A Cell-Based Epistemology: Human Genetics in the Era of Biomedicine

The compilation of papers included in this special Issue of *Historical Studies in the Natural Sciences* aspires to contribute to the historical study of human genetics knowledge and practices from the 1940s to the 1980s. Performed in the cytogenetic laboratory, in permanent contact with the consulting room, most of the knowledge and practices labelled in the papers that follow as human biological heredity belonged to clinical practice. Therefore we present a perspective of postwar human genetics articulated by the clinic as well as the laboratory, driven by diagnostic intentions and intensively promoted by the research agenda of the atomic era at the intersection of international and local health policies. Moreover, human genetics is also analyzed as a driving force of genetics and biomedical research in the period, shaping postwar policies, anxieties, and concerns with public health demands in a variety of geographical and epistemological settings. Bearing in mind experimental practices on one hand, and the priorities of the atomic age research policies on the other, these papers emphasize the circulation—from plant and animal genetics to human genetics—of tools, radiation sources, and cytological methods for making cellular entities visible, including the old, long-used optic microscope.

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The following abbreviations are used: *JHB*, *Journal of the History of Biology*; *SHPBBS*, *Studies in History and Philosophy of Biological and Biomedical Sciences*.

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In the contributions we are introducing, cells and chromosomes are taken not as stable, well-defined objects of inquiry, but as places where biology and medicine encountered each other in a particular period in history, to be observed and to qualify the normal and the anomalies—whether lesions, damage, or simply the unusual. The cell geography presented here furthers our understanding of the atomic age in light of the uses of radioactivity in research agendas and medical practice, and the extent to which their practitioners incorporated and reconstructed earlier cytological methods to explore heredity at the cellular level on the laboratory bench. Both scenarios, the material-experimental and the socio-political, provide the epistemic cell-based space in which human heredity was born in its contemporary form, attached to medical genetic practice.

The majority of the papers included in this special Issue was presented in a double session under the title *Out of the Shadow of DNA, Part I: Chromosomes and Genes* and *Part II: Population and Genes* at the meeting of the International Society for the History, Philosophy and Social Studies of Biology, at the University of Utah, Salt Lake City, in July 2011. With this title, the organizers, Santesmases and Suárez-Díaz, aspired to relocate the historical subject of human heredity in cells and bodies. The set of papers presented here trace human genetics back in a genealogy of practices that included cells, mutations, and health care, but not molecules. A history of biology rooted in practices and visual cultures of the domains of plants, laboratory animals, and radioactivity contributed to these new histories of human genetics, which provide a rich picture of this domain during the era of biomedicine, throughout the second half of the twentieth century.

The pioneering experiments within medical genetics reconstructed in this special Issue were concerned with the cell and the chromosomes: the sites at which explanations on human heredity were pursued. To represent human cells and their components in relation to health, disease, and disease-related disorders, clinical laboratories adapted plant and invertebrate cytology techniques to produce images visualizing these otherwise hidden hereditary phenomena. The historical argument of this collection focuses thus in the reconfiguration of health and disease based on approaches to human genetics associated with medical practices that were performed from the mid-1940s until the late 1980s, the most common identification of the Cold War era, running from 1949 and the Korea War to 1989 and the fall of the Berlin wall. The diversity of approaches and localities, and the biological and geopolitical spaces of medical genetics during the long, postwar atomic age in the West—that is, in Europe and the Americas—provide a collective history, one that

reconfigured medical practice and manufactured the contemporary cytogenetic laboratory. Most of the case studies, however, exhibit complexities, both political and experimental, beyond Cold War agendas.

During this long period, besides the explorations of human beings as populations and as races, studies on individual genetics and on genetic kinship were particularly encouraged by the cultures of medicine¹—that is, human genetics found in the cytogenetic laboratory an influential disciplinary setting. Until that moment (the early 1960s), population studies had been practically alone regarding human genetics. Not that human population became reconfigured by medical genetics, or left aside, but, even if mutually influencing each other, human population genetics and medical genetics developed somehow in parallel. According to the contributions to this special Issue, medical queries provided insights into a biological, cell-based interpretation of human bodies. Human bodies were reconstructed and re-identified through their lesions, disorders, and unusualness, and it was the individual as patient—the human being studied by medicine, both the subject and object, the agent—who became disciplined in the production of human genetics on medical basis.

