13 Social Studies of Scientific Imaging and Visualization

Regula Valérie Burri and Joseph Dumit

Images are inextricable from the daily practices of science, knowledge representation, and dissemination. Diagrams, maps, graphs, tables, drawings, illustrations, photographs, simulations, computer visualizations, and body scans are used in everyday scientific work and publications. Furthermore, scientific images are increasingly traveling outside the laboratories and entering news magazines, courtrooms, and media. Today, we live in a visual culture (e.g., Stafford, 1996), which also values numbers (Porter, 1995; Rose, 1999) and science (Hubbard, 1988; Nelkin & Tancredi, 1989). Scientific images rely on these cultural preferences to create persuasive representations. The ubiquity of scientific images has raised the interest of STS scholars in studying visual representations and in exploring the visual knowledges they engender.

Visual representations in science have been studied from a variety of different theoretical and disciplinary perspectives. Philosophers of science have raised ontological questions about the nature and properties of visual representations in science and have theorized about the intersection of hermeneutics and science (among others, Griesemer & Wimsatt, 1989; Ruse & Taylor, 1991; Griesemer, 1991, 1992; Ihde, 1999). Historians of science have pointed to the importance of scientific depictions of nature for the emergence of a new concept of objectivity in the nineteenth century (Daston & Galison, 1992, 2007). They have drawn attention to visualization instruments and visual representations used in experimental systems from the Early Modern period to today (among many others see Cambrosio et al., 1993; Galison, 1997; Rheinberger, 1998; Kaiser, 2000; Métraux, 2000; Breidbach, 2002; Francoeur, 2002; Lefèvre et al., 2003; Hopwood, 2005; Lane, 2005). Other works have reconstructed the histories of (medical) visualization technologies and their introduction in the field of medicine (e.g., Yoxen, 1987; Pasveer, 1989, 1993; Blume, 1992; Lenoir & Lécuyer, 1995; Holtzmann Kevles, 1997; Warwick, 2005; Joyce, 2006). Laboratory studies have examined the use of images in the manufacture of scientific knowledge from sociological and anthropological perspectives (Latour & Woolgar, 1979; Knorr Cetina, 1981; Latour, 1986, 1987, [1986]1990; Lynch, 1985a, b, 1990, 1998; Lynch & Edgerton, 1988; Lynch & Woolgar, 1990; Knorr Cetina & Amann, 1990; Amann & Knorr Cetina, [1988]1990; Traweek, 1997; Henderson, 1999; Prasad, 2005a).

Work on visual images at the intersection of STS and other disciplines is also thriving. Scholars working in art studies proclaimed a "pictorial turn" in culture (Mitchell, 1994) and reflected on the relation of artistic and scientific images and on the regimes of representation in which they are displayed (e.g., Stafford, 1994, 1996; Jones & Galison, 1998; Elkins, forthcoming). In *Picturing Science, Producing Art*, Caroline Jones and Peter Galison (1998) staged an encounter between art theorists' analyses of the modes of interpretation and STS's ideas about social construction of scientific knowledge and technologies of production. Style and genre as understood by art historians created contexts in which laboratory practices and cultural practices could be seen to share specific aesthetic forms. Finally, cultural studies explored the intersections of scientific imagery with popular narratives and culture (e.g., Holtzmann Kevles, 1997; Lammer, 2002; van Dijk, 2005; Locke, 2005) and reflected about images of the body from a feminist perspective (e.g., Duden, 1993; Cartwright, 1995; Casper, 1998; Treichler et al., 1998; Marchessault & Sawchuk, 2000). Some of this work draws on semiotic, linguistic, psychoanalytical, and philosophical traditions of thinking about the visual and the existence of a visual language (e.g., Goodman, 1968; Arnheim, 1969; Metz, 1974, 1982; Rudwick, 1976; Barthes, 1977; Mitchell, 1980, 1987; Myers, 1990; Elkins, 1998; Davidson, [1996]1999) and about specific "techniques of the observer" (Crary, 1990; Elkins, 1994).

The body of work concerned with scientific visualizations is thus extremely diverse, and any attempt to synthesize the various strands would necessarily be reductive and selective. Because it is also a very lively area of concern, its boundaries are difficult to demarcate. Accordingly, instead of an exhaustive overview of the work done so far, this chapter outlines approaches to the social studies of scientific imaging and visualization (SIV) and raises some further questions and directions concerning the future study of visual representations in science.

IMAGING PRACTICES AND PERFORMANCE OF IMAGES

SIV asks questions such as what is the specificity of the visual as a form of (scientific) knowledge? If the visual is a special form of knowledge, understanding, and expression, how and why is it different from other forms of knowledge? In contrast to most philosophical, art historical, or linguistic studies on visual representations in science, SIV answers these questions by focusing on the social dimensions and implications of scientific images and visual knowledge rather than inquiring into their nature,[1] as has been exemplarly demonstrated by Gordon Fyfe and John Law's *Picturing Power: Visual Depiction and Social Relations* (1988). SIV follows the practice turn in social theory (Schatzki et al., 2001) by its interest in the epistemic practices of the production, interpretation, and use of scientific images.

This manner of exploring the role of visual representations in scientific activities when examining the manufacture of scientific knowledge has been one of the trademarks of laboratory studies. In his ethnomethodological studies of scientific work, for example, Michael Lynch analyzed the constitution of images and showed how specimens are modified in the laboratory and turned into visual displays for purposes of investigation (Lynch, 1985a,b, 1990, 1998; Lynch & Edgerton, 1988). Karin Knorr Cetina explored how visual representations interact with scientists' versatile discourses in everyday practice and how they work in experiments (Knorr Cetina, 1981; Knorr Cetina & Amann, 1990; Amann & Knorr Cetina, [1988]1990) while Bruno Latour has argued that images are deployed by researchers to find allies within the scientific community and create networks that stabilize their research findings (Latour & Woolgar, 1979; Latour, 1986, [1986]1990, 1987).

SIV shares these concerns with laboratory studies but extends the focus beyond scientific laboratories and communities. It asks: What happens when images travel outside academic environments and diffuse into other contexts? SIV explores the trajectories of scientific images from their production and reading through their diffusion, deployment, and adoption in different social worlds to their incorporation into the lives and identities of individuals, groups, and institutions. Following the "social life of images," SIV includes the study of both imaging practice and the performance of scientific imagery with particular attention to its visual power and persuasiveness.

Scientific images and visualizations are exceptionally persuasive because they partake in the objective authority of science and technology, and they rely on what is regarded as immediate form of visual apprehension and engagement. As Donna Haraway observed, "There are no unmediated photographs . . . only highly specific visual possibilities, each with a wonderfully detailed, active, partial way of organizing worlds." (Haraway, 1997: 177). Haraway's feminist approach treats scientific images as objectivizing gazes that appear universal and neutral while selectively privileging certain points of view and overlooking others. In the daily news, for instance, images of the earth as seen from space—originally products of the space program—are often used to invoke concern for the environment by appealing to the idea of one earth as a precious place shared by all (Haraway, 1991; Jasanoff, 2004). This earth image, even though it is highly processed, suggests the *realism* of a photograph, an unmediated (as in unaltered, immediate, direct, or true) relationship between the viewer and the object. In semiotic terms, an image of earth as seen from space, without clouds, is *hyper-real*: it is stylized, reduced in layers, and produced to correspond not with what would be seen by an astronaut but with an idealized *concept* of Nature. As such it is more compelling than a "real" picture would be.

