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The Life Sciences, 1900–2000: Analysis and Social Welfare from Mendel and Koch to Biotech and Conservation

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Abstract

The life sciences underwent a dramatic transformation during the twentieth century, with an expansion in fundamental knowledge of the process of evolution and its molecular basis, through advances in health care that greatly extended human life, and by the combination of these advances to address the problem of conserving the many forms of life threatened by expanding human society. The essay highlights the worldwide emphasis on social welfare in the years 1945–1980 and the expanding role of international collaboration, especially in the International Biological Program and its advances in ecology and the notion of the biosphere, and in the emergence of molecular biology. This was also the era of the Cold War, yet military confrontation had fewer implications for life sciences than for the natural sciences in that era. After 1980, deregulation and neoliberalism weakened programs for social welfare, yet links among the varying strands of life sciences continued to grow, bringing the development of genomics and its many implications, expanding epidemiology to include reliance on social sciences, and deepening ecological studies as the Anthropocene became more and more prevalent. In sum, the experience of the life sciences should make it clear to world historians that scientific advance goes beyond the achievements of brilliant but isolated researchers: those same advances rely substantially on social movements, migration, and the exchange of knowledge across intellectual and physical boundaries.

Keywords

conservation – decolonization – disease – genetics – life science – medicine – molecular biology – social welfare – United Nations

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Introduction

World historians, while they have been expanding their scope in many directions, have been cautious about incorporating scientific study into interpretations of global society. World historians have focused effectively on technology—from stone tools through agriculture and factory production to the internet—but their approach has been more to celebrate the benefits of practical advance than to analyze the complex evolution of knowledge.[1] Yet the expansion of scientific knowledge has been central to global transformation, especially in recent times.

For the life sciences in particular, the dramatic changes in twentieth-century human health are not to be ignored. Especially for the tropical and colonial world, the advances in nutrition, new limits on disease, and improvements in basic health services lie at the base of the rebalancing of the global order. World historians—especially world historians with Asian and African foci—will benefit from expanding their knowledge about the life sciences and the social impact of science more broadly on global patterns.

The present essay reviews some of the main fields within the life sciences and their developments during the twentieth century.[2] Its narrative highlights scientific achievements, but explains them more through processes of social collaboration than through the triumph of great scientific minds. The essay points to areas of debate, contention, and even malfeasance, but subordinates these to major achievements, with an emphasis on the interplay of new scientific knowledge and global social patterns. Three underlying themes recur throughout the narrative. First, the debates and the innovations within the life sciences early in the twentieth century continued to fuel advances throughout the century. Second, the great postwar focus on programs of social welfare provided the platform for dramatic expansion in many areas of the life sciences. Third, these two processes led to steady integration of life-science subfields

1 History of science, a learned and largely autonomous field of study, has recently been reviewed in *The Cambridge History of Science* (Lindberg and Numbers 2002–). The much newer field of world history has also been reviewed recently in *The Cambridge World History* (Wiesner-Hanks 2015). This collection, broadly cross-disciplinary, gives only modest attention to the place of science in world history. Among works providing introductory overviews of science in world history are Trefil 2012 and McClellan and Dorn 2015; these works focus more on listing inventions than on processes in scientific knowledge.

2 This work arose out of the results of a 2014 conference on "The Life Sciences After World War Two," held at the University of Pittsburgh and supported by the Andrew W. Mellon Foundation. The conference volume is Patrick Manning and Mat Savelli, eds., *Global Transformations in the Life Sciences, 1945–1980* (Pittsburgh: University of Pittsburgh Press, 2018).

with each other, so that old dichotomies of basic versus applied science or internal versus external sources of scientific advance lost their relevance.[3]

Neo-Darwinism in the Age of Imperial Chaos, 1900–1945

At the beginning of the twentieth century, the life sciences focused significant effort on studies in the increasingly professionalized field of medicine as they developed the insights of Louis Pasteur and Robert Koch, which had yielded the germ theory of infectious disease and brought success in treating bacterial infections.[4] The Rockefeller University, founded in 1901, took up a broad campaign of medical research that focused increasingly on the theoretical and basic-research side of the life sciences, especially in biochemistry (Olby 2004).

At the same time and also on the theoretical side of the life sciences, Mendel's genetic experiments and the laws he proposed, as they were rediscovered by three botanists working independently, laid the groundwork for the expanded study of genetics. By 1930, British statistician Ronald A. Fisher had developed an effective argument for the consistency of Mendelian genetics with Darwinian natural selection; this argument became the basis for the emerging field of population genetics (Fisher 1930). The notion of "genes" associated with chromosomes came to be widely adopted, but with the expectation that proteins rather than other chemical species provided the mechanism for reproduction. Protein analysis thus became a major focus of biochemical research in the 1920s and 1930s.

