between two exposures, creating the stereoscopic effect.

it like an orange."[48] By 1875, more than 100 American photographers were trading in stereograph sets totaling over 1,000 different motifs, mostly landscapes and other sightseeing topics allowing virtual tours throughout the continent.[49] The London-based *Stereoscopic Society* (founded in 1893) advertised with the telling slogan: "No home without a stereoscope." The invention of anaglyphic prints in which the stereo images were superimposed on the same surface, but in two complementary colors (such as red and cyan or green), spread stereoscopic 3D effects to new user groups at very low cost (see Lorenz (1985) for examples). The only accessory needed to obtain the 3D effect is a pair of cheap color-coded anaglyph glasses with a filter in those two colors, one for each eye.[50] But travel impressions, vivid portraits or erotic scenes were only some of what stereographs could depict. One pioneer, Charles Wheatstone, envisioned as early as 1852, "works on crystallography, solid geometry, spherical trigonometry, architecture,

[48] Holmes (1861) p. 27; on astronomical photography and stereography see, e.g., de Vaucouleurs (1961), Pang (1997b), Hentschel (1999*a*) and Hentschel & Wittmann (eds. 2000).

[49] See Jenkins (1975) and Halsband (2008) pp. 20f. on the USA and Albrecht Hoffmann (1990) pp. 16f. on the UK and Germany.

[50] Anaglyph images were developed in 1852 by Wilhelm Rollmann in Leipzig, Germany, but became widespread only in the 20th century: see http://en.wikipedia.org/wiki/Anaglyph_3D ; see Reynaud et al. (eds. 2000) pp. 121–31 for references, examples and links to modern applications.

machinery, &c, might be thus rendered more instructive."[51] In the period of mass-produced stereographs (c.1880–1920), their omnipresence in popular contexts led to a veritable craze in various areas of science to improve visualization of complex objects. Complex molecules, for instance, or crystallographic grids were more clearly understandable and almost graspable through a stereoscope. Paul Groth (1843–1927) was the first crystallographer to embellish later editions of his textbook with a set of stereoscopic plates of the crystal structures then known.[52] These plates allowed practitioners and researchers alike rapid localization and spatial contextualization of individual atoms in a complex crystallographic lattice. Thus they could dispense with the imaginary "internal view" [*inneres Sehen*] to visualize such structures.[53] Even as this "stereomania" was subsequently declining, due to the diffusion of new technologies such as cinematography, stereography continued to be used in certain niche visual science cultures. In crystallography, William and Lawrence Bragg issued sets of stereoscopic photographs of crystals as late as 1928 and 1930,[54] and in Germany, Max von Laue and Richard von Mises also published such stereoscopic plates in two bilingual sets in 1926 and 1936.[55]

Within the somewhat related field of photogrammetry, in which the exact dimensions of an object are determined by accurate measurements of two perspectival views of it, truly stereoscopic applications had an even later start. Stereoscopic aerial photographs were taken as a convenient base from which to set out, for surveying large objects such as trenches, mountains or other difficult terrain.[56] In 1899, the Jena physicist Carl Pulfrich (1858–1927) introduced his first device for determining spatial distances based on stereoscopic photographs. In 1901, the fully fledged stereo-comparator followed, marketed by the optical company *Zeiss*,

[51] See Wheatstone (1838/1852) p. 6; Brewster (1856) likewise foresaw technical applications.

[52] See Paul Groth's *Physikalische Krystallographie und Einleitung in die krystallographische Kenntniss der wichtigsten Substanzen*, Leipzig: Engelmann, 1st edn 1876 with stereoscopic plates in its 3rd and 4th edns of 1895 and 1905.

[53] See Herlinger (1928) p. 165 on this scopic domain within crystallography: "Thereby the problem mentioned at the beginning falls away of having to put oneself into a position to get an internal view, so to speak, of the precise manner in which the individual atoms arrange themselves around each other in the lattice." ("Damit fällt die eingangs erwähnte Schwierigkeit fort, daß man sich gewissermaßen durch ein inneres Sehen hineinversetzen muß in die Art und Weise, wie die einzelnen Atome sich im Gitter gegenseitig umgeben.")

[54] See Bragg & Bragg (1928/30). For the periodization of the invention, innovation and diffusion of this visual technology see Halsband (2008) p. 41.

[55] See von Laue & von Mises (eds. 1926/36), with the assistance of Clara von Simson, drawn by Elisabeth Rehbock-Verständig (1897–1944), and translated into English by Gabriel Greenwood.

[56] See, e.g., Rudolf Burkhardt in Kemner (ed. 1989) pp. 33–42, Reynaud et al. (eds. 2000), pp. 200ff. for examples from Paris (the earliest dating from 1923) and further literature.

