SCIENCE FROM SIGHT TO INSIGHT

How Scientists Illustrate Meaning

ALAN G. GROSS AND
JOSEPH E. HARMON

THE UNIVERSITY OF CHICAGO PRESS
CHICAGO AND LONDON

ALAN G. GROSS is professor of communication studies at the University of Minnesota–Twin Cities. He is the author or coauthor of several books, including *The Rhetoric of Science* and *Starring the Text: The Place of Rhetoric in Science Studies*.
JOSEPH E. HARMON works as a science writer and editor at Argonne National Laboratory. He is the coauthor with Alan Gross of several books, including *Communicating Science*, *The Scientific Literature: A Guided Tour*, and *The Craft of Scientific Communication*.

The University of Chicago Press, Chicago 60637
The University of Chicago Press, Ltd., London

Printed in the United States of America

23 22 21 20 19 18 17 16 15 14 1 2 3 4 5

ISBN-13: 978-0-226-06820-6 (cloth)
ISBN-13: 978-0-226-06848-0 (paper)
ISBN-13: 978-0-226-06834-3 (e-book)
DOI: 10.7208/chicago/9780226068343.001.0001

Library of Congress Cataloging-in-Publication Data

Gross, Alan G.
Science from sight to insight : how scientists illustrate meaning / Alan G. Gross and Joseph E. Harmon.
pages. cm.
Includes bibliographical references and index.
ISBN 978-0-226-06820-6 (cloth : alk. paper) — ISBN 978-0-226-06848-0 (pbk. : alk. paper) — ISBN 978-0-226-06834-3 (e-book) 1. Visual communication in science. 2. Communication in science. I. Harmon, Joseph E. II. Title.
Q223.G772 2014
501'.4—dc23

2013005918

♾ This paper meets the requirements of ANSI/NISO Z39.48-1992 (Permanence of Paper).

SCIENCE FROM SIGHT TO INSIGHT

The esthetic image is first luminously apprehended as selfbounded and selfcontained upon the immeasurable background of space or time which is not it. You apprehended it as *one* thing. You see it as one whole. You apprehend its wholeness. That is *integritas*. . . .—Then—said Stephen—you pass from point to point, led by the formal line; you apprehend it as balanced part against part within its limits. . . . In other words, the synthesis of immediate perception is followed by the analysis of apprehension. Having first felt that it is *one* thing you feel now that it is a *thing*. You apprehend it as complex, multiple, divisible, separable, made up of its parts, the result of its parts and their sum, harmonious. That is *consonantia*. . . . [*Claritas* is] the artistic discovery and representation of the divine purpose in anything or a force of generalization which would make the esthetic image a universal one, make it outshine its proper conditions.
—James Joyce, *A Portrait of the Artist as a Young Man* (1916)

The fundamental event of the modern age is the conquest of the world as picture.
—Martin Heidegger, "The Era of the World Picture" (1938)

Seeing is . . . an amalgamation of the two—pictures and language.
—N. R. Hanson, *Patterns of Discovery* (1958)

CONTENTS

INTRODUCTION

Verbal-Visual Interaction in Science

It is remarkable but seldom remarked that scientific communication is unique among the learned enterprises. To see what we mean, flip through the pages of a research article in *Science* or *Nature*. Only in the case of the sciences do practitioners communicate routinely not only through words, but also through tables and images. In literary criticism and science studies, to take two typical scholarly instances, words are ordinarily the sole means of expression, a practice that can sometimes lead to results seriously at odds with reality. Much that passes for Shakespearean criticism, for example, treats its subject as a literary artist. But except in his poems Shakespeare was a literary artist only by accident. By intent, he was a playwright, that is, he made plays, or rather scripts for plays, those combinations of words, actions, actors, sets, and costumes that, with a director's help, constitute the "two hour's traffic" on our stages. It is these verbal-visual amalgams that are the only proper objects of Shakespearean dramatic criticism; to these, Shakespeare is only a contributor. To treat him otherwise is, as Gilbert Ryle (1949) would say, to make a category mistake. Analogously, in much that passes for science studies, scholars eschew the careful analysis of images, despite the fact that the texts with which science studies deal are replete with them. In our view, this is another category mistake, one we hope this book will help correct.