There is a *desire to see* the truth in the visualizations of phenomena such as the whole earth, the brain in action, DNA diagrams, or global warming. The history of images in science and art, however, has shown that seeing and recognition are historically and culturally shaped (e.g., Alpers, 1983; Daston & Galison, 1992; Hacking, 1999). Foucault's ([1963]1973) analyses of medicine, madness, and prison systems demonstrated the value of historicizing *what can be seen*, through close attention to the sciences and technologies, bureaucracies, and classification systems (cf. Rajchman, 1991; Davidson, [1996]1999; Hacking, 1999; Rose, 1999).

The practice turn in STS taught us to attend to the *work* of science and technology in terms of both the processes of production and the resulting products. The challenge of SIV is now to incorporate together the work of science and technology in producing particular visual objects with the historicity of what any scientific or lay audience is given to see.

Representation in Scientific Practice, edited by Michael Lynch and Steve Woolgar (1990), has provided a touchstone for further work in this area. This collection of articles draws on laboratory studies and uses ethnographic and ethnomethodological methods to study what scientists do with words, pencils, paper, computers, technologies, and colors when dealing with images. Furthermore, the volume expanded the use of semiotic and rhetorical tools of linguistic analysis to the social study of visual objects and scientists' representational practices when using terms such as "inscription" or "evidence" (Latour & Woolgar, 1979; Rheinberger, 1997). The volume shows that visual representations cannot be understood in isolation from the pragmatic situations in which they are used. Since scientists "compose and place representations within texts, data sets, files, and conversations . . . and . . . use them in the course of a myriad of activities" (Lynch & Woolgar, 1990: viii), it is not enough to simply describe the things images depict or the meanings they reflect. We have to focus also on the textual arrangements and discursive practices within which these representations are embedded.

Lynch and Woolgar's collection is a starting point for studying the cultural embeddedness of the practices of the making and handling of visual representations and of the shaping, distributing, applying, and embodying of scientific visual knowledge. If seeing is so often believing, SIV must demonstrate how the making and using of images come together with seeing and believing in practices of scientific truth-making and perceptual convention.

In the remainder of this essay, we organize our discussion around three artificially separated topics: the production, engagement, and deployment of visualizations. When studying *production*, STS scholars examine how and by whom images are constructed by analyzing the practices, methods, technology, actors, and networks involved in the making of an image. The analysis of *engagement* focuses on the instrumental role of images in the production of scientific knowledge. Research on *deployment*, finally, refers to the use of scientific visualizations in different social milieus. It studies how images diffuse into nonacademic environments and analyzes the intersections of different forms of (visual) knowledge. Deployment also includes scientific images becoming parts of the body image of individuals and "objectively" grounding the everyday givenness of the social world. In other words, examining production means studying images as artifacts; examining engagement means analyzing the role of images as instruments in science; and examining deployment stands for focusing on how images are used outside the laboratories and how they intersect with different forms of knowledge about ourselves and our world. This analytic grid draws special attention to the interpretative openness of scientific images and to their persuasive power.

PRODUCTION

Like all artifacts, scientific images and visualizations are constructed by combinations of machines and people using concepts, instruments, standards, and styles of practice. STS offers methodological tools for telling the history of *how* a particular image—a picture in a scientific journal or a computer screen showing the visual result of a program—was created. The retrospective approach demonstrates that images result from a lengthy series of technological opportunities and constraints, negotiations, and decisions.

To illustrate image production, we offer the example of magnetic resonance images. MRI images depend on a series of decisions about the setup of the MRI machine and the data to be generated. Scientists and technicians make decisions about parameters such as the number and thickness of the cross-sectional slices, the angle they are to be taken from, and the scale or resolution of the image data. Decisions also have to be made when it comes to post-processing the images on the screen: perspectives can be rotated, contrast modified, and colors chosen for scientific publications. These specific decisions do not depend on technical and professional standards alone but also on cultural and aesthetic conventions or individual preferences (cf. Burri, 2001, and forthcoming). An MRI scan thus is not a "neutral" product but the result of a series of specific, culturally shaped sociotechnical negotiations, which imply—like any technological fabrication—processes of formalization and transformation (Lynch, 1985a, 1985b, 1990).

Examining visual displays used in scientific publications, Lynch (1990) described their pictorial space as a graphic, coordinate space, entailing a previous stage when the scientific object—whether a mouse, a cell, a brain, or an electron—had been rendered spatial and measurable, "mathematized." As this requirement is formalized, "mathematization" becomes a *necessary assumption* of the science and image that depends on it. We can thus attend to the costs and the powers of this assumption. In this case, the parts of the cell that could not be measured became unimportant to the work being done in the experiment. When mathematization is built into computerized instruments and software, the unmeasured can be completely and invisibly erased.

Who is involved in image production stages is as important a question to pursue as *how* the images are produced. While some images are produced by a single person from start to finish (even if relying on software and instruments produced by others), other images are the result of a series of hand-offs among individuals, and still others are coordinated team efforts. Schaffer and Galison have each attended closely to this labor dimension of image production. Schaffer's (1998) article "How Astronomers Mark Time" delineates the variety of different labor arrangements possible within the same community of scientists at the same time. In one case, a number of individuals were organized so that they could virtually replicate the operation of an automatic pattern-recognition machine. Above them, the scientist as expert and manager consolidated their work as the author and true interpreter of the meaning of the images they selected. Galison (1997) has shown similar processes in physics, including many instances where gender and class divisions mirrored discriminatory practices found elsewhere in industry at the time. Today this form of labor organization continues: the authors have witnessed many instances of undergraduates employed in brain imaging laboratories to perform recognition tasks that either cannot currently be automated or are cheaper to accomplish by employing undergraduates than by using specialized hardware and software.

It is important to understand who knows what, who is allowed to know, and who can actually say what he or she knows. Early x-ray technicians, for instance, professionalized in alliance with radiologists through an agreement that the technicians would learn anatomy so as to be able accurately to position x-ray machines, but they would not learn pathology in order to preserve the exclusive diagnostic ability of the radiologist-doctor (Larkin, 1978). CT scanning posed a problem to this division of epistemic labor because adjusting the CT scanner to produce diagnostically useful images *required knowing* what pathological objects such as tumors *looked like.* CT technicians therefore had to learn pathology. Barley (1984) documented instances when technicians had developed apparent visual diagnostic expertise through deep familiarity with the instrument but were not allowed (legally and conventionally) to express it and instead had to guide some less familiar radiologists indirectly to the proper conclusions. Barley noted that this type of interpretive hierarchy reversal was a contingent local phenomenon as it occurred only in one of the two hospitals he studied. Noticing local variation in who *can* read images and who is *allowed* to read them is a hallmark of STS insight (e.g., Mol & Law, 1994; Jasanoff, 1998).

Visual expertise also creates its own form of literacy and specialization. Scientific and medical illustrators have often been valued members of experimental teams, but with computer visualization, a great number of new specialties have arisen. Simulation modelers, programmers, interface designers, graphic designers, as well as computer-based electron and fluorescent microscope makers have all established distinct subdisciplines of visual science and technology necessary to most cutting-edge labs, with their own journals and professionalized career tracks. They also can move among many different disciplines—e.g., biology, chemistry, physics, engineering, and mathematics—creating not just trans-disciplinary visual and digital standards but new trading zones in visual and interactive instruments, algorithms, and concepts.