The period we label as the long postwar atomic age reflects the lasting influence that the events of World War II held over contemporary culture as U.S. technological and political leadership became evident. Moreover, what would later be called molecular politics had its roots in this cellular exploration of life promoted by the policies of the U.S. Atomic Energy Commission.² The

1. On contemporary human population genetics, see the discussions in the contributions to Jenny Bangham and Soraya de Chadarevian, eds., “Special Section on Heredity and the Study of Human Populations after 1945,” *SHPBBS* 47, Part A (Sept. 2014): 45–190; and Bernd Gausemeier, Staffan Müller-Wille, and Edmund Ramsden, eds., *Human Heredity in the Twentieth Century* (London: Pickering & Chatto, 2013). A link between populations and the early medical genetics in the U.S. is suggested in Nathaniel Comfort, *The Science of Human Perfection: How Genes Became the Heart of American Medicine* (New Haven, CT: Yale University Press, 2012). See also Susan M. Lindee, *Moments of Truth in Genetic Medicine* (Baltimore, MD: Johns Hopkins University Press, 2006). For a discussion on biological kinship from anthropology, see, among others, the inspiring contribution by Sarah Franklin, “Biologization Revisited: Kinship Theory in the Context of the New Biologies,” in *Relative Values: Reconfiguring Kinship Studies*, ed. Sarah Franklin and Susan McKinnon (Durham, NC: Duke University Press, 2001), 302–22. See also Alexandra Minna Stern, *Telling Genes: The Story of Genetic Counselling in America* (Baltimore, MD: Johns Hopkins University Press, 2012); and Daniel Kevles, *In the Name of Eugenics: Genetics and the Uses of Human Heredity* (Cambridge, MA: Harvard University Press, 1998).

2. Susan Wright coined this concept in her insightful study on the origins of biotechnology policies. See Susan Wright, *Molecular Politics: Developing American and British Regulatory Policy for Genetic Engineering, 1972–1982* (Chicago: University of Chicago Press, 1994).

links between the events analyzed in this Issue were multiple and multilayered, as we will argue further in this introduction. As part and parcel of the atomic policies, this complex domain experienced a dramatic turn as national agencies, first in the United States and later in other countries, funded and promoted research into the effects of atomic radiation on human beings and on cancer.³ Human heredity studies benefitted from this support: mutations produced by low- and high-level radiation—the most prominent amongst these being the cancer process—were to be studied through the correlation of chromosomes with the disorders and diseases under medical scrutiny. Mutation as a research subject and the funding priorities of the time were mutually dependent, as the papers here will demonstrate. As a set of priorities, human genetics participated in Western research agendas, in Europe and the Americas, regarding biological and medical sciences. Health care provision as a national public policy, however, was instrumental in European countries and in Mexico, but not in the United States. This difference contributed to a divergence of trajectories regarding the biomedical sciences and their links with medical practice.

THE CELL, THE MICROSCOPE, AND THE CLINICAL LABORATORY

The cell, by displacing the body, came to represent the individual patient in postwar human cytogenetics, in the process named by Abby Lipmann as “genetization.”⁴ The issue of a biological domain—in this instance, cytology—interacting with medical practices and, more specifically, with pathology has been tackled within historical and social studies of biology through analysis of the trajectory of the post–World War II term, “biomedicine.” Jean Paul Gaudillière has convincingly characterized postwar biomedicine as shaped by a focus on cells and molecules.⁵ In part inspired by Gaudillière, Peter Keating and Alberto Cambrosio have stated that “biology has to a certain extent encircled medicine.” According to these authors and their reading of the French philosopher of medicine, George Canguilhem, biomedicine consisted of

3. Stephen P. Strickland, *Politics, Science, and Dread Disease: A Short History of United States Medical Research Policy* (Cambridge, MA: Harvard University Press, 1972).