The motives for this communicative mix of words, tables, and images are not hard to find. Tables are an integral part of so many scientific texts because running text is always a poor choice when masses of data must be presented. Visual representations also play an important role in so many scientific texts because establishing scientific truth "almost always requires making something visible and analyzable" (Taylor and Blum 1991, 126). Words, tables, images—each semiotic mode is a vital tool for learning how the world works and for communicating that information to others: indeed, scientific meaning is, we would contend, the product of the interaction among these three elements.[1] The history of scientific communication constitutes our evidence for this claim. We know of no other genre of written communication in which the tabular and visual have held so privileged a place over so long a time. Leonardo da Vinci's notebooks, to use one of the most illustrious early examples, are an intricate web of visual and verbal information on just about every manuscript page, as the following image illustrates.

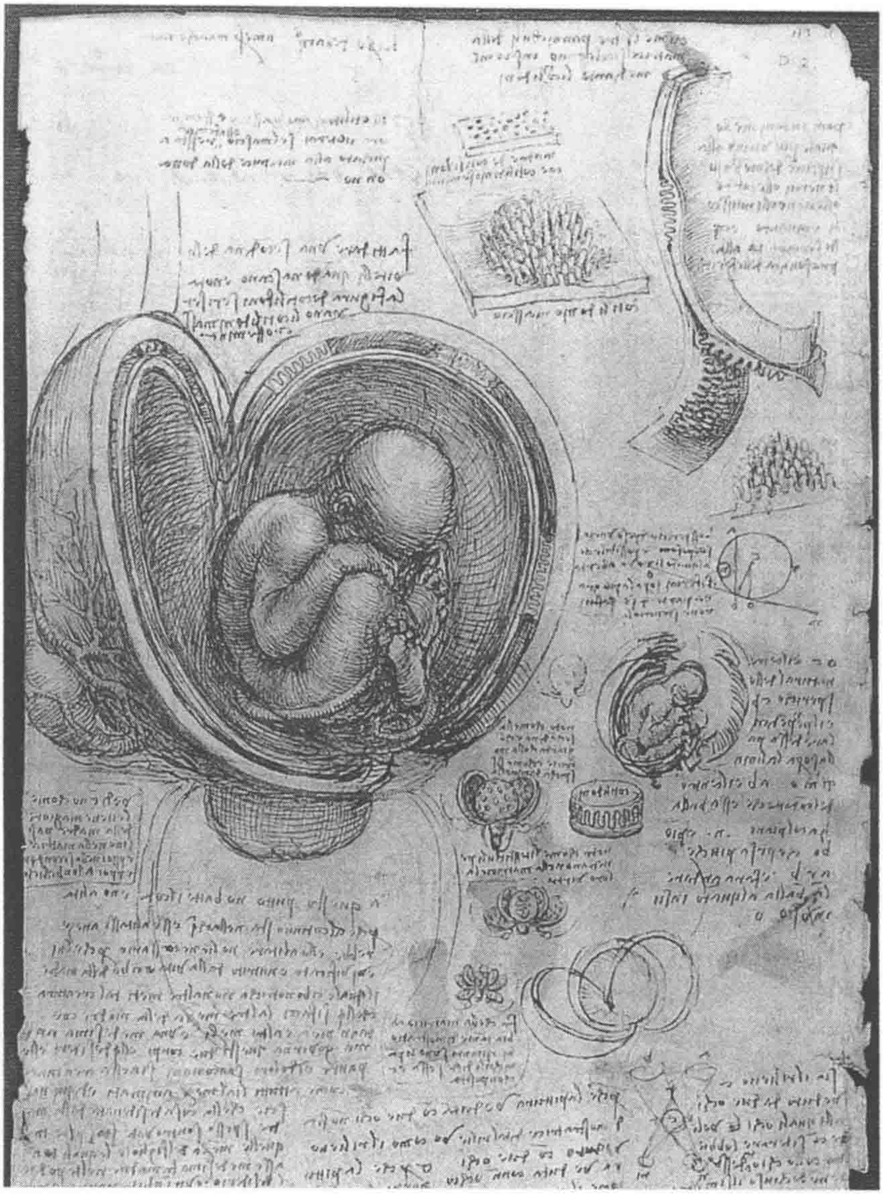
We are not claiming Leonardo's notebooks are typical of the early scientific literature. On the printed page, it was not until the middle of the nineteenth century that the full integration of the textual, tabular, and visual was realized. But we do contend that, at least from the vantage of the twenty-first-century scientific literature, the evolution in that direction from the earliest days of the printed scientific literature now seems inevitable.