ENGAGEMENT

If studying production examines how and by whom an image is *made,* studying engagement means examining how images are *used* in the course of scientific work and are made instrumental in the production of scientific knowledge. How are images talked about? What roles do they play in this talk? What concepts do they represent, and what forms of creativity do they engender? Engagement analysis treats each visual form as an actor in its own right, actively involved in the doing of science.

In disciplines using computer visualization, hundreds of images are often produced in the course of a single experiment. Some of these images are treated as uninterpreted raw data, other images are manipulated visually in order to make data meaningful, and still other images are interpretive summaries of known meanings. In a biology experiment, for instance, a digital confocal microscope may collect data on protein changes in a moving cell in full color plus three fluorescent channels (each keyed to a different gene) over a ten-minute period. The resulting data file contains what the scientists call seven dimensions of data (three physical dimensions, time, and the three different gene activities, all located spatially). The total size of this one collection of data is over three terabytes (over 3000 gigabytes). Although many choices have been made as to what is being collected, this visual data collection is treated by the researchers as *raw data* requiring extensive processing, analysis, and interpretation as well as massive reduction in size to become meaningful at all.

A variety of data-mining techniques, qualitative visual selections, and quantitative algorithms are then applied to generate a series of different screen images. These visualizations—alternatively called models, hypotheses, maps, and simulations—are provisional and interactive. The researchers constantly tweak them, altering parameters, changing color scales, substituting different algorithms or statistical analyses. These visualizations are part of *making the data meaningful*. They are interstitial, facilitated modes of seeing and intervening. One way of analyzing this process is to investigate how images contribute to the generation of an "objectified" knowledge by reducing the uncertainty of the observations and narrowing down the interpretative flexibility of research findings (Latour, 1986, [1986]1990, 1987; Amann & Knorr Cetina, [1988]1990; Lynch & Woolgar, 1990; and Beaulieu, 2001). In some cases, the same computer interface that enables data reconfiguration also runs the experimental instruments themselves, shaping future data collection.

Finally, when a research team reaches a provisional conclusion, the same software can be used to construct a clear summary of this conclusion as a meaningful visualization of the *data as knowledge*. In this construction, the image is tweaked toward a coherence of reception, with aesthetic and scientific conventions in mind (Lynch & Edgerton, 1988). The work of Edward Tufte (1997) is important to consider here from an STS perspective as he has spent a career looking at how one can most effectively convey a complex known meaning to an audience via a scientific graph or visualization. He demonstrates the hard work and many forms of visual literacy required to create shared meanings.

Once an image becomes part of a body of knowledge, it can be used to diffuse and stabilize the knowledge and theoretical concepts it represents. As Latour and others have shown, visualizations are instruments to support and transport arguments used to convince other scientists (see also Keith & Rehg, chapter 9 in this volume). In other words, images are advantageous in "rhetorical or polemical" situations, and they help researchers find allies within the scientific community (cf. Latour, 1986, [1986]1990; Traweek, 1997; Henderson, 1999).

A consequence of any scientific image or visualization is that the representational practice involves a new conceptual space. Whether these are the two dimensions of branching trees on a piece of paper (Griesemer & Wimsatt, 1989) or the complex simulated "world" of artificial life (Helmreich, 1998), the material basis of the representation invokes its own rules, which in turn bear upon the scientific object in creative and challenging ways. In the *Visible Human Project*, for instance, a data set was created by finely slicing a frozen cadaver, photographing the cross-sections, and digitizing the images, generating a new body space with depth, volume, and colors that could be "flown through" (Waldby, 2000). Questions about the generalizability of this body space based on one individual led to a *Visible Woman Project*, and a *Visible Korean Project*, illustrating the intractable yet generative problems of universalistic projects (Cartwright, 1998). The *Visible Human Project* in turn serves as the basis for virtual simulations expected to train future generations of surgeons, creating additional questions about how to prepare them for the human variability they will face with "real" patients (Prentice, 2005). To use visualization, then, is to be disciplined by its spatial and epistemic standards (see Cussins, 1998).

Returning to the experimental engagement with scientific images, we can note their wild fecundity with respect to creativity and invention. Just as for models, paper tools, thought experiments, and diagrams, a key source of legitimacy for visualizations in science lies in their usefulness (Morgan & Morrison, 1999). Data volume alone often serves as the justification for visualizations as indispensable first steps in generating hypotheses. Learning to see with the help of diagrams and models has been documented throughout science and medicine (Dumit, 2004; Myers, forthcoming; Saunders, forthcoming). Cambrosio, Jacobi, and Keating's essay on "Ehrlich's 'Beautiful Pictures' " (1993) shows how a series of hand-drawn animations of antibodies were crucial in making such objects "visible" in the microscope. These hand-drawn images were themselves *epistemic creations*, essential tools in thinking, theorizing, and creating (see also Hopwood, 1999; Francoeur, 2000).

Attending to visualizations as *interactive* also requires attention to the researchers' bodily engagement with computers and other instruments. In direct contrast with a simplistic analysis that sees interaction on a computer screen as a form of disembodiment and of a virtual separation of person and object, Myers (forthcoming) found that protein crystallographers had to develop an intense form of embodied relationship with the complex three-dimensional (3D) objects on the screen in front them whose structure they were trying to "solve." In previous decades, 3D models of the same proteins were painstakingly built out of wire, wood, glass or plastic. But these had the physical disadvantage of being too heavy and unwieldy and were difficult to modify (Francoeur, 2002; de Chadarevian & Hopwood, 2004). Visual interactive expertise still required mentoring, Myers showed, but new forms of tacit knowledge included having good software hands and a 3D sense that crystallographers often expressed through contorting their bodies and minds in front of the screen.

DEPLOYMENT

Exploring deployment requires us to look at the trajectories of images leaving their production site, entering different social milieus, and interacting with different forms of knowledge. On the one hand, scientific images' persuasiveness depends on their being regarded as the simultaneous voice of technoscientific authority and as expressions of nature. On the other hand, the semiotic openness of images leaves many openings for contesting their meaning and calling into question their objective authority.

Outside the laboratories, scientific images intersect with a range of other items and images at a given time (Jordanova, 2004). These images and items, from science, art, mass culture, and digital media, converse with each other and with previous eras in conjuring meanings and generating significance for viewers. In *The Visible Woman: Imaging Technologies, Gender, and Science* (1998), editors Paula Treichler, Lisa Cartwright, and Constance Penley integrated feminist and cultural studies with STS by foregrounding medicine. In attempts to understand how diagnostic and public discourses interact, these essays examine the continuum of digital medical images, public health posters and films, advertisements, and photographs in order to disclose social inequalities, personal and political identities, and disciplinary and economic formations.

Images traverse scientific and nonscientific domains supporting prevailing metaphors and stories (Martin, 1987). Photographs, ultrasounds, videos, and other visualizations reinforce some narratives and disempower others. Following Emily Martin, we can understand how the so-called abstract graphs and images operate within codes that tell "very concrete stor[ies] rooted in our particular form of social hierarchy and control. Usually we do not hear the story, we hear the 'facts', and this is part of what makes science so powerful" (Martin, 1987: 197).

The lives of cells, for instance, are known to us through early attempts of graphical representation (cf. Ratcliff, 1999) and the visual narratives of film. Early cell microcinematography and motion pictures were developed in tandem, exchanging concepts, equipment, and styles (Landecker, 2005). Framing, long exposures, time-lapse photography, slow motion, and close-ups familiarize or defamiliarize our perception and understanding of events. Scientists manipulate these techniques to understand the processes in the first place and to persuade others of their reality. Similar visual tactics have been used to portray technical and scientific issues in the public sphere (Treichler, 1991; Hartouni, 1997; Sturken & Cartwright, 2001).