4. Abby Lippman, “Prenatal Genetic Testing and Screening: Constructing Needs and Reinforcing Inequalities,” *American Journal of Law and Medicine* 17 (1991): 15–50; see also Comfort, *Science of Human Perfection* (ref. 1).

5. Jean-Paul Gaudillière, *Inventer la biomédecine: la France, l'Amérique et la production des savoirs du vivant, 1945–1965* (Paris: La découverte, 2002).

a parallel development of biological research and medical practices; that is, it developed in research on the biology of the normal, in parallel with the study of pathological lesions.⁶ The primacy of the patient remained, however, keeping the laboratory firmly rooted in medical practice.

Within the clinic the meaning of genetics went beyond the heritable, expanding to include explanations of lesions at the chromosomal level. In this biomedical space the cell became a biomedical system, a space of knowledge and reference for the inherited and congenital character of traits in bodies, and of the connection between inheritance and the environment.⁷ Our set of papers brings cells and chromosomes back into the historical framework to explain the growing, ambitious space of knowledge and practices of human genetics, not only in the clinic but in society at large and as part of sharp debates.⁸ The cell is represented as a mediator of the cultures and practices of biology, for thinking, experimenting, and observing both life and lesions through the microscope.⁹

6. Peter Keating and Albert Cambrosio, *Biomedical Platforms: Realigning the Normal and the Pathological in Late-Twentieth-Century Medicine* (Cambridge, MA: MIT Press, 2003). Between George Canguilhem, *Le normal et le pathologique* (Paris: Presses universitaires de France, 1972) [*The Normal and the Pathological*, trans. Carolyn R. Fawcett and Robert S. Cohen (New York: Zone Books, 1991)], and the recent collection by anthropologists Katharina Schramm, David Skinner, and Richard Rottenburg, eds., *Identity Politics and the New Genetics. Re/Creating Categories of Difference and Belonging* (New York: Berghahn Books, 2012), an epistemological approach to the borders built up by experimental biology is presented. On the anthropology of genes and molecules, see Margaret Lock and Vinh-Kim Nguyen, *Anthropology of Biomedicine* (Oxford: Wiley-Blackwell, 2010).

7. Anne Fausto-Sterling, *Sexing the Body: Gender Politics and the Construction of Sexuality* (New York: Basic Books, 2000), 235–38.

8. Lindee, *Moments of Truth* (ref. 1); and Susan M. Lindee, *Suffering Made Real: American Science and the Survivors at Hiroshima* (Chicago: University of Chicago Press, 1997); see also John Beatty, “Genetics in the Atomic Age: The Atomic Bomb Casualty Commission, 1947–1957,” in *The American Expansion of Biology*, ed. Keith Benson, Ronald Rainger, and Jane Maienschein (New Brunswick, NJ: Rutgers University Press, 1991). For the historical roots of contemporary genetics, see the contributions to Staffan Müller-Wille and Hans Jörg Rheinberger, eds., *Hereditry Produced: At the Crossroads of Biology, Politics and Culture* (Cambridge, MA: MIT Press, 2007); and Staffan Müller-Wille and Hans Jörg Rheinberger, *A Cultural History of Hereditry* (Chicago: University of Chicago Press, 2012). A contemporary depiction of the field is in Victor McKusick, “The Growth and Development of Human Genetics as a Clinical Discipline,” *American Journal of Human Genetics* 27 (1975): 261–73.

9. On the cell as a mediator, see Maureen O’Malley and Staffan Müller-Wille, “The Cell as a Nexus: Connections between the History, Philosophy and Science of Biology,” *SHPBBS* 41 (2009): 169–71; see also Mathias Grote, “Surfaces of Action: Cells and Membranes in Electrochemistry and the Life Sciences,” *SHPBBS* 41 (2010): 183–93; and Staffan Müller-Wille, “Cell Theory, Specificity, and Reproduction, 1837–1870,” *SHPBBS* 41 (2009): 225–31.