Our book extends a vital but generally neglected insight of historian of geology Martin Rudwick (1976)—that the images embedded in scientific texts have epistemic importance and ought not be ignored or subordinated in exegesis. While in his writings on the history of geology Rudwick has consistently employed this insight, and while historians, philosophers, cognitive scientists, and sociologists have written insightfully about visualization in science, no one, to our knowledge, has attempted a general theory of verbal-visual interaction in the communication of science. Our book is intended as a first step in that direction.

A SHORT HISTORY OF SCIENTIFIC VISUALS AND TABLES

From the sixteenth to the nineteenth century, the illustrated scientific book remained the gold standard of scientific communication. The sixteenth century saw the publication of detailed anatomical drawings in Andreas Vesalius's *De humani corporis fabrica*, and astronomical tables and Euclidean diagrams supporting Nicolaus Copernicus's unfolding mathematical argument for a heliocentric universe in *De revolutionibus*; the seventeenth century, intricate drawings of the microscopic world in Robert Hooke's *Micrographia*, and geometric diagrams related to fundamental laws of motion in Isaac Newton's *Principia*; the eighteenth century, schematics mapping the refraction of light rays through a prism in Newton's *Optics*, and drawings of

1. And, importantly, equations—though their integration into a comprehensive theory of scientific communication awaits an expertise that exceeds ours.



A typical page from Leonardo's notebooks (c. 1510), integrating the verbal and the visual.
Credit: Luc Viatour.

scientific instruments and tables systematically arranging the known universe of chemical elements and compounds in Antoine Lavoisier's *Traité élémentaire de chimie*; the nineteenth century, geographic strata that reveal the earth's history in Charles Lyell's *Principles of Geology*, and drawings of floating microbes produced by fermentation in Louis Pasteur's *Études sur la bière*.

Visuals and tables have also figured prominently in the main competitor to the scientific book, the research article, which made its debut in 1665 in London and Paris. Until the early nineteenth century, the emphasis in journal articles was firmly on establishing facts of observation and communicating them by means of verbal descriptions and pictures, primarily realistic drawings and schematics of natural and man-made objects. Still, only half the articles from this period contain tables or visuals. Moreover, the physical integration of figure with text tended to be haphazard in large part as a result of limitations in printing practices. Figures might appear gathered together at the end of each article or at the end of the journal. They might appear in the margins. They might appear within an article on pages separate from the text or integrated into the page, close to their mention. They might or might not have descriptive captions. They might or might not be numbered. Tighter integration of text with the accompanying images, along with titles and numbers, did not occur until well into the nineteenth century when innovations in imaging technology made this practice economically feasible.

The nineteenth century also added a new visual modality to scientific books and journal articles: photographs, sometimes taken with the aid of a telescope or microscope. Prominent nineteenth-century examples include Edgar Crookshank's photographs of bacteria, Jules Janseen's photographs of the sun's surface, and Wilhelm Röntgen's X-ray photographs revealing the skeletal structure of the human hand.[2] Despite their advantages, for technological and economic reasons black-and-white photographs did not become routine in scientific books and articles until the mid-twentieth century. Outside the precincts of popular science journals such as *National Geographic* and *American Scientist*, the regular appearance of color photographs had to wait for personal computers and the Internet. Now well-funded journals such as *Nature* and the *Journal of the American Medical Association*, better known as *JAMA*, are full of them.

The nineteenth century also marks an important conceptual shift in visualization practices, first noted by Martin Rudwick: geologic schemat-

2. These and other examples of early scientific photographs appear in Keller (2008).

ics shifted from the representation of geologic structures to that of structural causes. With this shift, geologic visuals became "a kind of thought-experiment in which a tract of country is imagined as it would appear if it were sliced vertically along some particular traverse of the topography, and opened along that slice in a kind of cutting or artificial cliff" (Rudwick 1976, 166). By the 1830s the visual language of such sections formed a set of conventions "that were generally accepted and widely understood not only by practicing geologists but also by the wider audience for geology" (172). During this same period other disciplines invented theory-laden means for representing the structures and mechanisms of nature, such as molecular models, evolutionary trees, and electromagnetic field schematics.