The journal *Nature,* for instance, has an ongoing discussion of the temptations of image manipulation (Pearson, 2005; Greene, 2005; Peterson, 2005; see also Dumit, 2004). This journal now requires researchers to explain exactly what photoshop filters and processes have been applied to published images. Many scientists complain about the unfairness of having to compete for grants or public support against "cool-looking projects" (Turkle et al., 2005). Given a top-tier visualization software program, for instance, even nonsignificant pilot data can look solid and complete (Dumit, 2000). Good simulations and visualizations are expensive, however, and given the constant increase in computer power and software complexity, the output of older computer programs looks dated even when the science behind it is cutting edge.

The antagonism between interpretative openness and persuasive authority can be well observed in scientific debates, court trials, and intersections of scientific visualizations of the body with experiential body knowledge. Visualizations of global temperature change have been attacked on the basis of data sources, selection of data, the algorithms used, how the analysis is organized, forms of presentation, exaggeration of conclusions, and captions. Oreskes (2003), Bowker (2005), Lahsen (2005), Edwards (forthcoming), among others, offer excellent STS analyses of how global climate change and biodiversity data are painstakingly produced through series of social and technical compromises and adjustments. Within the political terrain of questions concerning the reality and causes of climate change, however, the large amount of work necessary to produce images can be used against the authority of those images to show that an enemy's images are not proof but "only" constructed to look like it. Thus, STS work may be read both as rigorous analyses of large-scale capital and expert labor intensive visualizations and as strategy manuals for attacking complex data claims on the grounds of not being "pure science" enough.

The courts are another key site where visual authority is regularly and formally challenged. Exploring a famous contemporary criminal trial in the United States, Sheila Jasanoff (1998) analyzed the trial as an arena in which visual authority was created and defended. She showed how the judge's comments and rulings established whose vision would be considered as visual expertise, and in what circumstances lay vision could take precedence over expert sight. Jennifer Mnookin (1998) and Tal Golan (1998, 2004) have traced how photographs and then x-rays entered courtrooms in the United States, first under a cloud of suspicion, requiring their producers to be present to testify to their veracity. In these cases, the story told by the photographer was the evidence to be considered. Because x-rays imaged objects that were invisible to the naked eye, the x-ray image required an expert to interpret it while the jury looked at it. This category of demonstrative evidence (evidence that is shown, or demonstrated, to the jury) again highlights the interpretive tension in every image: representations are never completely self-explanatory, and they are polyvocal, or open to many meanings. Photographs, x-rays, and other medical images and computer visualizations of all kinds require captions and expert interpretations. In tension with this requirement, the relative power of images to convey stereotypical, expected, or conventional meanings is quite strong. We all think we know what a fractured bone on an x-ray should look like. This creates a visual and haptic rhetorical space in which images can convey meanings despite expert protest, and courts have to constantly manage this persuasive power of images.

The deployment of scientific images and persuasion are most striking perhaps when the images are of our own bodies and lives. Our bodies as objects of knowledge and perception are *educated* bodies, shaped by descriptions, drawings, and visualizations (Duden, 1991). We learn about our bodies during childhood and throughout our lives. This form of meta-learning Emily Martin calls "practicums," ways of learning that change how we think and act with regard to the "ideal and fit person" (Martin, 1994: 15). Using examples of cells endowed with personhood, sperm and egg stories told with diagrams, and micro-photos that are narrated, framed, and cut up, Martin emphasizes the disjunction between what is necessarily in the data and what can be done with the data.

Biomedical seeing is not only persuasive but also *entangling*. Scientific images of humans are images of us, they point deictically at us (Duden, 1993), telling us truths about ourselves. Images of disease—of viruses, bad genes, and abnormal brain scans—create and reinforce basic categories of personhood, of normal and abnormal. The everyday identification with these scientific images can be called "objective self-fashioning" (Dumit, 2004). Medical images of ourselves are deeply personal; they partake in diagnosing our illnesses and foretelling our fate. At the same time, medical images are fascinating and exciting, providing tales to tell. Biomedical technologies also materialize new types of bodies with visualizable interiors (Stacey, 1997). Such visualizations seem to imply that seeing equals curing (van Dijck, 2005). Public discourse about seeing-eye machines promises utopian futures, but rarely acknowledges how seldom these machines actually change clinical outcomes. Medical narratives are quite routinized in this respect (Joyce, 2005).

Ultrasound images, for example, have entered into the experience and trajectory of pregnancy. Feminist anthropologists and sociologists found that ultrasound imaging simultaneously provokes both hope and anxiety. The images "fast-forward" pregnancy, conveying a special reality of the fetus often before the pregnancy is physically felt by the mother (Rapp, 1998). But these insightful sociotechnical observations need to be carefully located historically and culturally. As Mitchell and Georges (1998) documented through comparative ethnographies, ultrasound functions quite differently in Greece and North America. Greek doctors do not show the images to mothers, for instance, while in the United States, images of ultrasound are often demanded, carried in wallets, posted on refrigerators. These images are also used in advertising and in antiabortion public relations campaigns. The latter images are particularly decontextualized, framing the autonomy of the fetus and therefore its personhood (Hartouni, 1997) and creating the image of the fetus as a patient and the mother therefore as womb and incubator (Casper, 1998). These brief examples show the importance of treating technoscience in each case as an ethnoscience (Morgan, 2000).

We still lack STS studies of the processes by which people are visually persuaded and of the deployment of scientific visual knowledge in other social milieus and with other forms of knowledge (though see Kress & van Leeuwen, 1996; Elkins, 1998; Sturken & Cartwright, 2001). However, there are more questions to be explored. The final section of this chapter outlines a research agenda for the social studies of scientific imaging and visualization in the future.

SOCIAL STUDIES OF SCIENTIFIC IMAGING AND VISUALIZATION: OUTLINING A RESEARCH AGENDA

One of the key problems in formulating and demarcating the field of SIV is locating and defining the specificity of the visual. How is the persuasiveness of visual images in science to be separated from the persuasiveness of textual arguments, numbers, models, and the like, especially when software allows the ready transformation and juxtaposition of these different forms? We thus need to study the status of images as "epistemic things" (Rheinberger, 1997) in the knowledge generation process: How do images serve as "boundary objects" (Star & Griesemer, 1989) and transgress disciplinary boundaries? How are symbolic meanings assigned to visual representations? How do images influence the way in which researchers think and look at things? How do images provoke changes in routine practices?