Pulfrich's employer. Later variants, such as the Zeiss 'stereoplanigraph,' made it possible to transform stereographic images of landscapes, taken by airplane, into topographic maps with height profiles.[57] Nowadays, computer-aided programs for digital photogrammetry are even easier.[58] Other aerial stereophotographs allowed meteorologists to reconstruct cloud shapes in 3D, whereas stereoscopic x-ray photographs yielded a 3D image of the interior of the human body long before the advent of computed tomography.[59] The fusion of stereoscopy with electron microscopic techniques allows a 3D impression of microorganisms or of microstructures of materials.[60] In all these cases of objects either at very close range or far away, the usual recipe of shifting the camera for the second exposure by an amount equaling the mean distance between the two eyes on a face (c. 2.5 inches) would not work. As a rule of thumb, stereophotographers chose an offset of roughly 1/30 of the distance to the objects in the foreground of their image, but sometimes even larger offsets were taken in order to heighten the effect. This practice became very popular among landscape photographers, but also highly controversial, since it led to a kind of enhanced perspective or 'hyperspace' that some observers regarded as "distorted," if not "monstrous."[61]

Jonathan Crary has described how each of these technical gadgets actually created a very specific *visuality* among their users at the height of popularity. Crary takes this term from Hal Foster's anthology on *Vision and Visuality* (1998), where "visuality" is defined roughly as the variegated bundle of social factors involved in the process of seeing, whereas "vision" is supposed to denote all of its anatomical, physical and geometric aspects. Foster's central idea was thus to historicize and to "socialize vision" by pointing out how the allegedly objective physical act of visual perception is heavily loaded with personal and social layers that infuse vision subjectivity and mold – if not warp – our sensorial impressions. Although this concept of visuality is most frequently taken to be a postmodern notion that has taken center-stage in the debate on visual cultures, it actually has much older roots: As Nicolas Mirzoeff has pointed out, the word had been coined by the Scottish essayist and historian Thomas Carlyle (1795–1881) in his lectures *On Heroes* (1841) simply to denote the increasing importance of visual representations

[57] See, e.g., Pulfrich (1902, 1911), Lorenz (1985) pp. 25ff., and A. Hoffmann (1990) pp. 33–7.

[58] See, e.g., Jörg Albertz in Kemner (ed. 1989).

[59] On meteorological applications, see Lorenz (1985) pp. 47–57 and in Kemner (ed. 1998) pp. 61–70; on CT scanning see below, pp. 200.

[60] On these applications, see, e.g., Jo-Gerhard Helmcke in Kemner (ed. 1989) pp. 71–8.

[61] On this controversy rooted in different norms of visuality, see Silverman (1993) pp. 748ff.

in the construction of heroic figures in the Victorian era.[62]

More recent discussants tend to agree that people from different eras as well as different subcultures, even at roughly the same times, often differ drastically in their 'visuality,' i.e., in the complex cultural baggage carried along in the process of visual perception. Members of different cultures select and conceptualize what they see differently. The same applies to their anticipations and associations, and even the intensity with which they observe, discriminate and recognize what they see. Our examples later will provide ample evidence for this claim. But here are a few findings by others also corroborating this claim of competing "visual subcultures," first advanced by members of the Birmingham School of Cultural Studies. Xiang Chen recently contrasted a visual tradition of optical measurements against a geometric tradition in his analysis of instrumental conventions and theories of light during the 19th century. The visual tradition regarded man-made optical instruments as "aids to the eye, and evaluated [them] according to how well they produced images suitable for the perception of the eye," as the ultimate "goal of the optical system." The geometric tradition strove to "reduce and eventually eliminate the role of the eye in optical experiments."[63] Following a similar vein, the Berlin historian of medicine Thomas Schlich distinguished between the subcultures of microscopic and photographic vision in the early history of bacteriology. To belong to the latter meant "to know how to 'read a photograph' and [...] to share certain presuppositions as to which interventions by the photographer were to be tolerated and which ones constituted forgery."[64] Likewise, we may regard the various types of spectroscopes, spectrographs and spectrometers encountered as competing 'visual technologies' in the sense spelled out by Mirzoeff,[65] which lead to different manifestations of visuality.

Interestingly, most of the above examples happen to come from the same era, the 19th century. This demonstrates how manifold and polyphonic these various visual domains can be, even in a limited comparative analysis of nearly synchronous case studies. If one starts to compare diachronically across longer time spans, the variations in the actors' visuality become even stronger. We

[62] For a closer analysis of these roots and possible definitions, see Mirzoeff (2006).

[63] See Chen (2000) pp. 121–8, esp. pp. 124f. for the quotes.

[64] See Schlich (2000) p. 50; cf. also Schlich in Rheinberger et al. (eds. 1997) pp. 165ff. and here p. 53 and color pl. XIII on Robert Koch's bacteriological drawings and photographs, Jordanova (1990) on medical practitioners' ways of looking, or Evelyn Fox Keller (1996) on the "biological gaze."

[65] "any form of apparatus designed either to be looked at or to enhance natural vision, from oil painting to television and the Internet." From the introduction to Mirzoeff (ed. 1998).