Design in Motion: Introducing Science/Animation

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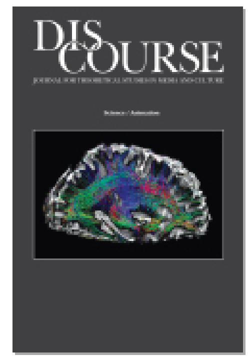

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As the joined yet distinct terms in our title indicate, this special issue seeks to foster dialogue across boundaries that often keep the fields, disciplines, and practices of science and animation separate. The walls that separate scholars from makers and theorists from practitioners, that divide work in fields such as film studies and science studies from each other, and that isolate the sciences from the humanities are not respected in the messiness of real life and actual work. While collaboration often goes unrecognized within formal disciplinary or industrial practices, people in these areas depend on the work being done in the others, whether that work serves as the object of research, suggests new ways of imagining (and imaging) the future, or supplies new tools to bring those imaginings into being. We think it is time to create new avenues for revealing and translating the work that is done in these divided but not separate spheres.

And we are not alone in recognizing this crossover. Discussions of visualization in news media and science journals regularly depict the scientist and the artist joined in a common task. Take, for example, a recent guide to visualization techniques published in the journal *Nature*. Its authors write that "The spectrum of techniques that we briefly survey represents a broad and deep continuum in which scientific and artistic minds can unite to better

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engage audiences ranging from peers to students and from grant reviewers to the general public."[1] But the crossover is also indicated in such trends as maker culture, whereby art/science projects regularly traverse multiple spheres, and film festivals, such as New York City's one-week Imagine Science Film Festival, now in its seventh year.[2] Scientific visualizations are ubiquitous throughout our entertainment media landscape as well. Television programs ranging from *House M.D.* to specials on the National Geographic Channel regularly feature 3-D animations in which the camera penetrates into the body and moves through its interior spaces. Blockbuster films such as Ridley Scott's *Prometheus* (2012) show bodies disintegrating to their molecular components, and video games such as *Nano Assault* propel the player through the body's veins in a chase to eradicate a killer virus.[3] Filled with compositions created using digital paintbrushes, these visualizations approximate what a microscope capable of illuminating the 3-D structures and movement of microcellular components might reveal, if only such a machine existed.[4] Such visualizations are not confined to the entertainment industries; they are also used for educational purposes, on pharmaceutical companies' websites to explain how drugs work, in medical apps for tablet computers, and in biology courses to convey understandings of cellular processes.[5] Databases of such animations are easily accessible to anyone with an Internet connection.[6]

Within newer digital forms of media, scientific animations get sutured seamlessly into live-action imaging, blurring the distinction between what the camera records and what a computer generates. The integration of computer-generated animation techniques into most other forms of media, coupled with many scientists' reliance on computer modeling as a means of conducting research, has led to an increased blurring of the visual cultures of science and popular media. With the rise of big data as a mechanism for characterizing phenomena whose dimensions exceed human perceptual capabilities, animation has become even more integral to the practice of scientific visualization in the twenty-first century. Many of the resulting "animations" are not perceived as such in any traditional sense; instead, they are part of a complex media ecosystem where distinct separations between photographic, animated, and computational modes of representation cease to exist. These changes provoke questions that have not yet been sufficiently answered: How are computer-generated animations reshaping the practice of scientific research in the digital era? How might theories of animation as a medium inform the conceptual modeling of scientific problems? How do techniques of scientific research generate new methods for imagining and visualizing reality?

This special issue on science/animation responds to the media convergence that has characterized both the history of animation and its foundational theories. The impossibility of understanding animation in isolation from other media is asserted in the formative and widely cited works of Alan Cholodenko, Giannalberto Bendazzi, and Lev Manovich.[7] Indeed, Manovich has famously claimed that other media may best be understood as “particular case[s] of animation.”[8] While the omnipresence of animation in contemporary life has many repercussions, its role in generating new conceptual frames for understanding and practicing science is of special interest. Indeed, the excellent recent collection *Animating Film Theory* supplies evidence of the ongoing scholarly recognition of that role; as its editor Karen Beckman notes, almost one-quarter of the volume’s essays are concerned with the role of scientific inquiry in generating theories of animation. Quoting the film theorist Jean Epstein, Beckman recalls the indispensable role that motion pictures played in the conduct of scientific experiments in the early twentieth century; these films did not simply capture evidence on film but instead actively fabricated new worlds by “disrupt[ing] natural phenomena while at the same time communicating new appearances.”[9] In this context, animation may be understood as the creation of new worlds out of research. The animated visualizations of scientific data and theories, both in the digital era and historically, have not only served an integral function in enabling scientists to represent phenomena invisible to the naked eye; they have also played a powerful role in persuading other scientists, the general public, and policy makers of the veracity of the new “truths” that emerge from these visualizations.[10] Color animations of functional magnetic resonance imaging brain scans, for instance, have generated enormous public interest in neuroscience, and the belief that these images will illuminate the most elusive processes of the human mind led to the announcement in 2013 of a major new funding stream at the National Institutes of Health: the Brain Research through Advancing Innovative Neurotechnologies (BRAIN) Initiative.[11]