The microscope has remained a reference tool for centuries and, during the process of lens development, has trained the eyes of observers. Observation was not a passive endeavor, as historians and philosophers alike have shown. Observers acquired experimental skills through working with images provided by the microscope.¹⁰ This circularity provided a mutual interactive space of experimenting: the microscope, the human eye, and the images they both made up were at the basis of biological practices analyzed in the papers we are presenting. Across time the plasticity of the cell as a concept and as an object under scientific inquiry has benefitted not only from the manufacturing of lenses, but also from the establishing of preparative techniques. A full history of cell theory, its generation, and reproduction has been produced by historians of biology in relation to the history of developmental biology: the *Entwicklungsmechanik*. The inner part of the cell provided evidence of living processes: cells were observed dividing, in mitosis and meiosis, in plants and animals of many kinds, with chromosomes as organelles dancing in a living space while losing their membranes.¹¹ In addition to being a locus of biochemical and biophysical experiments in the late nineteenth century, cell mechanics resonated with the cultures of the time. By the end of that century, chromosomes had become objects of inquiry in their own right; freed from their cell membranes, they were exhibited during cell division—ready to be seen at the very origins of cytology. As the biological setting of heredity, observed between the 1870s and 1890s by Oscar Hertwig and Eduard Strasburger, then named “chromatin” by Walther Flemming, chromosomes had been under scrutiny for decades before the Barr body was first identified in the 1940s, as Nathan Ha insightfully narrates in his contribution to this Issue.¹² The distinctive shape and number of chromosomes from many species contributed to taxonomy and natural history in the first decades of the twentieth century. A vast array of

10. Jutta Schickore, *The Microscope and the Eye: A History of Reflections, 1740–1870* (Chicago: University of Chicago Press, 2007); Hennig Schmidgen, “Pictures, Preparations, and Living Processes: The Production of Immediate Visual Perception (Anschauung) in Late-19th-Century Physiology,” *JHB* 37 (2004): 477–513.

11. Lindee, *Moments of Truth* (ref. 1); Peter S. Harper, *A Short History of Medical Genetics* (Oxford: Oxford University Press, 2008); María Jesús Santesmases, “Size and the Centromere: Translocations and Visual Cultures in Early Human Genetics,” in *Making Mutations: Objects, Practices, Contexts*, ed. Alexander von Schwering and Luis Campos (Berlin: Max Planck Institut für Wissenschaftsgeschichte, 2010).

12. See also references in Ha, this Issue; Harper, *Short History* (ref. 11); Jane Maienschein, “Cell Theory and Development,” in *Companion to the History of Modern Science*, ed. G. N. Cantor, J.R.R. Christie, M.J.S. Hodge, and Robert C. Olby (London: Routledge, 2012), 357–73.

gender-related taxonomies inundated—in a mutually influential process—the laboratory and the clinic. Among these were the classifications that shook gender dichotomies and resisted easy correlation with chromosomes.¹³ The transition from natural history to the clinical laboratory and medical diagnosis centered on chromosomes as the site where inherited lesions were to be identified, as demonstrated by a number of the papers included in this Issue. The practical details of the manufacture of knowledge are crucial for an experiment-based history of biology: the laboratory was the arena where a composition of practices for handling and modifying material from living bodies was intended to display human cells and their components.

The link between biology and the clinic is a long one in the history of human heredity, having roots in the eighteenth century.¹⁴ The public dimension and the use of cytological evidence in medical practice are, however, the new contributions of contemporary heredity science. Since the late nineteenth century, plant biology and experimental agriculture have been domains in which genetics—the new term for heredity, coined by William Bateson—has also been practiced by breeders, plant biologists, and cytologists.¹⁵ As practical agricultural research intersected with academic botany, human genetics developed in parallel with studies in human genealogies and population genetics.¹⁶ But, as Santesmases shows in her contribution to this volume, the two arenas did not remain separated at the level of practices.

13. Isabel Delgado Echeverría, *El descubrimiento de los cromosomas sexuales: un hito en la historia de la biología* (Madrid: CSIC, 2007); Sarah S. Richardson, *Sex Itself: The Search for Male and Female in the Human Genome* (Chicago: University of Chicago Press, 2013); María Jesús Santesmases, “Superfemale: cromosomas humanos y representaciones del sexo, 1922–1959,” in *Cartografías del cuerpo: biopolíticas de la ciencia y la tecnología*, ed. Eulalia Pérez Sedeño and Esther Ortega Arjonilla (Madrid: Cátedra 2014), 393–422. Soraya de Chadarevian, “Chromosome Surveys of Human Populations: Between Epidemiology and Anthropology,” *SHPBBS* 47, Part A (Sept. 2014): 87–96.