The Rockefeller University program on the "chemical basis of biological specificity," established in 1927, expanded from biochemistry into biophysics. That is, physicists were called upon in the hope that their focus on relatively simple analytical models would cut through the empirical complexity of biochemical analysis. The Rockefeller Foundation followed an approach that has subsequently been labelled "reductionism," in that it sought to encourage research that would discover the most elemental mechanisms of life—in particular, by putting physicists to work on problems previously studied by biochemists (Morange 1998, 84–85). Similarly, in Britain, the Medical Research

3 For a manifesto advocating top priority and government funding of "basic" research, see Bush 1946. For challenges to this vision, see Zachary 1997. For a substantial and updated critique of the dichotomy between basic and applied science, see Narayanamurti and Odumosu 2016.

4 Koch (1843–1910), who confirmed the identity of the anthrax bacterium in 1876 while working as a provincial German medical officer, concluded his career as leader of a 1905–1906 campaign against trypanosomiasis (sleeping sickness) in German East Africa and Uganda.

Council began to support a program of biophysical study in the 1930s, especially at Cambridge University (Chadarevian 2002). Experimental work turned to bacteria, especially *Escherichia coli*, and then to bacteriophages, viruses that reproduce through their interaction with bacteria.

As the biochemical and biophysical research continued, a "neo-Darwinian synthesis" emerged in the field of population genetics, affirming in the early 1940s that Mendelian genetics and not Lamarckian principles were consistent with Darwinian evolution. Yet this neo-Darwinian synthesis, while based on the notion of "genes" as carriers of heredity, had no verified interpretation of the chemical or molecular form of genes; the consensus of researchers continued to focus on proteins as the key element in biological replication (Dobzhansky 1937). A breakthrough did come, however, through a 1944 publication by Oswald Avery of the Rockefeller University. He clarified the chemical basis of biological specificity by showing that the essential step in biological reproduction was performed by nucleic acids rather than proteins. The implications of Avery's work were adopted slowly because of the established belief in the centrality of proteins. Ultimately, however, Avery's results strengthened the neo-Darwinian synthesis and opened the door to the emergence of molecular biology (Morange 1998, 30–39). Ironically, while Avery's work was neglected, eugenics gained attention. Eugenics grew as a complex and problematic dimension of the neo-Darwinian synthesis. In it, certain social scientists and biologists sought to apply the synthesis to humans with the intention of breeding to improve the human race. The Rockefeller Foundation provided support for the study of eugenics to the Kaiser Wilhelm Institute of Anthropology, Human Heredity, and Eugenics in Berlin, from 1930 to 1939; overall, however, interest in eugenics declined both before and especially after the war.[5]

Other interwar biomedical research proceeded in many directions. Biochemical researchers developed an understanding of vitamins A, B, C, and D in the decades before World War II. Also in the interwar years, penicillin, discovered as an antibiotic in 1928 and applied in clinical treatment beginning in 1941, came to be acquired by the Glaxo firm in Britain and then by Merck, Pfizer, and Squibb in the U.S.[6] DDT, first synthesized in 1874, was found in 1939 to have insecticidal properties by Swiss chemist Paul Hermann Müller; it came to be applied in wartime and postwar anti-malarial campaigns. Another

5 In programs associated with eugenics, sterilization programs were implemented in Europe, North America, and parts of Asia, mostly in the interwar years but also in postwar years. See Lynn 2001, 34–43; Gillette 2007; Bashford and Levine 2010.

6 Penicillin was used during World War II, but only by U.S. troops; it was produced for general use only after the war. See Bud 1998; Neushul 1993.

key antibiotic, streptomycin, was developed in 1944. In the Soviet Union, genetic studies moved ahead but were subordinated to efforts to advance agricultural productivity. The great global classifier, Nikolai Vavilov, played a key role in Soviet biology, but the younger Trofim Lysenko, who had achieved success in plant breeding, argued that exceptions to Mendelian limits could be achieved. This provided the basis for Lysenko to advance himself in the late 1930s and achieve the adoption of his views as the official Soviet approach to genetics (Joravsky 1970; Roll-Hansen 1985; Soyfer 1994; DeJong-Lambert and Krementsov 2012).

Despite the international atmosphere of imperial competition and growing ideological confrontation, as in that among nationally based pharmaceutical firms, the interwar years also brought relatively smooth circulation of ideas through communication of researchers in European and American centers and through migration of metropolitan researchers to colonial territories. The International Research Council (IRC) took form in 1919 to coordinate scientific organizations, but excluded Germany and the other former Central Powers as punishment for war guilt (Kevles 1971; Crawford 1988; Somsen 2008). The ineffectiveness of this approach to scientific collaboration became clear during the 1920s, and the IRC dissolved itself in 1931 in order to reconstitute itself as the International Council of Scientific Unions (ICSU), now open to organizations from every country. Germany joined immediately and the Soviet Union joined in 1933. Yet soon another type of migration rose in significance, especially as the Nazi regime in Germany began persecuting Jewish and Communist researchers.