The ubiquitous presence and powerful impact of these scientific visualizations calls out for scholarly inquiry into their origins, their historical development, and the futures they are enabling. The field of science studies has long recognized that visual images and modeling contribute to scientific knowledge production, but the convergence of visual images and computer-generated modeling raises new questions for a wide range of disciplines, from humanities to engineering and from visual arts to life sciences. Even more than 2-D or 3-D models, the emergent properties of these algorithmically generated visualizations seem to endow their phenomena with "life," inviting greater attention to the underpinnings of these creative practices. As visualizations become increasingly embedded within practices of scientific knowledge creation and dissemination, it becomes ever more pressing that we consider what occurs within that inscription, when interpretive techniques of visualization become scientific apparatuses for producing new "life." This special issue aims to address that inscription by considering the historical and contemporary intersections of animation with science, medicine, and computing.

Science/Animation's (Long) History

As a technology that could record and then reanimate moving bodies, cinema was born out of scientific research. Scholars have excavated this aspect of early film history, showing how the motion-capture experiments of Eadweard Muybridge and Étienne-Jules Marey contributed to the evolution of cinematographic technology.[12] In particular, artist Muybridge's 1877 photographic studies of a horse in motion and scientist Marey's chronophotography studies of human and animal motion were significant for their invention of new devices to visualize phenomena that were otherwise invisible to the naked eye.[13] These studies, along with the work of many inventors in this era, contributed to the eventual ascendancy of Thomas Edison's Vitagraph as the dominant cinematographic technology.[14] But the scientific investigations of Marey, Muybridge, and others are especially notable in the present context, for the representational practices of these early scientific recording devices can also be understood as foundational techniques of animation. When these scientists sought to capture living bodies in animated motion in order to establish precise measurements that could eventuate in scientific laws, they at once performed research and created a representation of the thing being researched. Animation thus emerged out of a mutually constitutive relationship between scientific techniques for measuring life and cinematic techniques for mimicking the liveliness of bodies, and this interconnection was present in cinema's originary moments.

The entwined evolution of science and animation continued beyond Muybridge and Marey, both in the cultivation of audiences who avidly consumed scientific actuality films alongside narrative fiction films and in the ongoing development of experimental techniques for scientific cinematography. Histories of cinema have often marked out a distinction between scientific and entertainment films, yet public screenings in the late nineteenth and early twentieth centuries did not separate news from fiction. Lisa Cartwright, Oliver Gaycken, and others have shown that science and cinema crossed paths frequently as the growing field of scientific filmmaking took shape in this era.[15] Hannah Landecker has demonstrated that early cinemicrographers continued to build on Marey's work: Julius Ries used time-lapse photography to document and analyze sea urchin fertilization and embryo development, and Jean Comandon set up a laboratory in 1907 where projection could be used as a tool for research, allowing the temporal dimension of a film to be adjusted according to the researcher's needs.[16] Timothy Boon has shown that chronophotography was used to film beating hearts and the movement disorders of patients with Parkinson's disease, and that numerous physicians used film to record and analyze their surgeries.[17] These films were not confined to the halls of science. Instead, showmen exhibited them alongside general theatrical films.[18] In their many and varied exhibition venues, these new techniques fascinated not only because of their research potential but also because, to use Tom Gunning's terminology, they "astonished" early cinema audiences with their ability to seemingly breathe life onto a screen.[19]

It was not only research scientists who were making use of this new technology; as early as 1912, some medical educators saw the motion picture as a promising pedagogical tool for training doctors. From the start, many medical films blended live-action and animation sequences to display processes that were otherwise invisible to the naked eye.[20] Health reformers of all kinds exploited the persuasive capabilities of the movies in this era, drawing on a widely held view of visual education as a more scientific form of instruction than lecturing at a blackboard.[21] By the late 1920s, a robust network of nontheatrical distributors was shipping reels of health and medical films full of animations across the United States and around the world to audiences clamoring for the latest in popular visualization techniques.[22]

The first decades of the twentieth century thus saw animation emerge as both a tool for producing scientific knowledge and a vehicle for explaining scientific concepts to the general public. At the same time, scientific experiments catalyzed the development of animation technologies and stylistic techniques. As Alla Gadassik's contribution to this volume argues, scientific motion analysis inspired by Muybridge's and Marey's work played a foundational role in establishing production practices and animation aesthetics in animation studios in the 1930s, most notably at Walt Disney Studios. A decade later the U.S. government recognized animation as a powerful weapon in the global theater, hiring Walt Disney Studios to produce a widely distributed set of animations about disease transmission that were shown in Latin American countries during the Cold War.[23]

The history of science and animation took a radical turn in the mid-twentieth century when digital computer animations began to appear, accelerating the fusion of these fields and the creation of new technologies for scientific research. However, Andrew Johnston's essay in this special issue demonstrates that the commonly assumed divide between photographic and digital animation was not so clear-cut due to the hybrid technical nature of digital animation in the 1960s and 1970s. As filmmakers helped to shape computer science by contributing to the code, languages, and platforms that produced the emerging digital media ecosystem in this era, the practice of animation as a branch of filmmaking merged with its function as a tool for generating scientific discovery. As Johnston's essay shows, this convergence was—and remains—provocatively visible in the pursuit of real-time digital animation.