Jordanova's (2004) insight that models are *incomplete concepts* may be used as a springboard for analysis. Jordanova is referring to the creative openness of models: they are constraining and suggestive at the same time, "implying the existence of something else, by virtue of which the model makes sense. As a result there are interpretive gaps for viewers to fill in, the 'beholder's share' in Gombrich's words" (Jordanova, 2004: 446). If models are incomplete concepts, then perhaps visualizations can be thought of as *incomplete models*. Interactive visualizations are practically and immediately manipulable. There is thus a "programmer's share" in addition to a beholder's share, leaving them remarkably difficult to black-box. Researchers familiar with the field of visualization can not only recognize the programs used but also single out the great number of assumptions and algorithms deployed in their making. Visualization disputes in the climate sciences are exemplary in this regard. As Naomi Oreskes (2003) and Paul Edwards (forthcoming) have each shown, critics can quite easily and ably create *countervisualizations*, calling into question the validity of the models implied by the original ones. Another response to the openness of visualizations to manipulation is a movement among scientists to "open-source" their data, making the raw data available online for other experimental groups to download and analyze themselves.[2]

Thus, images and imaging technologies have an impact on the social organization, the institutional and disciplinary arrangements, the work culture (cf. Henderson, 1999), and the interactions between members of research communities. We need case studies of these disciplinary transformations and comparative investigations that might allow us to identify the specificity of the visual. A preliminary series of workshops conducted at MIT showed that scientists in a variety of disciplines found these topics important and worth pursuing (Turkle et al., 2005). We also need international comparisons that would complement local and historical studies (e.g., Pasveer, 1989; Anderson, 2003; Cohn, 2004; Acland, forthcoming). Ethnographic research on visual practices suggests there is very little about seeing, drawing, framing, imaging, and imagining that can be assumed to be the same across cultures (e.g., Eglash, 1999; Riles, 2001; Strathern, 2002; Prasad, 2005b).

The labor- and capital-intensive nature of imaging and visualization also requires more attention. Bourdieu's work on science and on art markets might be brought together to examine the symbolic capital of scientific images (Burri, forthcoming). Research along these lines is beginning in the fields of bioinformatics, geographic information systems (GIS), computer-generated imaging, and nanotechnology (e.g., Schienke, 2003; Fortun & Fortun, 2005). Some of this work has identified "hype," which depends in part on visual persuasiveness, as a crucial part of contemporary scientific authority (e.g., Milburn, 2002; Kelty & Landecker, 2004; Sunder Rajan, 2006). As science and technology become inextricably market- and marketing-oriented, we need more STS studies of advertising and public relations (e.g., Hartouni, 1997; Fortun, 2001; Hogle, 2001; Fischman, 2004; Greenslit, 2005).

Finally, the growing conversations and hybridization between STS and art, as a site where *counterimages* are being produced, need to be explored from the point of view of SIV. We think of counterimages as civic responses to the postulate that in some cases, the best exploration of and response to the rhetorical power of images may be visual. The series of STS-art exhibitions curated by Bruno Latour, Peter Weibel, Peter Galison, and others—including "Iconoclash" and "Making Things Public" at ZKM Karlsruhe (Latour & Weibel, 2002, 2005) and "Laboratorium" in Antwerp (Obrist & Vanderlinden, 2001)—are exemplary in this regard. Other examples are the projects of STS scholars working at the intersection of science and art.[3] Critical appraisals of all these works are an important task for SIV and STS more generally.

Notes

1. We distinguish SIV as one of the many approaches to the study of scientific images, which all together we understand as constituting the virtual field of Visual STS.

2. OME, 2005 (Open Microscopy Environment). Available at: http://www.openmicroscopy.org/.

3. For example, the works of Natalie Jeremijenko (available at: http://visarts.ucsd.edu/node/view/491/31); Chris Csikszentmihályi (available at: http://web.media.mit.edu/~csik/); Phoebe Sengers (available at: http://cemcom.infosci.cornell.edu/); Chris Kelty (available at: http://www.kelty.org/). See also the project "Information Technology and Creativity" of the U.S. National Academies (available at: http://www7.nationalacademies.org/cstb/project_creativity.html) and various initiatives at institutional levels, e.g., the Arts & Genomics Centre at the University of Amsterdam (available at: http://www.artsgenomics.org), the Artist residency project at the BIOS Centre (available at: http://www.lse.ac.uk/collections/BIOS/); the sciart project funded by the Wellcome Trust and others (available at: http://www.sciart.org); and collaborations between Caltech and Pasadena's Art Center College of Design.

References

Acland, Charles R. (forthcoming) "The Swift View: Tachistoscopes and the Residual Modern," in C. R. Acland (ed), *Residual Media: Residual Technologies and Culture* (Minneapolis: University of Minnesota Press).

Alpers, Svetlana (1983) *The Art of Describing: Dutch Art in the Seventeenth Century* (Chicago: University of Chicago Press).

Amann, Klaus & Karin Knorr Cetina ([1988]1990) "The Fixation of (Visual) Evidence," in M. Lynch & S. Woolgar (eds), *Representation in Scientific Practice* (Cambridge, MA: MIT Press): 85–121.

Anderson, Katharine (2003) "Looking at the Sky: The Visual Context of Victorian Meteorology," *British Journal for the History of Science* 36(130): 301–32.

Arnheim, Rudolf (1969) *Visual Thinking* (Berkeley: University of California Press).

Barley, Stephen R. (1984) *The Professional, The Semi-Professional, and the Machine: The Social Ramifications of Computer Based Imaging in Radiology,* Ph.D. diss., Massachusetts Institute of Technology.

Barthes, Roland (1977) *Image-Music-Text* (London: Fontana Press).

Beaulieu, Anne (2001) "Voxels in the Brain: Neuroscience, Informatics and Changing Notions of Objectivity," *Social Studies of Science* 31(5): 635–80.

Blume, Stuart S. (1992) *Insight and Industry: On the Dynamics of Technological Change in Medicine* (Cambridge, MA: MIT Press).

Bowker, Geoffrey C. (2005) *Memory Practices in the Sciences* (Cambridge, MA: MIT Press).

Breidbach, Olaf (2002) "Representation of the Microcosm: The Claim for Objectivity in 19th Century Scientific Microphotography," *Journal of the History of Biology* 35(2): 221–50.

Burri, Regula Valérie (2001) "Doing Images: Zur soziotechnischen Fabrikation visueller Erkenntnis in der Medizin," in B. Heintz & J. Huber (eds), *Mit dem Auge denken: Strategien der Sichtbarmachung in wissenschaftlichen und virtuellen Welten* (Wien, New York, and Zürich: Springer, Edition Voldemeer): 277–303.

Burri, Regula Valérie (forthcoming) "Doing Distinctions: Boundary Work and Symbolic Capital in Radiology," *Social Studies of Science*.

Burri, Regula Valérie (forthcoming) *Doing Images: Zur Praxis medizinischer Bilder*.

Cambrosio, Alberto, Daniel Jacobi, & Peter Keating (1993) "Ehrlich's 'Beautiful Pictures' and the Controversial Beginnings of Immunological Imagery," *Isis* 84(4): 662–99.

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

Cartwright, Lisa (1998) "A Cultural Anatomy of the Visible Human Project," in P. A. Treichler, L. Cartwright, & C. Penley (eds), *The Visible Woman: Imaging Technologies, Gender and Science* (New York: New York University Press).

Casper, Monica J. (1998) *The Making of the Unborn Patient: A Social Anatomy of Fetal Surgery* (New Brunswick, NJ: Rutgers University Press).

Cohn, Simon (2004) "Increasing Resolution, Intensifying Ambiguity: An Ethnographic Account of Seeing Life in Brain Scans," *Economy and Society* 33(1): 52–76.

Crary, Jonathan (1990) *Techniques of the Observer: On Vision and Modernity in the Nineteenth Century* (Cambridge, MA: MIT Press).

Cussins, Charis M. (1998) "Ontological Choreography: Agency for Women Patients in an Infertility Clinic," in M. Berg & A. Mol (eds), *Differences in Medicine: Unraveling Practices, Techniques, and Bodies* (Durham, NC: Duke University Press): 166–201.

Daston, Lorraine & Peter Galison (1992) "The Image of Objectivity," in *Representations* 40: 81–128.