The threat of war was then followed by war itself. In Britain and the United States, certain microbiologists were enabled to continue their research during the war; to a greater degree, all available energies in every participating nation or colony were applied to the war effort. Scientific studies suffered during the war, except for the medical and public health discoveries that were made on battlefields or on the home front.

1945–1980: Decolonization, Social Welfare, and Biomedical Innovation

Of all the great postwar changes, the impact of decolonization most strikingly and permanently reshaped the world order—in the structure and application of the life sciences as in many other areas of life. Decolonization was accompanied by a generation of campaigns to expand social welfare services in every region of the world, and by campaigns for various sorts of "development" of economic and social conditions. International organizations—including those associated with the Cold War confrontation of American and Soviet camps—expanded as never before, and helped to transform the landscape of the life sciences. In the atmosphere of these many types of social change, new knowledge emerged in the life sciences, initially in molecular biology and epidemiology and later in ecology. Throughout, the mobility of scientific personnel and health workers expanded the sharing and innovation in biomedical knowledge. These multiple factors, in their interaction, are considered in this section.

The territories occupied by Japan, from Manchuria to Burma, underwent at least two politico-military transformations within a decade. The waves of decolonization were centered in Asia during the 1940s, in Africa from the 1950s to the 1970s, and in island and other territories from the 1960s. This expansion in national independence not only created governments responsible to their national constituents but also shifted the balance of global politics, confirming nationhood as a near-universal basis for government.[7] Many newly independent nations saw in the life sciences the promise of development and nation building, offering shortcuts to improving health, agriculture, and nutrition.

In Asia and Africa, decolonization overlapped greatly with social welfare programs.[8] Asian nations, as they gained independence in the 1940s, immediately expanded formal citizenship to all inhabitants and invested energy in systems of public education and public health. Yet the path of decolonization was not easy—it brought great and military struggles and tragic massacres that set back the social advances that appeared to be unfolding. The colonial powers responded by turning promptly to parallel reforms in their remaining African and island territories, expanding public health efforts, schooling, and some voting rights—in an effort to provide reform but also to prolong colonial rule.[9] These colonial social welfare policies would be expanded as soon as the territories gained national independence, now with direct international aid.

7 From the original 51 charter members of the UN, membership grew to 60 in 1950, 99 in 1960, 127 in 1970, and 154 in 1980. The voting power of new nations in the General Assembly of the United Nations and of UNESCO ensured that the perspectives of these nations would be respected in one way or another.

8 The colonial powers did launch colonial development programs in the interwar years, such as the British Colonial Development Act of 1929 (expanded in 1940 and 1945), but large-scale colonial development programs came in the postwar atmosphere of decolonization.

9 For the case of France and perhaps Portugal, some Marshall Plan funds were sent to Africa to sustain the colonial regime (Maldant and Haubert 1973).

Indeed, the hindsight of history shows that, in the aftermath of war, social welfare became a high priority for societies everywhere. Recent economic analyses have confirmed that the era from 1945 to 1980 was a time of relative social equality—that is, of an unusual minimization of social inequality.[10] These comparative studies show—especially for well-documented nations—a deep decline in economic inequality during World War II, followed by a consistently low level of economic inequality up to 1980. After 1980, patterns of inequality shifted substantially, with rapidly rising levels of within-nation inequality, while between-nation inequality declined somewhat with time. Figures for less wealthy economies, while not as precise, followed a similar pattern. Although most ex-colonial regions did not experience rapid increases in per-capita income, they did on the whole achieve remarkable advances in literacy and in the average expectation of life at birth. In Asian and African countries, adult literacy had reached from 30 percent to 60 percent by 1980, while expectation of life at birth had risen from 35–40 years in 1940 to 50–60 years by 1980 (Riley 2005). A major expansion in old-age pensions, workers' compensation, and other forms of social insurance also began in this era, with the support of the International Labour Organization (Hu and Manning 2010). Meanwhile, debates and shifts in racial categorization persisted through the postwar era. Formal racial segregation was challenged in country after country; programs of "affirmative action" were implemented in India, Malaysia, and then in the United States.

In addition, comparisons across the planet during the postwar generation show that national investment in social services of health, education, and employment was unusually high in all parts of the world. In Western Europe, programs that became explicitly known as "the welfare state" were established by social-democratic governments (MacKenbach 2012; MacKenbach and McKee 2013). The British national health system was established and parallels were set up in other countries; social insurance programs and trade union rights were also well supported in this era. The United States, as compared with Europe, was relatively limited in the extension of such programs: nevertheless, postwar American pension programs, trade union recognition, public education, and even provision of health systems were relatively strong as compared with the preceding and succeeding eras. The Soviet Union, the socialist states of Eastern Europe and Asia, and China after 1949 sought to expand their systems of public education and social welfare. Further, Latin American countries expanded systems of education and set up social insurance systems along the

10 For global studies, see Piketty 2014; Milanovic 2016. For a global commentary that includes national and continental specifics for all world regions, see Hudson and Tribe 2016.

lines propagated by the International Labour Organization. Japan, which had made a strong start in social insurance programs in the interwar years, including the first national health care system, established a welfare state parallel to those in Europe as it recovered from the war. These included systems of national health care, pension systems and, at least initially, trade union rights. Finally, the decolonizing nations of Asia and Africa invested great amounts of national energy in expanding education and health care.