During the twentieth century, scientific journals surpassed books as the preferred host for scientific publication. And in these journals, visuals and tables occupy about one-quarter of the average article. Few pages are without them. Of the different visual types on display, Cartesian graphs dominate, a by-product of a major shift in the emphasis of scientific practices from the gathering of observations to the generation and analysis of data, measured or calculated. Cartesian graphs made their first appearance in the scientific literature in the late eighteenth century, invented independently by William Playfair in England and Johann Heinrich Lambert in Germany (Tilling 1975; Wainer 2005). The first visual form with genuine heuristic potential, they contribute to the process of discovery by helping scientists detect changes in data that would not otherwise be apparent. They also contribute to scientific argument by representing law-like relationships as correlations between values on their ordinates and abscissas, and by allowing easy comparisons between theory and experimental data. Although during the eighteenth and nineteenth centuries, this new form for representing data was codified and championed by Playfair and William Whewell in England, James Joseph Sylvester and J. Willard Gibbs in America, and Étienne-Jules Marey in France (Hankins 1999), in our study of the scientific journal literature (Gross et al. 2002), we found no evidence that Cartesian graphs were in general use until the early twentieth century. Until that time, tables remained the principal means for displaying data outside of running text.

The twentieth-century invention of image-producing research equipment—X-ray-based material analyzers, cloud chambers, particle accelerators, electron microscopes, satellite space telescopes, DNA analyzers, and so forth—has moved image creation and analysis closer to the heart of scientific discovery and dissemination. Given the importance of such equipment, the near absence of their depiction in the modern scientific literature may seem odd. Before the twentieth century, after all, such pictures were not uncommon. For example, all of the visuals in Antoine Lavoisier's *Traité élémentaire de chimie* are illustrations of experimental instruments. This is no accident: all the effects Lavoisier writes about in a book that turned chemistry into a modern science are the products of the instruments he uses. But the scarcity of illustrations of instruments in contemporary science is due not to their diminished importance; it is due to their standardization:

> The rapid movement of research equipment from one modification to the next is key to the mode of rapid discovery in which scientists take so much confidence; they feel that discoveries are there to be made along a certain angle of research because the previous generation of equipment has turned up phenomena which are suitable for the intellectual life of the human network. . . . The genealogy of equipment is carried along by a network of scientific intellectuals, who cultivate and cross-breed their technological crops in order to produce empirical results that can be grafted onto an ongoing lineage of intellectual arguments. (Collins 1998, 870–71)

In general, those arguments are fortified by images of the products of research equipment.

Until the late twentieth century, scientific visualization was limited by the printed page, a medium in which color is often too expensive for editorial budgets, space frequently prohibits images large enough to achieve epistemic clarity, and three-dimensional imaging and motion pictures are out of the question. That has changed with the invention of PowerPoint and similar slide projection programs. In the case of these, the subject of our penultimate chapter, the image is absolutely central, an alteration affecting the representation of science. More important on this front, however, is the movement of the scientific literature from the printed page to the computer screen via the Internet, particularly in such preeminent and well-financed journals as *Science*, *Nature*, and *JAMA*. As will be shown in our last chapter, this new development, combined with the power of the computer for the visual representation of large masses of data, has unleashed a wave of creative image-making unprecedented in the history of scientific visualization.

STATE OF THE FIELD

The classical works in rhetorical criticism paid little heed to the visual element. Neither Aristotle nor Cicero in ancient times, and neither Chaim