The development of ever faster and more powerful computing technologies joined to graphics engines capable of generating algorithmic animations has profoundly changed the playing field for scientific animations. Computer-generated imagery (CGI) departs from traditional practices associated with cel or stop-motion animation in its erasure of the human hand from the visualization process. In contrast to the potential for mismatch and discontinuity of forms introduced by the indeterminacies of hand-drawn animation, images produced by software are established out of binary code and discrete time shifts, a logic that often dictates smooth transitions from state to state.[24] Christopher Kelty and Hannah Landecker have persuasively shown that this logic entails both an aesthetics and a theoretical model. In the opening sequence of the film *Fight Club* (Fincher, 1999), Kelty and Landecker argue, the animated fly-through of the protagonist's brain "is not a simulation of cells; it is an animation of a *theory* of cellular life."[25] The sequence was created using L-Systems, a mathematical formula developed in 1968 by botanist Aristid Lindenmayer to describe cellular life. The visualization is thus the realization of a particular theory of how cellular life functions, one that endeavored to formalize biological processes into axioms. Lindenmayer borrowed this particular formalism from computer science, and consequently, L-Systems represents cellular processes using the formal syntax of computational code. Cells in the L-Systems language undergo change at the exact same time, as if, like the pulse of a computer chip, they all change state at the same moment. So, when we see an L-Systems animation on the screen—and L-Systems are included in most major animation software packages today—what we are really seeing is a computational model of changing states, with some visual "interpretation" tacked on (such as the algae, galactic material, or protein molecules that are depicted on the screen). Kelty and Landecker conclude that scientific representations "establish the conditions for how we are able to see life today,"[26] and importantly, those conditions are being set through a computational logic.

As Lily Kay has shown, the computational view of life arose at the dawn of molecular research and was popularized by Richard Dawkins's 1976 best seller *The Selfish Gene*.[27] This culturally pervasive conceptual model has penetrated the animation industry as well through the industry-standard CGI program Maya. The authors of *In Silico,* a guide to using Maya in animations of cellular activities, write that "Phenomena at the cellular and molecular levels . . . are often difficult or impossible to see in the lab, in real time, as they happen. . . . Instead, they are measured—mapped as numerical properties. But how can we envision what the numbers mean? . . . [We can use] the computer as a visual information machine to harness the brain's enormous power for insight into the knowledge *encoded in cellular data and computer models*."[28] In this account, both the computer and cellular life operate by encoding data. Maya then steps in to make data meaningful by visualizing the knowledge that awaits us once the computer itself can crack that code. In this feedback loop, knowledge emerges without reflective interpretation or critical perspective; instead, the meaning of computational data is revealed through computational algorithms, and animation itself serves as the visual demonstration of that revelation.

The authors of the *In Silico* handbook draw on the pervasive rhetoric of life as code, easily integrating computer-generated animation as a step within knowledge generation. Whether scientists themselves would accept this understanding is an open question, but the manual's understanding of *animation's* role in this process corresponds with new approaches to scientific research that consider animations—effectively computer algorithms rendered as 3-D forms—as plausible substitutes for microscopes. These virtual models are treated as legitimate sources for understanding and verifying hypotheses about the forms and functions of cellular and microcellular entities. For instance, digital animations are seen as valuable tools in the development of systems biology, which has the daunting task of modeling the interaction of complex systems. As Scott Curtis and Robert Lue show in their contribution to this volume, these animations are also seen as significant tools for visualizing and informing work on the intersection between cellular and molecular biology.[29] These examples highlight animation's function in the development of what Hans-Jörg Rheinberger has called "epistemic things."[30] For Rheinberger, whose work considers the histories and epistemologies of twentieth-century life sciences, it was the suite of techniques, protocols, and material things at play in laboratories that brought the gene into being as an object of research and study—not, as the story of scientific innovation is often told, the ideas that scientists had prior to planning out and conducting experimental research itself. As tools that are increasingly embedded in the processes of technofabrication, digital animations used as plausible-enough models for real-world structures join the suite of techniques by which epistemic things are generated.