14. See Carlos López-Beltrán, “The Medical Origins of Heredity,” in Müller-Wille and Rheinberger, eds., *Heredity Produced* (ref. 8), 105–32; Carlos López Beltrán, *El sesgo hereditario: ámbitos históricos del concepto de herencia biológica* (México: Programa Editorial de la Coordinación de Humanidades UNAM, 2004).

15. See Vassiliki Betty Smocovitis, “The ‘Plant *Drosophila*’: E. B. Babcock, the Genus *Crepis* and the Evolution of a Genetics Research Program at Berkeley, 1912–1947,” *HSNS* 39, 3 (2009): 300–55; and Vassiliki Betty Smocovitis, “Genetics Behind Barbed Wire: Masuo Kodani, Émigré Geneticists, and Wartime Genetics Research at Manzanar Relocation Center, 1942–1945,” *Genetics* 187 (2011): 357–66; Jonathan Harwood, “Biology and Agriculture,” *JHB* 39 (2006): 237–39. Christophe Bonneuil, & Thomas, Frédéric, *Gènes, pouvoirs et profits: recherche publique et régimes de production des savoirs de Mendel aux OGM* (Versailles: Éditions Quae, 2009).

16. Gausemeier et al., eds., *Human Heredity* (ref. 1); Bangham and de Chadarevian, “Special Section on Heredity and the Study” (ref. 1).

ATOMIC POLITICS AND MEDICAL GENETICS

The support provided by the atomic energy agencies in several countries fostered research on the genetics of radiation and cancer, while also contributing to medical genetics as a clinical practice. Biologists, clinicians, and policy makers took the destructive capacity of the atom seriously. As a tool and as a therapy, atomic energy articulated the promotion of biological research during the so-called Golden Era of scientific funding. Radioisotopes began to become available in the Western Hemisphere after World War II, first from the U.S. Atomic Energy Commission and later from the United Kingdom and Canada, thus contributing to the expansion of radiobiology and studies on the genetic effects of radiation in Western countries.¹⁷ Although none of the papers presented here deal with it, the genetic knowledge and radiobiology developed in the Soviet Union and the communist Eastern European countries during the whole twentieth century was also rich and influential.¹⁸ It was in the 1960s when the sciences achieved their twentieth-century pinnacle, both in

17. Angela N. H. Creager, *Life Atomic* (Chicago: University of Chicago Press, 2013); Nicolas Rasmussen, "The Mid-Century Biophysics Bubble: Hiroshima and the Biological Revolution in America Revisited," *History of Science* 35 (1997): 245–93; John Krige, "The Politics of Phosphorus-32: A Cold War Fable Based on Fact," *HSPS* 36, no. 1 (2006), 71–91; Angela N. H. Creager and María Jesús Santesmases, "Radiobiology in the Atomic Age: Changing Research Practices and Policies in Comparative Perspective," *JHB* 39 (2006): 637–47; María Jesús Santesmases, "From Prophylaxis to Atomic Cocktail: Circulation of Radioiodine," *Dynamis* 29 (2009): 337–63; Alison Kraft, "Between Medicine and Industry: Medical Physics and the Rise of the Radioisotopes, 1945–65," *Contemporary British History* 20 (2006): 1–35; Xavier Roqué and Néstor Herran, eds., *Isotopes: Science, Technology and Medicine in the Twentieth Century*, dossier of *Dynamis* 29 (2009): 123–364; Karin Zachmann, *Risky Rays for an Improved Food Supply? National and Transnational Food Irradiation Research as a Cold War Recipe* (Munich: Deutsches Museum, 2013), available at <http://www.deutsches-museum.de/verlag/aus-der-forschung/preprint/>, Heft 7 (accessed 30 Jun 2014).