Daston, Lorraine & Peter Galison (2007): *Images of Objectivity* (New York: Zone Books).

Davidson, Arnold ([1996]1999) "Styles of Reasoning, Conceptual History, and the Emergence of Psychiatry," in M. Biagioli (ed), *Science Studies Reader* (New York: Routledge): 124–36.

de Chadarevian, Soraya & Nick Hopwood (2004) *Models: The Third Dimension of Science* (Writing Science) (Stanford, CA: Stanford University Press).

Duden, Barbara (1991) *The Woman Beneath the Skin: A Doctor's Patients in Eighteenth-century Germany* (Cambridge, MA: Harvard University Press).

Duden, Barbara (1993) *Disembodying Women: Perspectives on Pregnancy and the Unborn* (Cambridge, MA: Harvard University Press).

Dumit, Joseph (2000) "When Explanations Rest: 'Good-enough' Brain Science and the New Sociomedical Disorders," in M. Lock, A. Young, & A. Cambrosio (eds), *Living and Working with the New Biomedical Technologies: Intersections of Inquiry* (Cambridge: Cambridge University Press): 209–32.

Dumit, Joseph (2004) *Picturing Personhood: Brain Scans and Biomedical Identity* (Princeton, NJ: Princeton University Press).

Edwards, Paul (forthcoming) *The World in a Machine: Computer Models, Data Networks, and Global Atmospheric Politics* (Cambridge, MA: MIT Press).

Eglash, Ron (1999) *African Fractals: Modern Computing and Indigenous Design* (New Brunswick, NJ: Rutgers University Press).

Elkins, James (1994) *The Poetics of Perspective* (Ithaca, NY: Cornell University Press).

Elkins, James (1998) *On Pictures and the Words That Fail Them* (Cambridge: Cambridge University Press).

Elkins, James (forthcoming) *Six Stories from the End of Representation* (Stanford, CA: Stanford University Press).

Fishman, Jennifer R. (2004) "Manufacturing Desire: The Commodification of Female Sexual Dysfunction," *Social Studies of Science* 34(2): 187–218.

Fortun, Kim (2001) *Advocacy After Bhopal: Environmentalism, Disaster, New Global Orders* (Chicago: University of Chicago Press).

Fortun, Kim & Mike Fortun (2005) "Scientific Imaginaries and Ethical Plateaus in Contemporary U.S. Toxicology," *American Anthropologist* 107(1): 43–54.

Foucault, Michel ([1963]1973) *The Birth of the Clinic: An Archaeology of Medical Perception* (New York: Pantheon Books).

Francoeur, Eric (2000) "Beyond Dematerialization and Inscription: Does the Materiality of Molecular Models Really Matter?" *HYLE—International Journal for Philosophy of Chemistry* 6(1): 63–84.

Francoeur, Eric (2002) "Cyrus Levinthal, the Kluge and the Origins of Interactive Molecular Graphics," *Endeavour* 26(4): 127–31.

Fyfe, Gordon & John Law (eds) (1988) "Picturing Power: Visual Depiction and Social Relations," *Sociological Review Monograph* 35 (London and New York: Routledge).

Galison, Peter (1997) *Image and Logic: A Material Culture of Microphysics* (Chicago: University of Chicago Press).

Golan, Tal (1998) "The Authority of Shadows: The Legal Embrace of the X-Ray," *Historical Reflections* 24(3): 437–58.

Golan, Tal (2004) "The Emergence of the Silent Witness: The Legal and Medical Reception of X-rays in the USA," *Social Studies of Science* 34(4): 469–99.

Goodman, Nelson (1968) *Languages of Art: An Approach to a Theory of Symbols* (Indianapolis, IN: Bobbs-Merrill).

Greene, Mott T. (2005) "Seeing Clearly Is Not Necessarily Believing," *Nature* 435 (12 May): 143.

Greenslit, Nathan (2005) "Depression and Consumption: Psychopharmaceuticals, Branding, and New Identity Politics," *Culture, Medicine, and Psychiatry* 29(4).

Griesemer, James R. (1991) "Must Scientific Diagrams Be Eliminable? The Case of Path Analysis," *Biology and Philosophy* 6: 155–80.

Griesemer, James R. (1992) "The Role of Instruments in the Generative Analysis of Science," in A. Clarke & J. Fujimura (eds), *The Right Tools for the Job: At Work in Twentieth Century Life Sciences* (Princeton, NJ: Princeton University Press): 47–76.

Griesemer, James R. & William C. Wimsatt (1989) "Picturing Weismannism: A Case Study of Conceptual Evolution," in M. Ruse (ed), *What the Philosophy of Biology Is: Essays Dedicated to David Hull* (Dordrecht, Netherlands: Kluwer Academic Publishers): 75–137.

Hacking, Ian (1999) *The Social Construction of What?* (Cambridge, MA: Harvard University Press).

Haraway, Donna J. (1991) *Simians, Cyborgs, and Women: The Reinvention of Nature* (London: Free Association Books).

Haraway, Donna J. (1997) *Modest-Witness@SecondMillennium.FemaleMan-Meets-OncoMouse: Feminism and Technoscience* (New York: Routledge).

Hartouni, Valerie (1997) *Cultural Conceptions: On Reproductive Technologies and the Remaking of Life* (Minneapolis: University of Minnesota Press).

Henderson, Kathryn (1999) *On Line and on Paper: Visual Representations, Visual Culture, and Computer Graphics in Design Engineering* (Cambridge, MA: MIT Press).

Helmreich, Stefan (1998) *Silicon Second Nature: Culturing Artificial Life in a Digital World* (Berkeley: University of California Press).

Hogle, Linda F. (2001) "Chemoprevention for Healthy Women: Harbinger of Things to Come?" *Health* 5(3): 311–33.

Holtzmann Kevles, Bettyann (1997) *Naked to the Bone: Medical Imaging in the Twentieth Century* (New Brunswick, NJ: Rutgers University Press).

Hopwood, Nick (1999) "Giving Body to Embryos: Modeling, Mechanism, and the Microtome in Late Nineteenth-Century Anatomy," *Isis* 90: 462–96.

Hopwood, Nick (2005) "Visual Standards and Disciplinary Change: Normal Plates, Tables and Stages in Embryology," *History of Science* 43(141): 239–303.

Hubbard, Ruth (1988) "Science, Facts, and Feminism," *Hypatia* 3(1): 5–17.

Ihde, Don (1999) *Expanding Hermeneutics: Visualism in Science* (Chicago: Northwestern University Press).

Jasanoff, Sheila (1998) "The Eye of Everyman: Witnessing DNA in the Simpson Trial," *Social Studies of Science* 28(5–6): 713–40.

Jasanoff, Sheila (2004) "Heaven and Earth: The Politics of Environmental Images," in M. L. Martello & S. Jasanoff (eds) *Earthly Politics: Local and Global in Environmental Governance* (Cambridge, MA: MIT Press).

Jones, Caroline A., & Peter Galison (eds) (1998) *Picturing Science, Producing Art* (New York: Routledge).

Jordanova, Ludmilla (2004) "Material Models as Visual Culture," in S. D. Chadarevian & N. Hopwood (eds), *Models: The Third Dimension of Science* (Stanford, CA: Stanford University Press): 443–51.

Joyce, Kelly (2005) "Appealing Images: Magnetic Resonance Imaging and the Production of Authoritative Knowledge," *Social Studies of Science* 35(3): 437–62.