Yet digital animations come with their own "epistemology"—the epistemology of code, whatever the epistemology of their particular programming language may be. In the context of Maya, this epistemology is called object-oriented (OO) programming. With its origins in software first developed in the 1960s, OO programming differs significantly from procedural and other forms of programming; it locates both "data and the operations that can manipulate this data" in objects rather than separating objects and operations into different classes.[31] Objects, rather than procedures, are paradigmatic in OO languages, with procedures occurring through messages sent among objects themselves. Some scholars in critical code studies consider OO programming to elide the complexity and ambiguity that characterizes both human life and the natural world; it is criticized as implementing ontological fixity, describing action only as slotting into predetermined paths, and abstracting in a way that refuses partial perspective, instead claiming neutrality and objectivity.[32] These criticisms highlight the values that are embedded within programming and computation but are often invisible to end users. Thus, to the discrete units shifting state all at once that Kelty and Landecker reveal at the heart of CGI animations we must add another way that computational operations leave their imprint on molecular and cellular animations produced in Maya: by informing them with an epistemology of OO ontology. What ramifica tions this holds for scientific developments generated through such animations-as-models is an area that remains to be explored.[33]

Theoretical Questions in Science/Animation

Throughout its history, animation has been used both to enhance our perception of profilmic reality and to replace it altogether by envisioning entirely new worlds. When computer-generated animation enters the science lab to serve the purpose of speculative modeling, those functions fuse into one. As our brief account of science/animation history makes clear, it has often been difficult to separate the practice of scientific research from the practice of creating visualizations of that research. While this intermingling goes virtually unacknowledged within the scientific literature, the blurry definition of animation as a medium has been the subject of considerable debate in media theory. As Karen Beckman points out, the difficulties that scholars and theorists of animation face when marking out the boundaries of their topic is evidence of the unclear boundaries between film and animation in media theory generally.[34] That muddiness has led critics to dwell extensively on questions of which category subsumes the other. The argument for animation's predominance has been voiced by Cholodenko, for whom cinema has always been a subset of animation. In his view, the defining characteristic of all film is that it animates, in the sense of both "endowing with life and endowing with motion."[35] With this definition in hand, it becomes impossible to cordon off live-action film as animation's parent; rather, both live-action and animated images present the spectator with the illusion that life appears on the screen.

In the widely cited and debated work of Lev Manovich, cinema arose out of animation but soon overtook and marginalized it, only to become, with the rise of digital cinema, a subset of animation once again.[36] In contrast to Cholodenko, Manovich claims that a real distinction between live-action film and animation inheres in live-action's indexicality. In Manovich's telling of animation's history, any claim to indexicality by cinema's progenitors (such as the Thaumatrope and the Kinetoscope) was usurped once motion pictures arrived on the scene because the latter refined photographic methods and technologies. Animation at that historical juncture became the bastard child, consigned to the realm of artifice, a "supplement and shadow" to cinema.[37] With digital animation, however, the familial relations are reversed: now nothing about live-action film can be presumed to be indexical, and so digital cinema demotes live-action film to one among its many subcategories. When we consider scientific animations in relation to this line of argument, the categories of media blur even more. For although indexicality in its strict sense is not assumed in scientific animations, a vital correspondence is nevertheless posited between the representation and the workings of the phenomena being visualized in research contexts whereby the animations serve as theoretical models. In these settings, animations are assumed to be adequate substitutes for the visualization tools we lack, plausible renderings of the invisible microcellular world. At the same time, indexicality undergoes revision as well. Reality—the "natural" structure being represented—is itself a theoretical space, unable to be seen and only able to be predicted or perceived through the hypothesis that a model provides. This implicates the animator in the construction of reality.

Indeed, the redefinition of indexicality in the context of scientific animations highlights the extent to which the concept has often bridged literal and figurative notions of realism. In his introduction to a recent collection of essays on science and documentary film, Joshua Malitsky notes that animation has often been seen as nonindexical because "it does not provide a promise of a trace to the real world."[38] Yet Malitsky argues against this limited definition, observing that a certain "co-presence" or "nowness" can be discerned in many types of animation (for instance, in the traces of the human hand that moved a clay figure for stop-motion animation). Through this broader understanding of the link between the image and the real, animation makes a new kind of sense within the documentary tradition. While documentary and animation might seem to occupy opposite ends of the spectrum of "objectivity," when deployed in the service of science both are preoccupied with their connection to traces of the "real world" as a source of empirical evidence.[39] In both Alla Gadassik's and Nathan Blake's contributions to this volume, the motion-study films of Frank and Lillian Gilbreth—and their resulting chronocyclegraph animations—demonstrate how photographic traces of human gestures can become conceptual models for scientific movement. The Gilbreths' films guided motion in both Disney cartoons and amputee soldiers' rehabilitation techniques, spanning the range of imaginative and empirical approaches to animation.

The question of indexicality in computer modeling further focuses our attention on the often theoretical evidentiary underpinnings of the algorithm, foregrounding the process of "emergence" as a core feature of both "life" and animation in the digital age.[40] In theoretical animations, the scientific gaze—assumed to be objective, free of perspective, and able to perceive truth—exists within the visualization process itself. Oliver Gaycken has illustrated this viewpoint at play in Ernst Mach's early cinematic research. Mach saw "the technological enhancement of vision" as "tied to conceptual growth" whereby conceptualization, the fuel of scientific knowledge practices, is "invigorated" through technology. Mach's perspective aligns with early film theorist Jean Epstein's view that the cinema neither captured nor reproduced "nature" but rather created it in a thaumaturgic act.[41] Scott Curtis also illuminates a kind of thaumaturgy at work in Paul Erlich's images of antibody formation.[42]