Thus, the processes of decolonization and the postwar expansion in social welfare programs had transformative impact on the life sciences and provided practitioners in the life sciences with exceptional opportunities to expand their knowledge through their contribution to postwar social change. In the same era, several other patterns of change interacted with social welfare to transform the life sciences in still different directions. Of these, the remainder of this section addresses the tensions of the Cold War, campaigns for socioeconomic development, the expansion of international organizations (especially UNESCO and its International Biological Program), the emergence of molecular biology and the understanding of the genetic code, the call for attention to biological conservation, and the mobility of scientific personnel around the world.

Postwar competition among states included contending nationalisms at all levels and tensions among the great powers. At the Cold War peak of the global order, the United States and the Soviet Union each gathered allies into grand coalitions. The United States invested heavily in the Marshall Plan, to provide support for the recovery of Western Europe and to weaken communist parties. After the Soviets exploded an atomic bomb in 1949, a hydrogen bomb in 1953, and sent up the Sputnik satellite in 1957, a military stalemate threatened war and divided societies globally until 1989 (Gerovitch 2015). The confrontation brought competition in every arena from sport to economy—and particularly in science. In addition, France and Britain struggled to maintain or re-establish their global roles. Japan and Germany designed long-term plans for recovery, while the national leaderships of many countries of intermediate power sought ways to advance their relative strength.[11] Meanwhile, for countries that were currently less powerful, the Non-Aligned Movement formed in 1961 in an attempt to carve out a third path, independent of the broader battle for influence and hegemony; the parallel Group of 77 formed within the United

11 Italy, India, China, South Korea, and, later, Turkey, Brazil, and Nigeria made claims for influence within the circle of hegemonic powers.

Nations in 1964.[12] Despite the prominence of the Cold War in world affairs, however, Soviet-American competition had less influence on the life sciences than it had on the physical sciences and engineering.

The notion of "development," intended to support public campaigns of economic and social advance, gained more attention than ever in the postwar world (Cooper and Packard 1998). An extreme example was the Great Stalin Plan for the Transformation of Nature, established in 1948 as a forest-creating exercise, dubbed "the world's first state-centered program to reverse human-induced climate change" (Brain 2010, 670). This program brought further prominence for Trofim Lysenko, who argued that the limits of Mendelian genetic heredity could be overcome with environmental programs to expand productivity. While innovative work continued in Soviet biomedical research, Soviet campaigns of top-down, mind-over-matter research that succeeded in atomic physics and rocketry did not generally succeed in the biological realm—nor (later) in the creation of an internet (Krementsov 2002; Peters 2016). Other programs of development, at all levels, proposed to rely on human agency to transform and improve the environment. Medical advances to prolong life were among the most inspirational examples of development and the hope that it set forth: the great hopes placed on DDT and penicillin were examples of the postwar logic of development. Those in the scientific community became devoted, in some cases, to the cause of development, reorienting their research around it; in other cases, scientists sought more opportunistically to appropriate resources from development programs to support their existing research. In one sense, competing national and corporate units sought to use science as an instrument for development, exploiting the natural world in new, more efficient, and sometimes more devastating ways.

International organizations arose during the immediate postwar era in the structures of government, economy, and society, and continued to expand without cease. The United Nations was to be the core of a wide range of international organizations that included the World Health Organization and the Food and Agriculture Organization. Of particular importance from the perspective of science was UNESCO, the United Nations Educational, Scientific, and Cultural Organization—its mission in education included the natural

12 The Group of 77, including United Nations members from Africa, Asia, Latin America, and the Pacific, formed in 1964, when total UN membership was 115. On its subsequent activities, see http://www.g77.org/. Early membership of the Non-Aligned Movement included nations from Europe (Yugoslavia), Africa (Ghana, Egypt), and Asia (Indonesia, India). The Non-Aligned Movement, in turn, was prefigured by the 1955 Bandung Conference of Afro-Asian Nations.

sciences, social sciences, human sciences, and cultural affairs.[13] This expanded wave of international organizations marked a new era of international institutional forces that regularly brought scientific actors from across the globe into contact with one another and raised a mix of concerns about development, conservation, race, mobility, and the developing understanding of thinking in terms of systems.[14]

The founding director-general of UNESCO (1946–1948), the British-born biologist Julian Huxley, became an outspoken advocate for internationalism in the full range of UNESCO's newly defined scope.[15] Within UNESCO, the ICSU was rechartered and expanded as the coordinating body for natural sciences. An array of international scientific unions, disciplinary-based organizations, and national academies of sciences filled out this academic map. Within the natural sciences, the physical sciences of physics, chemistry, and geology were best organized, while the life sciences had less access to resources.[16] The most striking early achievement of UNESCO was its collaboration with ICSU in directing the International Geophysical Year (IGY, July 1957–December 1958), involving collection of data and testing of theories worldwide. This campaign brought verification of the principle of plate tectonics and the notion of continental drift.