Joyce, Kelly (2006) "From Numbers to Pictures: The Development of Magnetic Resonance Imaging and the Visual Turn in Medicine," *Science as Culture* 15(1): 1–22.

Kaiser, David (2000) "Stick-figure Realism: Conventions, Reification, and the Persistence of Feynman Diagrams, 1948–1964," *Representations* 70: 49–86.

Kelty, Chris & Hannah Landecker (2004) "A Theory of Animation: Cells, Film and L-Systems," *Grey Room* 17 (Fall 2004): 30–63.

Knorr Cetina, Karin (1981) *The Manufacture of Knowledge: An Essay on the Constructivist and Contextual Nature of Science* (Oxford: Pergamon Press).

Knorr Cetina, Karin & Klaus Amann (1990) "Image Dissection in Natural Scientific Inquiry," *Science, Technology & Human Values* 15(3): 259–83.

Kress, Gunther R. & Theo Van Leeuwen (1996) *Reading Images: The Grammar of Visual Design* (London and New York: Routledge).

Lahsen, Myanna (2005) "Technocracy, Democracy and U.S. Climate Science Politics: The Need for Demarcations," *Science, Technology & Human Values* 30(1): 137–69.

Lammer, Christina (2002) "Horizontal Cuts & Vertical Penetration: The 'Flesh and Blood' of Image Fabrication in the Operating Theatres of Interventional Radiology," *Cultural Studies* 16(6): 833–47.

Landecker, Hannah (2005) "Cellular Features: Microcinematography and Early Film Theory," *Critical Inquiry* 31(4): 903–97.

Lane, K. Maria D. (2005) "Geographers of Mars: Cartographic Inscription and Exploration Narrative in Late Victorian Representations of the Red Planet," *Isis* 96(4): 477–506.

Larkin, Gerald V. (1978) "Medical Dominance and Control: Radiographers in the Division of Labour," *Sociological Review* 26(4): 843–58.

Latour, Bruno (1986) "Visualization and Cognition: Thinking with Eyes and Hands," *Knowledge and Society: Studies in the Sociology of Culture Past and Present* 6: 1–40.

Latour, Bruno ([1986]1990) "Drawing Things Together," in M. Lynch & S. Woolgar (eds), *Representation in Scientific Practice* (Cambridge, MA: MIT Press): 19–68.

Latour, Bruno (1987) *Science in Action. How to Follow Scientists and Engineers Through Society* (Cambridge, MA: Harvard University Press).

Latour, Bruno & Peter Weibel (eds) (2002) *ICONOCLASH: Beyond the Image Wars in Science, Religion and Art* (Cambridge, MA: MIT Press).

Latour, Bruno & Peter Weibel (eds) (2005) *Making Things Public: Atmospheres of Democracy* (Cambridge, MA: MIT Press).

Latour, Bruno & Steve Woolgar (1979) *Laboratory Life: The Construction of Scientific Facts* (Princeton, NJ: Princeton University Press).

Lefèvre, Wolfgang, Jürgen Renn, & Urs Schoepflin (eds) (2003) *The Power of Images in Early Modern Science* (Basel, Boston, and Berlin: Birkhäuser).

Lenoir, Timothy & Christophe Lécuyer (1995) "Instrument Makers and Discipline Builders: The Case of Nuclear Magnetic Resonance," *Perspectives on Science* 3(3): 276–345.

Locke, Simon (2005) "Fantastically Reasonable: Ambivalence in the Representation of Science and Technology in Super-Hero Comics," *Public Understanding of Science* 14(1): 25–46.

Lynch, Michael (1985a) *Art and Artifact in Laboratory Science: A Study of Shop Work and Shop Talk in a Research Laboratory* (London and New York: Routledge & Kegan Paul).

Lynch, Michael (1985b) "Discipline and the Material Form of Images: An Analysis of Scientific Visibility," *Social Studies of Science* 15(1): 37–66.

Lynch, Michael (1990) "The Externalized Retina: Selection and Mathematization in the Visual Documentation of Objects in the Life Sciences," in M. Lynch & S. Woolgar (eds), *Representation in Scientific Practice* (Cambridge, MA: MIT Press): 153–86.

Lynch, Michael (1998) "The Production of Scientific Images: Vision and Re-vision in the History, Philosophy, and Sociology of Science," *Communication & Cognition* 31: 213–28.

Lynch, Michael & Samuel Y. Edgerton Jr. (1988) "Aesthetics and Digital Image Processing: Representational Craft in Contemporary Astronomy," in G. Fyfe & J. Law (eds), *Picturing Power: Visual Depiction and Social Relations* (London and New York: Routledge): 184–220.

Lynch, Michael & Steve Woolgar (eds) (1990) *Representation in Scientific Practice* (Cambridge, MA: MIT Press).

Marchessault, Janine & Kim Sawchuk (eds) (2000) *Wild Science: Reading Feminism, Medicine, and the Media* (London and New York: Routledge).

Martin, Emily (1987) *The Woman in the Body: A Cultural Analysis of Reproduction* (Boston: Beacon Press).

Martin, Emily (1994) *Flexible Bodies: Tracking Immunity in American Culture from the Days of Polio to the Age of AIDS* (Boston: Beacon Press).

Métraux, Alexandre (ed) (2000) "Managing Small-Scale Entities in the Life Sciences," *Science in Context* 13(1).

Metz, Christian (1974) *Film Language: A Semiotics of the Cinema* (Oxford: Oxford University Press).

Metz, Christian (1982) *The Imaginary Signifier: Psychoanalysis and the Cinema* (Bloomington: Indiana University Press).

Milburn, Colin Nazhone (2002) "Nanotechnology in the Age of Posthuman Engineering: Science Fiction as Science," *Configurations* 10(2): 261–95.

Mitchell, W. J. T. (ed) (1980) *The Language of Images* (Chicago: University of Chicago Press).

Mitchell, W. J. T. (1987) *Iconology: Image, Text, Ideology* (Chicago: University of Chicago Press).

Mitchell, W. J. T. (1994) *Picture Theory: Essays on Verbal and Visual Representation.* (Chicago: University of Chicago Press).

Mitchell, Lisa M. & Eugenia Georges (1998) "Baby's First Picture: The Cyborg Fetus of Ultrasound Imaging," in R. Davis-Floyd & J. Dumit (eds), *Cyborg Babies: From Techno-sex to Techno-tots* (New York: Routledge): 105–24.

Mnookin, Jennifer (1998) "The Image of Truth: Photographic Evidence and the Power of Analogy," *Yale Journal of Law and the Humanities* 10: 1–74.

Mol, Annemarie & John Law (1994) "Regions, Networks and Fluids—Anemia and Social Topology," *Social Studies of Science* 24: 641–71.

Morgan, Lynn M. (2000) "Magic and a Little Bit of Science: Technoscience, Ethnoscience, and the Social Construction of the Fetus," in A. R. Saetnan, N. Oudshoorn, & M. Kirejczyk (eds), *Bodies of Technology: Women's Involvement with Reproductive Medicine* (Columbus: Ohio State University Press): 355–67.

Morgan, Mary S. & Margaret Morrison (eds) (1999) *Models as Mediators: Perspectives on Natural and Social Science* (Ideas in Context) (Cambridge: Cambridge University Press).

Myers, Greg (1990) *Writing Biology: Texts in the Social Construction of Scientific Knowledge* (Science and Literature Series) (Madison: University of Wisconsin Press).