18. See Susanne Bauer, "Mutations in Soviet Public Health Science: Post-Lysenko Medical Genetics, 1969–1991," *SHPBBS*, 47, Part A (Sept. 2014): 163–72; Nikolai Kremenstov, *The Cure: A Story of Cancer and Politics from the Annals of the Cold War* (Chicago: University of Chicago Press, 2002); William De Jong-Lambert, *The Cold War Politics of Genetic Research: An Introduction to the Lysenko Affair* (Netherlands: Springer, 2012). A brief reference to work done at Vladimir Engelhardt's Institute of Radiation and Physicochemical Biology in Moscow (later, Institute of Molecular Biology) is included in Edna Suárez-Díaz and Vivette García-Deister, "That 70s Show: Regulation, Evolution and Development beyond Molecular Genetics," *History and Philosophy of the Life Sciences*, 36, 4 (2014). For a historical frame of the relationship between the two blocks regarding atomic politics, see Michael Gordin, *Red Cloud at Dawn: Truman, Stalin, and the End of the Atomic Monopoly* (New York: Picador, 2009).

funding and public acclaim: during this decade medical genetics experienced its early and influential development.

Experimenting as an invention, or reinvention, of living things, as Donna Haraway has phrased it and Canguilhem insightfully had analyzed, was deeply reinforced by postwar funding of research both into the effects of radiation in living bodies and into its possibilities as a cancer therapy.¹⁹ During this empire of radiation, the cell and chromosomes were biomedical entities, if we accept biomedicine as a creation of the long atomic age running through the Cold War.²⁰ Soraya de Chadarevian has insightfully analyzed the rise of early cytogenetic practices in light of the promotion of research on the genetic effects of radiation, by considering the importance of cells and chromosomes for defining human genetics during the postwar decades.²¹ Previous narratives have also contributed to reconstructing the roots of contemporary medical genetics by suggesting the relevance of radiation as a powerful tool, not only for the development of physics and nuclear power, but also for biology and the shaping of research priorities during this period.²²

THE POWER OF PLACE

As Robert Kohler has stated, the research laboratory can be regarded as a standardized locus for producing knowledge.²³ Change and innovation have been prompted by the transfer of techniques from one place to another and, as David Edgerton has argued, by the use, and at times the rejection or the reuse,

19. Donna J. Haraway, *Simians, Cyborgs, and Women: The Reinvention of Nature* (New York: Routledge, 2013); George Canguilhem, *Le normal et le pathologique* (ref. 6).

20. See Ilana Löwy, "Cancer: The Century of the Transformed Cell," in *Science in the Twentieth Century*, ed. John Krige and Dominique Pestre (Amsterdam: Harwood Academic, 1997), 461–77. For a reflection on the origins and meaning of biomedicine, see the introduction to Soraya de Chadarevian and Harmke Kamminga, eds., *Molecularizing Biology and Medicine: New Practices and Alliances, 1920s to 1970s* (London: Taylor & Francis, 1998); and Gaudillière, *Inventer la biomédecine* (ref. 5).

21. Soraya de Chadarevian, "Mice and the Reactor: The 'Genetic Experiment' in 1950s Britain," *JHB* 39 (2006): 707–35; Karen Rader, *Making Mice: Standardizing Animals for American Biomedical Research, 1900–1955* (Princeton, NJ: Princeton University Press, 2004).

22. See Creager, *Life Atomic* (ref. 17); Rasmussen, "Mid-Century Biophysics" (ref. 17); Elof Axel Carlson, *Genes, Radiation, and Society: The Life and Work of H. J. Muller* (Ithaca, NY: Cornell University Press, 1981), available at <http://www.citeulike.org/group/24/article/1294973> (accessed 18 Nov 2014); and Creager and Santesmases, "Radiobiology in the Atomic Age" (ref. 17).