Soviet officials were cautious about collaboration with UNESCO, at least until they gained firmer control over Eastern Europe. But Soviet advances in atomic science, followed by the death of Stalin and the rise of Khrushchev, both in 1953, gave them increasing confidence in their ability to compete and collaborate in scientific advancements. On one hand, the Soviets expanded the

13 Other UN agencies included the World Meteorological Organization and the International Atomic Energy Agency. The International Labour Organization and the World Health Organization, formed in 1919 and 1920, became agencies of the United Nations. The directors general of UNESCO from 1946 to 1987 were Julian Huxley, United Kingdom (1946–1948); Jaime Torres Bodet, Mexico (1948–1952); John W. Taylor, United States (acting DG, 1952–1953); Luther Evans, United States (1953–1958); Vittorino Veronese, Italy (1958–1961); René Maheu, France (acting DG 1959, 1961–1962; DG 1962–1974); and Amadou-Mahtar M'Bow, Senegal (1974–1987).

14 As new ways of "doing science" materialized in the years after World War II, philanthropic bodies like the Rockefeller Foundation lost their central role (Kay 1999; Abir-Am 2010).

15 Huxley's rapidly produced manifesto (Huxley 1946) is an outstanding statement of the universalist view that prevailed briefly in the postwar atmosphere. On Huxley's involvement in eugenics and his evolutionary humanism, see Waters and Van Helden 1992.

16 For an excellent history of the ICSU, see Greenawaye 1992. It notes, for instance (p. 72), that Huxley became director-general of UNESCO in 1946 only after brief service by Sir Alfred Zimmern.

Stalin Plan, imposing it in Eastern Europe. On the other hand, Khrushchev's optimistic diplomatic initiatives included joining UNESCO in 1954, participating with increasing activity in UNESCO projects, and joining in the Geneva Summit of 1955. The Soviets joined the research efforts of the International Geophysical Year and launched the first satellite, Sputnik, in October 1957.

The International Biological Program (IBP), launched in 1964, was initially proposed as a parallel to IGY, with a focus on basic and theoretical scientific knowledge. Yet it was transformed, in broader UNESCO discussion, to emphasize "The Biological Basis of Productivity and Human Welfare": "As a consequence of the rapid rate of increase in the numbers and needs of the human populations of the world and their demands on the natural environment, there is an urgent need for greatly increased biological research" (IBP 1964, 43).[17]

The Report of the IBP's Planning Committee went on to stress the need for hitherto unparalleled international collaboration and data collection across the life sciences because "[m]any of the situations, both biological and human, are changing fast or even disappearing and may soon no longer be available for scientific understanding" (IBP 1964, 49). The planners of the IBP, having consulted with the World Health Organization, the Food and Agricultural Organization, and UNESCO, sought to develop a global understanding of the relationship between humans and their environment.

In practice, the IBP came to be caught not only in the contemporary debate distinguishing basic from applied science but in the conflicting aims of welfare and development. The vision of IBP as a tool for development was expressed by F.E. Smith (1968, 6): "[N]ow that the most favourable environments of the earth are occupied and developed, man is concerned with the development of the remaining countries." The contrasting focus on welfare was emphasized in the statement of India's S.K. Ghaswala (1968, 144–145) that India's participation in the program was "[a]n ambitious attack on India's twin problems of exploding population and lagging food production." From the outset, the IBP was conceived as an opportunity for "conserving and expanding the world's biological resources to better serve human needs" (Revelle 1967, 1).

In addition, while the IGY had focused on issues in basic science but had also brought to a head problems that had been long researched, notably in confirming the model of plate tectonics, the IBP was investing in early stages of ecological research. Ecological studies were relatively new and required wide-ranging field research, so that any hope for definitive results in the short term was illusory. Thus, the IBP was often equated with failure for its lack of landmark discoveries and for the insufficiency of its climate of international

17 See also Greenaway 1992, 175–176.

collaboration. The training fellowships and personnel exchange that were supposed to elevate the life sciences within the developing world never materialized. Such was the lack of collaboration that some scientists from developing countries described the IBP as a form of "scientific imperialism" at the program's last general assembly meeting in 1974 (Lewin 1975, 559). As one retrospective account noted just after the program's completion, "[n]ow, of course, everyone knows about ecology and the environment" (558). For one IBP scientist, the program's findings vindicated their decision to eschew the reductionism of molecular biologists, imploring fellow biologists that "[w]e wonder whether once in a while you shouldn't put down your microscopes and look at things about you" (E.S. Lee, quoted in Arehart-Treichel 1973, 157).