Myers, Natasha (forthcoming) "Molecular Embodiments and the Body-work of Modeling in Protein Crystallography," *Social Studies of Science*.

Nelkin, Dorothy & Laurence Tancredi (1989) *Dangerous Diagnostics: The Social Power of Biological Information* (New York: Basic Books).

Obrist, Hans-Ulrich & Barbara Vanderlinden (eds) (2001) *Laboratorium* (Antwerp, Belgium: DuMont).

Oreskes, Naomi (2003) "The Role of Quantitative Models in Science," in C. D. Canham, J. J. Cole, & W. K. Lauenroth (eds), *The Role of Models in Ecosystem Science* (Princeton, NJ: Princeton University Press): 13–31.

Pasveer, Bernike (1989) "Knowledge of Shadows: The Introduction of X-ray Images in Medicine," *Sociology of Health and Illness* 11(4): 360–81.

Pasveer, Bernike (1993) "Depiction in Medicine as a Two-Way Affair: X-Ray Pictures and Pulmonary Tuberculosis in the Early Twentieth Century," in I. Löwy (ed), *Medical Change: Historical and Sociological Studies of Medical Innovation* (Paris: Colloques INSERM 220): 85–104.

Pearson, Helen (2005) "Image Manipulation CSI: Cell Biology," *Nature* 434 (21 April): 952–53.

Peterson, Daniel A. (2005) "Images: Keep a Distinction Between Beauty and Truth," *Nature* 435 (16 June): 881.

Porter, Theodore (1995) *Trust in Numbers: The Pursuit of Objectivity in Science and Public Life* (Princeton, NJ: Princeton University Press).

Prasad, Amit (2005a) "Making Images/Making Bodies: Visibilizing and Disciplining Through Magnetic Resonance Imaging (MRI)," *Science, Technology & Human Values* 30(2): 291–316.

Prasad, Amit (2005b) "Scientific Culture in the 'Other' Theater of 'Modern Science': An Analysis of the Culture of Magnetic Resonance Imaging Research in India," *Social Studies of Science* 35(3): 463–89.

Prentice, Rachel (2005) "The Anatomy of a Surgical Simulation," *Social Studies of Science* 35(6): 837–66.

Rajchman, John (1991) "Foucault's Art of Seeing," in *Philosophical Events: Essays of the '80s* (New York: Columbia University Press): 68–102.

Rapp, Rayna (1998) "Real-Time Fetus: The Role of the Sonogram in the Age of Monitored Reproduction," in G. L. Downey & J. Dumit (eds), *Cyborgs and Citadels: Anthropological Interventions in Emerging Sciences and Technologies* (Santa Fe, NM: School of American Research Press): 31–48.

Ratcliff, M. J. (1999) "Temporality, Sequential Iconography and Linearity in Figures: The Impact of the Discovery of Division in Infusoria," *History and Philosophy of the Life Sciences*, 21(3): 255–92.

Rheinberger, Hans-Jörg (1997) *Toward a History of Epistemic Things: Synthesizing Proteins in the Test Tube* (Stanford, CA: Stanford University Press).

Rheinberger, Hans-Jörg (1998) "Experimental Systems, Graphematic Spaces," in T. Lenoir (ed), *Inscribing Science*: *Scientific Texts and the Materiality of Communication* (Stanford, CA: Stanford University Press): 298–303.

Riles, Annelise (2001) *The Network Inside Out* (Ann Arbor: University of Michigan Press).

Rose, Nikolas S. (1999) *Powers of Freedom: Reframing Political Thought* (Cambridge: Cambridge University Press).

Rudwick, Martin J. S. (1976) "The Emergence of a Visual Language for Geological Science, 1760–1840," *History of Science*, 14: 149–95.

Ruse, Michael & Peter Taylor (eds) (1991) "Pictorial Representation in Biology," *Biology and Philosophy* 6(2): 125–294.

Saunders, Barry F. (forthcoming) *CT Suite: The Work of Diagnosis in the Age of Noninvasive Cutting* (Durham, NC: Duke University Press).

Schaffer, Simon (1998) "How Astronomers Mark Time," *Science in Context* 2(1): 115–45.

Schatzki, Theodore R., Karin Knorr Cetina, & Eike von Savigny (eds) (2001) *The Practice Turn in Contemporary Theory* (London and New York: Routledge).

Schienke, Erich W. (2003) "Who's Mapping the Mappers? Ethnographic Research in the Production of Digital Cartography," in M. Hård, A. Lösch, & D. Verdicchio (eds), *Transforming Spaces: The Topological Turn in Technology Studies* (Darmstadt, Germany: Online Conference Proceedings).

Stacey, Jackie (1997) *Teratologies: A Cultural Study of Cancer* (London and New York: Routledge).

Stafford, Barbara (1994) *Artful Science: Enlightenment, Entertainment, and the Eclipse of Visual Education* (Cambridge, MA: MIT Press).

Stafford, Barbara Maria (1996) *Good Looking: Essays on the Virtue of Images* (Cambridge, MA: MIT Press).

Star, Susan Leigh & James R. Griesemer (1989) "Institutional Ecology, 'Translations' and Boundary Objects: Amateurs and Professionals in Berkeley's Museum of Vertebrate Zoology, 1907–1939," *Social Studies of Science* 19(3): 387–420.

Strathern, Marilyn (2002) "On Space and Depth," in J. Law & A. Mol (eds), *Complexities: Social Studies of Knowledge Practices* (Durham, NC: Duke University Press).

Sturken, Marita & Lisa Cartwright (2001) *Practices of Looking: An Introduction to Visual Culture* (Oxford: Oxford University Press).

Sunder Rajan, Kaushik (2006) *Biocapital: The Constitution of Postgenomic Life* (Durham, NC: Duke University Press).

Traweek, Sharon (1997) "Iconic Devices: Toward an Ethnography of Physics Images," in G. L. Downey & J. Dumit (eds), *Cyborgs and Citadels: Anthropological Interventions in Emerging Sciences and Technologies* (Santa Fe, NM: School of American Research Press): 103–15.

Treichler, Paula A. (1991) "How to Have Theory in an Epidemic: The Evolution of AIDS Treatment Activism," in C. Penley & A. Ross (eds), *Technoculture* (Minneapolis: University of Minnesota Press): 57–106.

Treichler, Paula A., Lisa Cartwright, & Constance Penley (eds) (1998) *The Visible Woman: Imaging Technologies, Gender, and Science* (New York: New York University Press).

Tufte, Edward R. (1997) *Visual Explanations: Images and Quantities, Evidence and Narrative* (Cheshire, CT: Graphics Press).

Turkle, Sherry, Joseph Dumit, David Mindell, Hugh Gusterson, Susan Silbey, Yanni Loukissas, & Natasha Myers (2005) *Information Technologies and Professional Identity: A Comparative Study of the Effects of Virtuality.* Report to the National Science Foundation, Grant No. 0220347.

van Dijck, José (2005) *The Transparent Body: A Cultural Analysis of Medical Imaging* (Seattle: University of Washington Press).

Waldby, Catherine (2000) *The Visible Human Project: Informatic Bodies and Posthuman Medicine* (New York: Routledge).

Warwick, Andrew (2005) "X-rays as Evidence in German Orthopedic Surgery, 1895–1900," *Isis* 96: 1–24.

Yoxen, Edward (1987) "Seeing with Sound: A Study of the Development of Medical Images," in W. Bijker, T. Hughes, & T. Pinch (eds), *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology* (Cambridge, MA: MIT Press): 281–303.