23. Robert E. Kohler, *Landscapes and Labscapes: Exploring the Lab-Field Border in Biology* (Chicago: University of Chicago Press, 2002).

of forgotten tools and knowledge.²⁴ Moreover, localities carried knowledge that became embedded in research agendas, thus modifying approaches and posing a diversity of questions about tools and living things. And this is how we would like to frame the stories told in the papers that follow: as a set of contributions to a diversity of histories of human genetics, based on a diversity of research, medical settings, and geopolitics. From Sweden to Mexico, through the influential technology-driven society that the biomedical complex became in the United States, this geographical and political diversity is presented here—as Rosi Braidotti has phrased it—“to resist the uncritical reproduction of sameness.”²⁵

The papers included in this Issue cover a range of geographic localities of the cell-based epistemology, which characterized most human heredity practices after World War II. In the first paper, Angela Creager presents the long and intense debate between geneticists, on one side, and on the other, the military and physicists, on the nature of the effects of atomic radiation on living beings, at a time when the newly created U.S. Atomic Energy Commission (AEC) was emphasizing the benefits of radiation for medicine. According to Creager’s reconstruction, the geneticists’ contested assumption that there was not a safety threshold but a linear relationship between dose and effect, even of low-level radiation, helped to link two previously separated phenomena: mutations produced by radiation, and the relationship between cancer and radiation. Whether a radiation limit could be agreed upon became a polemical issue: geneticists insisted that not only would individuals be affected, but their offspring would suffer too. As Creager argues, it was in this climate of atomic politics that research on the biological effects of radiation—that is, the genetic effects—would be funded by the AEC. A permissible maximum dose would participate in the prevention of cancer and mutations among workers and the general population. A few influential geneticists had previously focused on the effects of radiation on *inherited* genetic mutations; now, as the atomic fallout debates erupted in the 1950s, they would focus on somatic effects. It was here that somatic mutation provided causality for cancer, one of the most targeted diseases of the era, the National Cancer Act being signed by President Nixon one decade later, in 1971.

24. David Edgerton, *The Shock of the Old: Technology and Global History since 1900* (London: Profile Books, 2008).

25. Rosi Braidotti, *Nomadic Subjects: Embodiment and Sexual Difference in Contemporary Feminist Theory* (New York: Columbia University Press, 1994).

The authority of genetics over other scientific and medical fields partly succeeded, at least temporarily, in regard to the correlation of gender and sex. By focusing on the history of the Barr body, Nathan Ha relates how a method for classifying human identities became a limited tool itself. A nucleus-related particle on human female cells, the Barr body or sex chromatin created great expectations with its promise as a scientific, laboratory-based, technological object for discerning whether a person was female or male. However, classifications relating to such sex chromatin, bodies, and “psychosocial gender” multiplied; new intermediary categories began to arise that participated in the blurring of a dichotomized sex system, disqualifying the sex chromatin as the authoritative assigner of sex. This biomedical object transited from the cell to the chromosomes and from cats to human beings, thus providing evidence of the contingency of interactions among biological experiments, living systems, and medicine.

From very different but complementary perspectives, the papers of María Jesús Santesmases and Soraya de Chadarevian deal with one of the oddest historical questions regarding the study of chromosomes: the late discovery of the “true” number of human chromosomes. Though this Issue has drawn the attention of previous historical narrators, Santesmases’ and de Chadarevian’s contributions look at this episode from original and divergent points of view.

The role of preparation techniques, and the circulation of practices and methods from botany and agriculture through experimental mouse models in cancer research, all the way to human tumor cells, enabled Albert Levan, Theodore Hauschka, and Joe Hin Tjio to arrive at the now accepted number of 46 human chromosomes. Santesmases argues that this winding trajectory is not without antecedents in the close domains of plant and animal genetics; more importantly, it reveals the highly contingent nature of biomedical research, where the intersection of biological materials and experimental techniques may yield stable, observational phenomena, otherwise unobserved in similar configurations.

De Chadarevian’s narrative takes up the story where Santesmases’ leaves off. The iconic images of human chromosomes produced by Levan and Tjio in 1956 are taken by de Chadarevian to depend on the quality of their cell preparations. Focusing on the visual cultures of drawing and photography, the author revisits the counting of human chromosomes by examining how the iconic micrograph became an object of contention between Tjio and Levan. The manipulation and production of images became the salient issues in this

dispute, where the comparative virtues of each representing medium—either drawings or photographs—were also at stake. According to de Chadarevian's reconstruction, because of the value of images, the acrimonious debate centered on the respective epistemic value of drawings and photographs.