Scholars in science and technology studies (STS) have long recognized that analogies and metaphors play an important role in the production of scientific knowledge.[43] However, little research exists on the use of animation within scientific research contexts as a means of generating new life forms, literally "animating life." A review of three significant readers in STS finds few mentions of animation: one, published in 1995, contains a few pages on computer modeling; another, published in 1999, contains no mention of animation at all; and a third, published in 2007, contains a chapter on visualization and modeling that pays scant attention to animation.[44] Of course, field readers cannot achieve total comprehensiveness, but surprisingly, while Soraya De Chadarevian and Nick Hopwood's excellent edited collection *Models* emphasizes the centrality of modeling and visualization to science studies, the volume contains only one essay that touches on animation proper.[45] (The single exception to all of this remains the work of Hannah Landecker, which explores in detail the history of science's intersection with cinema and animation and its ramifications for STS.)

This special issue aims to launch a dialogue between STS and animation studies. In its current deployment in scientific contexts, animation enters and reimagines the sociotechnical systems that generate new forms of organic life, machinic entities, and cyborg bodies. Animation is imbricated with techniques, technologies, procedures, and protocols by which knowledge is produced and disseminated across scientific infrastructures. Just as these visualizations travel across disciplinary boundaries, the professionals creating them also travel across fields as varied as chemistry, engineering, visual art, computer science, physics, biology, and medicine, importing to each their standards and protocols and serving as the human agents through which sociotechnical systems coalesce.

We might also understand scientific animations through the concept of sociomaterial assemblage, a technique that figures the relations between humans and nonhuman things as informed by social relations and cultural imaginaries.[46] In naming the traffic between social relations and technologies, the concept of sociomaterial assemblage has allowed feminist thinkers such as Anne Balsamo to suggest specific interventions that might be made into technology design and use practices.[47] Once we recognize that technoscience's fabrications are imbued with the social—that they are not simply determined by objective, neutral techniques—we are afforded opportunities to refigure them through our agency within social spaces. This special issue includes interviews between scholars and animators in the hopes of clearing a space for thinking about what each might offer the other in order to spark new thinking about the transactions that could be possible across the traditionally walled-off areas of scholarship and practice.

Content Map

As the histories and theoretical questions discussed in the preceding sections attest, the field of science/animation demands attention to the complex interplay between conceptual models, aesthetics, technical affordances, and visualization practices. Within this nexus, boundaries between animator and scientist, or between animation and scientific model, break down. So too does any clear distinction between theory and practice. In science/animation, we see a Latourian "science in action" take shape; midcentury animation pioneers John Halas and Roger Manvell called it "design in motion."[48] Each of the contributions to this volume pays close attention to the process of creating animations as a means of understanding their theoretical foundations, their role in the development of new visualization techniques, and their impact on ways of doing and seeing science.

The dissolving boundaries between animators and scientists open the dialogue between molecular biologist Robert Lue and film scholar Scott Curtis; in their exchange, it is clear how much Lue's work as an animator is informed by the scientist's desire to amaze and teach through the power of art. Lue explains how the widely seen animation of cellular life he directed, *The Inner Life of the Cell,* came about and how he conceives its role in communicating scientific concepts to the public and inspiring interest in science. Curtis's querying of the visualization process provides insights into how Lue, as a scientist, views animations of cellular structures as both representations of reality and theoretical models. The interview itself, which displays a film scholar and a molecular biologist engaged in a lively and thick dialogue, demonstrates that conversations across disciplinary fences not only can happen but also deliver rich rewards. By contextualizing Lue's work historically and theorizing this animation in terms of the aesthetics of new modes of visual pedagogy, Curtis proposes new models for media scholars engaged in the study of science.

Although the history of science/animation is not well known, the interviews in this special issue examine recent animations that have been widely viewed, creating an opportunity for readers to consider two prominent examples of how the field operates today. As Oliver Gaycken notes in his comments, his interview with Ariana Killoran uncovers the varied paths that can lead to participation in the animation labor force, highlighting how the relative ease of accessing animation production tools in today's digital media environment reshapes who participates in creating animations for educational purposes. In addition, the story of Killoran's creative process in dialogue with science advisers from genomics and biotechnology company 23andMe, reveals how scientific review over visualization is conducted within the context of a consumption-oriented science, with the creative decisions often winning out over scientific understandings. Interestingly, Killoran's animations made for 23andMe are now used by the online free education site Khan Academy, and their example demonstrates the traffic now occurring in digital media's spaces for education between visualizations designed to sell a product and educational contexts conceived as operating outside of the commercial marketplace.