Financing the IBP had also been a consistent problem; loans from UNESCO and the ICSU were needed to keep things afloat, a problem worsened by the beginnings of global economic stagnation. As one commentator noted midway through the project, "[t]he more innocent biologists had clearly been misled by the vast sums of the International Geophysical Year" (Pirie 1967, 125). Consequently, many of the project's aims were abandoned midway through. Finally, the loftier hopes of some organizers that the IBP might challenge humankind's reckless approach to the environment were of course ultimately dashed. And in terms of practical data accumulation, the Global Data Centers, designed at the time of the IGY and proposed for extension into the IBP, seem never to have met their objective.

Another example of the role of international organizations in scientific debate arose during the 1976 threat of an influenza pandemic. The global health organization, WHO, took a wait-and-see approach to the threatened pandemic, while the U.S. national affiliate, the Centers for Disease Control (which in fact had greater research capability than WHO), proposed a worldwide campaign of creating and distributing immunization against certain influenza strains (Dehner 2012). In practice the pandemic never materialized, and both CDC and WHO had to reconsider their positions in preparing for future pandemic threats. The structure of international scientific organizations, under the UN umbrella, allowed this sort of interplay of different outlooks dominating at different levels.

Meanwhile, laboratory work on issues in heredity brought the emergence of molecular biology, a new field of study that confirmed many of the basic processes of genetic reproduction during the 1950s and 1960s. Combining insights from biochemistry, physics, biology, and chemistry with new instrumentation, researchers in a few key labs established the centrality of nuclear DNA in genetic reproduction and its role in the production of proteins throughout each cell's cytoplasm. The details of these discoveries in the processes of biological replication have been written up widely and effectively; the objective here is to give a brief outline of the main steps to reveal their parallels and links to developments elsewhere in the life sciences.[18] British and American labs, at Cambridge and Caltech, took up seriously the structure of heredity in the postwar years, focusing increasingly on DNA rather than proteins once the significance of Oswald Avery's 1944 publication came to be understood. In Cambridge, Rosalind Franklin's analysis of DNA using x-ray crystallography allowed new insights into the still-unknown structure and conformation of DNA. When Linus Pauling at Caltech, highly skilled in modeling, was not able to visit Cambridge or see the images, his colleague Max Delbrück sent James Watson, a young American postdoc at Caltech, to Cambridge.[19] Watson moved rapidly and, along with physicist Francis Crick of Cambridge, published in 1953 a rough double-helix model of DNA structure, which ultimately came to be seen as the solution to the problem of heredity.[20] Still, it took time before the significance of the double helix could be validated. In the late 1950s, the establishment of a new field was confirmed by the creation of academic departments of molecular biology in the U.S. and Britain, displacing biochemistry and biophysics from the leading edge of microbiology. Still, it was not clear what precise role DNA played in reproduction. Most important in clarifying DNA's role was the 1961 work of a group led by Marshall Nirenberg that validated the DNA code for selecting the amino acid phenylalanine. This confirmed that DNA contained a code for selection of amino acids in proteins, but it took years of experimental work to break the full code. Meanwhile, the award of the 1962 Nobel Prize in Physiology to Watson, Crick, and Maurice Wilkins reaffirmed the significance

18 Of the many fine works on molecular biology, Morange 1998 is excellent in describing the logic and steps in research. Other key works include Rasmussen 1997; Kay 1993; Abir-am 1997; Chadarevian and Kamminga 1998; Chadarevian 2002.

19 Pauling and other senior scientists were denied visas for travel as a result of fears about their political views.

20 Pnina Abir-Am has emphasized the Cold War restriction of academic communication at this crucial moment of discovery. As she argues, the double-helix story brought "the convergence of transdisciplinary, transinstitutional, and international movements, more political than poetic (for almost any scientist of distinction was prevented from entering or leaving the US, the new center of action, by the raging McCarthyism), resulted in a discovery that assembled formerly isolated scientific problems and results through the contingent agency of the only scientist who was young enough (less than 25) not to merit a dossier with the FBI during the Cold War, or to be hindered by pre–Cold War standards of social or scientific grace" (Abir-Am 1997, 511).

of the new understanding of DNA.[21] A key confirmation of the full mechanism came with the discovery of messenger RNA in 1960. These small molecules of ribonucleic acid, produced in the cellular nucleus, convey genetic information from DNA to other parts of the cell where they indicate the amino acid sequence in the production of proteins. One more advance was the discovery—at once exciting and frightening—of recombinant DNA, the combination of genetic materials from different sources in nature or in the laboratory. Paul Berg, a biochemist working on recombinant DNA, organized a 1975 conference at Asilomar on the California coast that articulated concerns about genetic manipulation and succeeded in imposing a moratorium on recombinant DNA research for several years.

As the full model of genetic reproduction became clear, the issue of "reductionism" arose explicitly within multiple fields of biology. That is, since the detailed mechanism of biological reproduction was now known through the work of molecular biology, could not all other fields of biology be reduced to their molecular basis? This challenge was posed to biochemists in the 1960s and extended to other fields thereafter.[22] In principle, reductionism now had to be accepted in general. In practice, however, good reasons arose for maintaining existing disciplinary frameworks, through modifying them to account for molecular knowledge. In turn, "molecular biology did not resign itself to having to live with other biological disciplines; it entered into a far more intimate relationship with them" (Morange 1998, 247).