Once Levan and Tjio's representation of chromosomes—both as iconic photograph and schematic drawing—had become reproducible, the new human cytogenetics travelled easily and thus was ready to become a tool, contributing to the social and medical classification of people. It rendered groupings of people deemed to be either normal or pathological. Ana Barahona's contribution illustrates the very local contexts where knowledge of the shape and number of chromosomes became a subject of study for scientists and a tool to be used in Mexican public hospitals. Such a network of public health care facilities became a hallmark of the "Mexican miracle" of the 1960s, with human cytogenetics as a signifier of the modernizing endeavor. Genetic knowledge and its objects and representations provided stable, usable results in contexts far from their original location. This required a permanent reproduction of practices, acquired in foreign settings and brought home to produce and reproduce new knowledge. Cytogenetics became a flexible tool for detecting the effects of malnutrition on chromosome lesions, as Barahona demonstrates in her reconstruction.

The fragile site of the X chromosome and the chromosome lesion is the focus of Andrew Hogan's contribution. He ties together many of the themes included in this Issue: the relation between clinic and laboratory, the early morphological study of chromosome anomalies, and the classification of anomalous bodies. Moreover, Hogan's piece reveals the overlapping of visual cultures and methods, with their emphasis on shape and morphology, and the molecular perspective, concerned with mechanisms and functions. As Hogan insightfully argues, images of the fragile X marker shaped conceptions of human bodies while, simultaneously, the individual bodies of the carriers fashioned the way the fragile X marker itself was conceptualized. Moreover, Hogan links two communities that have been historically presented as distinctly separate groups from different eras, namely, cytogenetics and molecular medicine.

While inheritance still held significance, congenital effects produced during cell division through the action of environmental factors—such as radiation and chemicals—became part of the meaning and practice of medical genetics as a new clinical domain. Chromosomes and the Barr body, seen under the microscope and disseminated through scientific communities, became

diagnostics, of either inherited or congenital anomalies, and participated in the history of both medical and biological images of cellular entities. Visual cultures played an instrumental role, as shown in the many figures of chromosomes included in the papers that follow. This imaging of human genetics produced for the clinic became an agent of the contemporary practices of biomedicine; images of the inner body continue to be scrutinized for diagnostic evidence of anomalies and disease.²⁶

Underlying the diversity of case studies is a historiographical argument that this collection of papers seeks to support: by focusing on scientific objects other than molecules, and on places and perspectives apart from the usual centers, a renewed understanding of the production of knowledge is shown as a multifaceted, and noncentralized endeavor that featured postwar biological and biomedical research. The histories told here provided a cell-based epistemology for health and disorders, and for selected human traits. This collection thus challenges the overconfident emphasis on molecules, DNA, and nucleic acids that is frequently presented, and instead provides accounts of the origins of the practices and thinking of contemporary human genetics as it was in the 1950s, and continues to be through the human genome era.²⁷ Embedded in this particular moment, medical genetics advertised its explanatory capacity in relation to health, disease, and the inheritance of orders and disorders, of usual and unusual bodily features, through its focus on chromosomes.

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

27. Dorothy Nelkin and M. Susan Lindee, *The DNA Mystique: The Gene as a Cultural Icon* (New York: Freeman, 1996) provides pioneering analysis, while Robert C. Olby, *The Path to the Double Helix: The Discovery of DNA* (1974; reprinted New York: Dover, 1994) insightfully considers the substantial knowledge and practices of biology and chemistry involved in the construction of the double helix. The historiography of molecular biology has since criticized the centrality of this image while keeping experimental practices and narratives as main objects of inquiry. See, among others, Soraya de Chadarevian, *Designs for Life: Molecular Biology after World War II* (Cambridge, MA: Cambridge University Press, 2002); Angela N. H. Creager and Gregory J. Morgan, "After the Double Helix: Rosalind Franklin's Research on *Tobacco mosaic virus*," *Isis* 99 (2008): 239–72.