Andrew Johnston's contribution bridges the gap between analogue and digital media that has provoked so much theory around the concept of indexicality. When visual artists first attempted to make computer animations, Johnston demonstrates, their process included mathematical calculations, paper punch cards, microfilm plotters, and direct photography of computer screens to capture the results. While this production process is riddled with indexical traces, the end result tells us more about the technological malleability of temporality than it does about the existential characteristics of any given moment in time. In this richly researched account of computer animation's infancy, Johnston shows that aesthetic and scientific practices were deeply interwoven in the 1960s and 1970s as visual artists embarked on experiments funded by the National Science Foundation, IBM, Bell Laboratories, and other sites of technical and creative intermingling. It was not just artists, though, who were interweaving these practices, for the scientists called on by the artists were often deeply interested in art. Johnston describes, for example, how programmer, physicist, and amateur historian of constructivism Dr. Jack Citron contributed to the work of artists. In these spaces, new kinds of crossovers among people drawn from disparate domains for imagining science began to take shape.

Nathan Blake's essay distinguishes three historical moments and their corresponding imaging techniques to construct a genealogy leading to today's motion-capture technology used for gait analysis for wounded war veterans. As an applied therapy for phantom limb pain and post-traumatic stress disorder, motion-capture technology becomes a method in which war wounds—both physical and mental—are obscured while the body is clinically regulated and normalized. When placed next to Blake's work, Alla Gadassik's essay describes a prehistory to modern motion-capture technology's simultaneous representation and study of gait analysis, arguing that this mutual constitution was present in a much earlier era of animation. She demonstrates that Disney animators undertook their own scientific research by conducting motion studies to guide their own animating practice—to discover what the body did and therefore how they could most efficiently represent and tweak its movements. She thus complicates how the field of media studies has traditionally separated such studies as the Gilbreths' out from commercial animation practice. In fact, there was significant overlap in how both fields applied motion-capture recording devices to the body's movement.

Conclusion: For Future Research

The contributions to this volume clearly illustrate that the often-invoked "two cultures" of science and humanities is an artificial separation. Taken together, the essays and interviews illustrate that the sciences and the humanities cannot be distinctly marked out when we consider the history of scientific animation or the history of animation's gestation out of science. In its modeling practices, science has been a prime user of the arts, integrating visualization techniques for predicting as well as implementing imaginative visualizations for the purpose of education. Animation is itself the product of scientific research, and its technological evolution has been driven by the efforts of scientists.

The essays and interviews collected here address many of the gaps in existing work on science and animation, yet they also engender new questions, perhaps most intriguingly around what remains invisible in the production process itself. For example, feminist STS scholarship has long argued that gendered epistemological assumptions operate within scientific knowledge production, while Tara McPherson and others have argued that racial concepts are embedded in the logic of computational code.[49] The question of whether cultural categories of gender, race, and other forms of difference are at work in the numbers of female and male workers and the division of their labor within the animation industry is an area that seems ripe for further exploration. The recent formation of the new feminist STS journal *Catalyst* signals the pressing need for focused attention to these questions.[50] Moreover, 3-D software packages have afforded the outsourcing of animation to countries with the lowest labor costs (and often the least regulation of work conditions), and the relation of this practice to scientific animations has been little explored.[51] Finally, while the cost of software packages has decreased significantly in recent years, these technologies still come at a cost, as does the labor required to produce animation, and there are questions to be pursued concerning how science in the least developed countries is affected by those costs.

While there remains much work to be done in the field of science/animation, it is our hope that this special issue will provide a valuable starting point for scholars in a wide range of disciplines to embark on new lines of inquiry. Just as the practice of science/animation has always brought together artists and researchers, the work collected here shows the value of cross-disciplinary collaboration for both creating and understanding digital visual culture. We believe that the contributions to this volume will serve as their own kind of conceptual models, and we look forward to the new methodologies, new histories, and new ways of seeing that emerge.

Notes

1. Graham Johnson and Samuel Hertig, "A Guide to the Visual Analysis and Communication of Biomolecular Structural Data," *Nature* 15 (October 2014): 690. See also Erik Olsen, "Where Cinema and Biology Meet," *New York Times,* November 15, 2010; Olsen, "The Animators of Life," *New York Times,* November 15, 2010; Carl Zimmer, "Watch Proteins Do the Jitterbug," *New York Times,* April 10, 2014.

2. See "Projects: Science," *Make: We Are All Makers,* http://makezine.com/category/science; "Open Source Water Testing Platform is 3D Printed," *Maker Faire,* http://makerfaire.com/category/science/. Information on the film festival is available at "Festival," *Imagine Science Films,* http://imaginesciencefilms.org/newyork/.

3. For recent scholarship of the power of scale in both scientific and other kinds of animations, see Sylvie Bissonnette, ed., *Animating Space and Scalar Travels,* special issue of *Animation: An Interdisciplinary Journal* 9, no. 2 (July 2014).

4. In 2011 scientists announced the Bessel beam plane illumination technique designed for imaging 3-D dynamics. The technique, however, degrades the material imaged and is diffraction limited; thus, "seeing" inside a cell remains for the time being a matter for creative visualizers. See T. A. Planchon et al., "Rapid Three-Dimensional Isotropic Imaging of Living Cells Using Bessel Beam Plane Illumination," *Nature Methods* 8 (2011): 417–23.

5. See "How Pulmozyme Works," *Pulmozyme,* http://www.pulmozyme.com/how-pz-works.html; iPad apps designed by 3D4Medical, such as "Images and Animations" (2013, version 2.0); and the video *The Inner Life of the Cell,* XVIVO Scientific Animation, 2006, http://www.xvivo.net/animation/the-inner-life-of-the-cell/.