The question of conservation of the natural world, while rarely the leading item on the life-science agenda, rose occasionally to prominence. The tension between development and conservation became especially clear with the expansion and then the restriction of DDT, a powerful insecticide.[23] While DDT

21 Watson and Crick published the initial 1953 paper on DNA (Watson and Crick 1953). Wilkins, who had participated in the essential x-ray crystallography, also shared in the 1962 Nobel Prize; Rosalind Franklin, even more central to the crystallography, had died in 1958 and was ineligible for the prize. Meanwhile, Thomas Kuhn's *Structure of Scientific Revolutions* appeared in 1962: his notion of "paradigms" and paradigm shifts was oriented toward the interpretation of physics, but his rejection of his earlier term "dogma" had a Cold War dimension and his framework came gradually to be applied to biology (Kuhn 1962).

22 Morange's (1998, 5–6, 83–84, 243, 245–252) commentary on reductionism is especially insightful on the interplay of various levels of study in biology.

23 Dichlorodiphenyltrichloroethane (DDT), first synthesized in 1874, was in 1939 shown to have powerful insecticidal properties by Paul Hermann Müller, who was awarded the Nobel Prize in Physiology or Medicine in 1948. During the war, the U.S. military sprayed DDT to combat typhus and malaria.

was highly effective in reducing malaria from 1945 onward, concerns arose that some insect species were developing resistance to it; in addition, DDT was suspected of reducing bird populations by thinning their eggshells, and of causing cancer in humans. Following the impact of Rachel Carson's critical study of insecticides, *Silent Spring* (1962), the United States banned use of DDT in 1972, and use of this chemical declined sharply thereafter. The debate on insecticides and other synthetic organic compounds continues to this day: on one side are those seeking to eliminate malaria and advance agricultural productivity; on the other side are those concerned over the poisoning of human, vertebrate, and arthropod species.

Human mobility, an omnipresent but fluctuating pattern in human affairs, played specific roles in the scientific world of the postwar era. Long-distance migration shifted with the long-distance dispatch of troops and the flight of refugees, both during and after the war. Postwar migration rose from a low level until the numbers again became large in the 1960s. Scientific personnel were relatively mobile throughout the postwar period; the terms "brain drain" and "brain gain" arose to reflect contemporaneous concerns about the movement of skilled workers.[24] Mobility of labor forces, especially skilled scientific labor, responded to all of the pressures of the expanding and transforming world, so that competing demand became a regular topic of discussion.

Since 1980: Biotech and Conservationism in a Multicentric World

The outstanding trends in the life sciences since 1980 have been the rise of ambitious programs in biotechnology, expanded attention to conservationism and ecological studies, plus encounters with new problems in infectious disease. Symbolic for both the advances in biotechnology and the concerns for human welfare was the remarkable research on mitochondrial DNA and human origins. The sequencing of mitochondrial DNA for 147 racially diverse individuals led to the confident assertion, in a 1987 paper, that all contemporary humans are descendants of African communities that can be traced back nearly 200,000 years (Cann, Stoneking, and Wilson 1987). In biological terms, the confirmation of this result in subsequent work led to support of the Human Genome Project, funded by the U.S. National Institutes of Health, which by 2003 was able to announce the complete sequencing of the human genome,

24 This issue retains its complexity. The victorious powers sought control of German and Japanese scientists at the end of World War II, and scientists were restricted from entering or leaving the U.S. during the McCarthy era. See n. 20 above.

including roughly 30,000 genes. In the general public, this result argued for the unity and close interrelationship of the human species and argued firmly against claims that racial categories reflected significant biological differences.

Meanwhile, the social conditions under which the life sciences carried out their work changed significantly after 1980. From the mid-1970s, the postwar era's growth in prosperity and attention to social welfare gave way to stagnation in output, rising levels of debt, and growing labor conflict. There was no single planetary shock to mark the end of an era as had been the case in 1945, but rather a complex transition. The petroleum crises of the 1970s raised oil prices, interest rates, and levels of debt, especially in tropical nations. Dictatorships arose in Latin America, Africa, Asia, and, more briefly, in Europe. From 1980, prosperity expanded mostly for the wealthy as rates of economic inequality grew worldwide, though the expanding economies of China and India tended to counter the global trend of stagnation.