Perelman nor Kenneth Burke in modern ones, addressed this issue. Their neglect is understandable. These critics focused on a range of texts in which the visual is of no, or only marginal, importance: orations, sermons, and philosophical and literary works. But despite the obvious communicative importance of the visual in science, in case studies in the rhetoric of science, the emphasis has remained firmly on the analysis and explanation of the verbal. Charles Bazerman's landmark *Shaping Written Knowledge* (1988) reproduces two scientific articles, each of which has a visual, neither of which is discussed; no other scientific images appear. Marcello Pera's *The Discourses of Science* (1994) has only four diagrams—none directly concerned with scientific visualization. Jean Diez Moss's *Novelties in the Heavens* (1993) and Leah Ceccarelli's *Shaping Science with Rhetoric* (2001) contain, respectively, one scientific image, and none. While Greg Myers's *Writing Biology* (1990) and Scott Montgomery's *The Scientific Voice* (1996) contain fourteen and ten scientific images, respectively, these are confined to a single chapter. Jeanne Fahnestock's *Rhetoric Figures in Science* (1999) contains only nine images, while our *Communicating Science* (2002), written with Michael Reidy, contains only sixteen.

In the case of most speeches, most novels, most poems, and most academic articles, exegesis that ignores the visual may be plausibly defended. But in the case of those subjects that depend for their meaning on verbal-visual interaction, science among them, no such defense is plausible. Despite this relative neglect, our review of the academic literature across various disciplines suggests that for the understanding of scientific images we can draw on a considerable body of work from a wide range of disciplines.

We start with a discipline one might think would not have much to offer about the visual—philosophy. Contemporary philosophers of science work within two very different research traditions—the analytic and the phenomenological. From both traditions, we have substantial contributions relevant to scientific visualization. In *Patterns of Discovery* (1958), analytical philosopher Norwood Russell Hanson made three prescient observations: first, that "seeing is a 'theory-laden' undertaking" (19); second, that discovery in science is essentially a matter of *seeing as*, of substituting for the eye we all possess the eye of analysis scientists develop through training and experience; and finally, that the intended meaning of a given visual "is brought out by the verbal context in which it appears" (15). For Martin Heidegger (1938), working in the wake of Edmund Husserl's phenomenology, truth—including scientific truth—is the consequence of "unconcealment," the lifting of a veil. But as scientific truth is a special kind, its visualization is also special: scientific truth is seen as "a calculable nexus of forces," a nexus that reveals itself largely by means of mathematical equations and specialized instruments designed to inquire into nature. It is this process of revelation that turns objects of nature into objects of science. And through this process, the world is "conceived and grasped" as a picture, a picture that is "En-framed," that is, seen through the lens of its mathematicization.

Heidegger's philosophy tends toward the abstract; his books reproduce not a single scientific visual. But some philosophers of science working in the analytical tradition have applied their critical intelligence to episodes in the history of science in which visual communication has figured prominently. Arthur I. Miller (1984) has brought Heidegger's philosophy into the real world by tracing the visual thinking central to the creative breakthroughs of eminent twentieth-century theoretical physicists. Ronald Giere (1996) has given us an instance in the history of geology in which the visual had crucial epistemic significance in settling the controversy over plate tectonics. James Griesemer and William Wimsatt (1989) have demonstrated that germ-plasma diagrams, initially developed by August Weismann in the late nineteenth century, then adopted and modified by others, form a body of evidence to which a theory of evolutionary epistemology can be applied.

In books and articles, cognitive experimentalists and theorists have contributed immeasurably to an increased understanding of how the brain processes verbal and visual stimuli. They have been interested mainly in two topics: the heuristic value of visuals in the thought processes of scientists and the cognitive processes involved in the comprehension of graphs. On the first topic, we have the work of Herbert Simon and such collaborators as Jill Larkin (1987); and on the second, the work of Stephen Kosslyn (1989), Steven Pinker (1983, 1990), and Edward Tufte (2001). William Cleveland and Robert McGill (1984, 1985) may also be counted in this group. In another book, *How Maps Work*, Alan MacEachren (2004) synthesized the published cognitive and semiotic literature into a comprehensive theory of cartographic comprehension.

Some historians have investigated episodes in the history of science that have revolved around the production and analysis of visuals. Julia Voss (2010) has scrutinized how drawings and photographs contributed to Darwin's development of evolutionary theory. David Kaiser (2005) has tracked how Feynman diagrams for representing subatomic particle behavior rapidly infiltrated the practice and teaching of physics after World War II. Peter Galison has addressed the question of "how pictures and counts got to be the bottom-line data of [twentieth-century] physics" (1997, xvii). Martin Rudwick (2005) has traced how both geological verbal and visual commu-