6. For example, MolecularMovies.org, http://www.molecularmovies.com/.

7. Alan Cholodenko, *The Illusions of Life* (Sydney: Power Publications, 1991); Giannalberto Bendazzi, *Cartoons: One Hundred Years of Animation* (Indianapolis: Indiana University Press, 1995); Lev Manovich, *The Language of New Media* (Cambridge, MA: MIT Press, 2001).

8. Manovich, *The Language of New Media,* 302.

9. Jean Epstein, quoted in Karen Beckman, "Animating Film Theory: An Introduction," in *Animating Film Theory,* edited by Karen Beckman (Durham, NC: Duke University Press, 2014), 8.

10. See Kirsten Ostherr, "Animating Informatics: Scientific Discovery through Documentary Film," in *The Blackwell Companion to Contemporary Documentary Studies,* edited by Alisa Lebow and Alex Juhasz, 280–297 (West Sussex, UK: Wiley-Blackwell, 2015).

11. "What Is the BRAIN Initiative?," *National Institutes of Health,* http://www.nih.gov/science/brain/.

12. Virgilio Tosi, *Cinema Before Cinema: The Origins of Scientific Cinematography* (London: British Universities Film & Video Council, 2005; original Italian edition, 1984).

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

14. See Charles Musser, *The Emergence of Cinema: The American Screen to 1907* (New York: Scribner, 1990), and *Before the Nickelodeon: Edwin S. Porter and the Edison Manufacturing Company* (Berkeley: University of California Press, 1991).

15. See Lisa Cartwright, *Screening the Body: Tracing Medicine's Visual Culture* (Minneapolis: University of Minneapolis Press, 1995); Oliver Gaycken, *Devices of Curiosity: Early Cinema and Popular Science* (New York: Oxford University Press, 2015).

16. Hannah Landecker, "Microcinematography and the History of Science and Film," *Isis* 97, no. 1 (March 2006): 121–32.

17. Timothy Boon, *Films of Fact: A History of Science in Documentary Films and Television* (London: Wallflower, 2008), chap. 1.

18. For the full story, see Gaycken, *Devices of Curiosity.*

19. Tom Gunning, "An Aesthetics of Astonishment: Early Film and the (In) Credulous Spectator," *Art & Text* 34 (1989): 31–45.

20. Kirsten Ostherr, *Medical Visions: Producing the Patient through Film, Television and Imaging Technologies* (Oxford: Oxford University Press, 2013).

21. Nancy Anderson and Michael Dietrich, eds., *The Educated Eye: Visual Culture and Pedagogy in the Life Sciences* (Lebanon, NH: Dartmouth College Press, 2012).

22. Devin Orgeron, Marsha Orgeron, and Dan Streible, "A History of Learning with the Lights Off," in *Learning with the Lights Off: Educational Film in the United States,* edited by Devin Orgeron, Marsha Orgeron, and Dan Streible, 15–66 (New York: Oxford University Press, 2012).

23. Lisa Cartwright and Brian Goldfarb, "Cultural Contagion: On Disney's Health Education Films for Latin American," in *Disney Discourse: Producing the Magic Kingdom,* edited by Eric Smoodin, 168–80 (New York: Routledge, 1994).

24. That is, unless the animation is deliberately programmed so that it appears to present discontinuities and mismatches.

[25.] Christopher Kelty and Hannah Landecker, "A Theory of Animation: Cells, L-Systems, and Film," *Grey Room* 17 (Fall 2004): 32.

[26.] Ibid., 34.

[27.] Lily Kay, *Who Wrote the Book of Life: A History of the Genetic Code* (Palo Alto, CA: Stanford University Press, 2000); Richard Dawkins, *The Selfish Gene* (Oxford: Oxford University Press, 1976).

[28.] Jason Sharpe, Charles John Lumsden, and Nicholas Woolridge, *In Silico: 3D Animation and Simulation of Cell Biology Using Maya and MEL* (Burlington, MA: Morgan Kaufmann, 2008), 4 (our emphasis).

[29.] See Robert Lue and Scott Curtis, "Bridging Science, Art, and the History of Visualization: A Dialogue between Scott Curtis and Robert Lue," *Discourse* 37, no. 3 (2015): 193–207. S. I. O'Donoghue et al., "Visualizing Biological Data—Now and in the Future," *Nature Methods* 7, no. 3 (2010): S2–S4; S. I. O'Donaghue et al., "Visualization of Macromolecular Structures," *Nature Methods* 7, no. 3 (2010): S42–S55; Nils Gehlenbourg et al., "Visualization of Omics Data for Systems Biology," *Nature Methods* 7, no. 3 (2010): S56–S68. On molecular and cellular intersections, see, for example, G. T. Johnson et al., "EPMV Embeds Molecular Modeling into Professional Animation Software Contexts," *Structure* 19, no. 3 (2011): 293–303.

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

[31.] Cecile Krutzen and Erna Kotkamp, "Object-Oriented Programming," in *Software Studies: A Lexicon,* edited by Matthew Fuller (Cambridge, MA: MIT Press, 2008), 210.

[32.] See Krutzen and Kotkamp, "Object-Oriented"; Krutzen and Kotkamp, "Doubting the OBJECT World," *Women, Work, and Computerization* (New York: Springer, 2000), 127–36.

[33.] Alexander Galloway's discussion of the shift from procedural to OO programming as central to the emergence of artificial life bears mention here. See Alexander Galloway, *Protocol: How Control Exists after Decentralization* (Cambridge, MA: MIT Press, 2004), 108–15.

[34.] Beckman, "Animating Film Theory," 1–2.

[35.] Alan Cholodenko, "'First Principles' of Animation," in *Animating Film Theory,* edited by Karen Beckman (Durham, NC: Duke University Press, 2014), 101.

[36.] Cholodenko, *The Illusion of Life;* Alan Cholodenko, "Animation (Theory) as the Poematic: A Reply to the Cognitivists," *Animation Studies* 4 (2009): 1–16; Manovich, *The Language of New Media.* See also C. Gehman and S. Reinke, *The Sharpest Point: Animation at the End of Cinema* (Toronto: XYZ Books, 2005); Thomas Lamarre, *The Anime Machine: A Media Theory of Animation* (Minneapolis: University of Minnesota Press, 2009); Donald Crafton, "The Veiled Genealogies of Animation and Cinema," *Animation: An Interdisciplinary Journal* no. 2 (2011): 93–110.

[37.] Manovich, *The Language of New Media,* 298.

[38.] Joshua Malitsky, "Science and Documentary: Unity, Indexicality, Reality," *Journal of Visual Culture* 11, no. 3 (2012): 248.

[39.] See Lorraine Daston and Peter Galison, "The Image of Objectivity," *Representations* 40 (1992): 81–123.

40. For a discussion of bioart and new understandings of media, see Robert Mitchell, *Bioart and the Vitality of Media* (Seattle: University of Washington Press, 2010), 11.

41. Oliver Gaycken, "'A Living, Developing Egg Is Present before You': Animation, Scientific Modeling, and Visualization," in *Animating Film Theory,* edited by Karen Beckman (Durham, NC: Duke University Press, 2014), 78.

42. Curtis and Lue, "Bridging Science, Art, and the History of Visualization," 199.

43. See Wendy Hui Kyong Chun, *Programmed Visions: Software and Memory* (Cambridge, MA: MIT Press, 2013).

44. Mario Biagioli's edited collection *The Science Studies Reader* (New York: Routledge, 1999) contains no significant discussion of animation. Edward J. Hackett et al., *The Handbook of Science and Technology Studies* (Cambridge, MA: MIT Press, 2007), includes the one article that addresses visualization: Regula Barri and Joseph Dumit, "Social Studies of Scientific Imaging and Visualization," 297–318. Sheila Jasanoff, Gerald Markle, James Peterson, and Trevor Pinch, eds., *Handbook of Science and Technology Studies* (Thousand Oaks, CA: Sage, 1995), presents a few pages on computer modeling in H. M. Collins's "Science Studies and Machine Intelligence," 286–301.

45. Soraya de Chadarevian and Nick Hopwood, eds., *Models: The Third Dimension of Science* (Palo Alto, CA: Stanford University Press, 2012); the article is Eric Francouer and Jérôme Segal, "From Model Kits to Interactive Computer Graphics," 402–29.

46. See Joan Fujimura, "Sex Genes: A Critical Sociomaterial Approach to the Politics and Molecular Genetics of Sex Determination," in *Women, Science, and Technology: A Reader in Feminist Science Studies,* edited by Mary Wyer et al. (New York: Routledge, 2013), 507–29. Fujimura, for example, defines the "sociomaterial" approach as one that "assumes that humans attribute meanings to things through complex interactions based within specific locations in society, culture, and history" (509).

47. Anne Balsamo, *Designing Culture: The Technological Imagination at Work* (Durham, NC: Duke University Press, 2011).

48. Bruno Latour, *Science in Action: How to Follow Scientists and Engineers through Society* (Cambridge, MA: Harvard University Press, 1987); John Halas and Roger Manvell, *Design in Motion: The Art and Technique of Animation* (New York: Hasting, 1962).

49. Tara McPherson, "U.S. Operating Systems at Mid-Century: The Intertwining of Race and UNIX," in *Race after the Internet,* ed. Lisa Nakamura and Peter Chow-White, 21–37 (New York: Routledge, 2013).

50. See home page, *Catalyst: Feminism, Theory, Technoscience,* http://catalystjournal.org/ojs/index.php/catalyst/index.

51. For a summary of these developments, see Toby Miller et al., *Global Hollywood 2* (London: British Film Institute, 2009), chap. 2, esp. 156–60. See also Adriana Petraya, *When Experiments Travel: Clinical Trials and the Global Search for Human Subjects* (Princeton, NJ: Princeton University Press, 2009).