In this era of shifting socioeconomic conditions, the nations of the Group of 77 flexed their new political muscles in an attempt to achieve global agreements that would advance equality among nations.[25] The 1974–1987 term of UNESCO Secretary-General Amadou Mahtar M'Bow, a geographer and the minister of education in Senegal, brought an era in which much of UNESCO's activity was oriented toward providing support for the ambitions of ex-colonial nations, centered substantially in the tropics. Also in 1974, the UN General Assembly, supporting the wishes of the Group of 77, called for creation of a New International Economic Order that would emphasize greater equity among nations in trade relations, and scheduled a 1979 United Nations Conference on Science and Technology for Development to implement this plan.[26]

In response to these calls for greater global collaboration, political and corporate leaders within the great powers expanded their critique of global collaboration and social welfare. This outlook became manifest especially in the rise to power of Margaret Thatcher in the United Kingdom (prime minister 1979–1990) and Ronald Reagan in the United States (president 1981–1989), and overlapped with efforts at reform in the Soviet Union under Mikhail Gorbachev (1985–1991). Only gradually did the term "neoliberalism" come to be accepted,

25 The pace of admission of new UN members declined after the fall of the Portuguese empire in 1975, yet the G-77 group then included roughly 100 of 140 UN members.

26 Arguably, it was the International Biological Program that laid the groundwork for the 1979 global conference in Vienna, the United Nations Conference on Science and Technology for Development. But this conference, in which members of the G-77 group pressed for major funding of science and technology throughout the world, failed to meet its objective, largely because the great powers declined to support it (Borowy 2016).

but in practice the outlook emphasized weakening of trade unions, limitations on spending for general welfare, reduction of pension programs, and reduction of regulations on private firms. This policy involved a more aggressive approach toward the Soviet bloc and the decolonizing or Non-Aligned nations—thus the United States (1984–2003) and the United Kingdom (1985–1997) withdrew from UNESCO, claiming that the organization was poorly administered but, more basically, opposing its favoring of ex-colonial countries.

The Cold War came to an end in the midst of massive social movements of populations making claims for democratic rights. These movements rose to great prominence during the 1989 demonstrations in Tiananmen and the succeeding 1989–1990 social movements in Eastern Europe, much of Africa, and elsewhere. The process took a confusing and conflicted turn with the August 1990 Iraqi seizure of Kuwait and the U.S.-led assault on Iraq up to February 1991. Following the late 1991 dissolution of the Soviet Union, the level of social contestation gradually died down. The United States briefly appeared supreme as the one superpower, but other shifts followed.

The post–Cold War era sharpened the contention between two visions of world governance: one emphasizing leadership by a few wealthy nations, the other preferring collaboration among nations of all sizes and levels of wealth. Governance by wealth or by population; by great powers or by national equality: each vision and each camp could rely on precedents going back to 1945. Among the wealthy nations, the European Union was formed in 1993 (and expanded dramatically in 2004), the World Trade Organization in 1995, and the Group of 20 in 1999.[27] These new structures, governed by relative wealth rather than population, allied themselves with United Nations structures founded in 1945 that also emphasized wealth rather than population: the UN Security Council, the World Bank, and the International Monetary Fund. Together, they appeared to indicate a neoliberal world order governed by a few powerful and wealthy nations in concert.

The contending approach relied on the structure of a different set of United Nations institutions, also founded in 1945 and governed not by wealth but based on the number of national members and their populations. These included the United Nations General Assembly, the World Health Organization, and UNESCO (each governed by the majority of member states); also included

27 The World Trade Organisation replaced and formally incorporated the General Agreement on Tariffs and Trade (GATT), which was founded in 1947 when participants at a United Nations conference failed in the plan to create an International Trade Organization. The Group of 20, which has no affiliation with the United Nations, formed in 1999, and is an expansion of the G-7 founded in 1975.

was the International Labour Organization (governed by a balance of state, employer, and employee representatives). Members of the Group of 77 and other regional groupings, combining to exercise substantial majorities in these organizations, adopted a continuing stream of resolutions proposing standards and regulations in scientific, social, economic, and cultural affairs. The tensions between the two approaches to global governance continued, and neither approach gained dominance.

One arena of struggle between the two outlooks was in the handling of old-age pensions. Neoliberal interests, with strong support in the World Bank, supported privatization of public pensions. In contrast, the International Labour Organization, a supporter of public pensions since the 1920s, maintained its support for them. One great contest between the two sides took place in China in the late 1990s, and the result was a draw, with portions of Chinese pensions privatized and other portions remaining publicly held (Hu 2015).[28] Yet another shift in international relations came with the relative growth of economies outside the North Atlantic. Especially from the 1990s, China and India accelerated their economic growth so that, from 1980 to 2015, the percentage of the G-7 countries' contribution to global output declined from just over 60 percent to roughly 45 percent.[29]

In the global mix of some two hundred nations—big and small, rich and poor—the meanings of "nationalism" were complex and contradictory. But after a half-century of social discourse and scientific results supporting the equality of human individuals, it remained clear that humans remained ready to turn to national identity to simplify the complexity of the world. Thus, while the results arising from analysis of the human genome gave primacy to the commonality of humans, it did not take long for merchants to begin selling DNA-testing procedures that identified people not by their individual characteristics but that classified people into national and racial groups, thus reifying the very categories that had been deconstructed by genomic research.

Biotechnology emerged as a field as researchers overcame their fears about interfering with recombinant DNA. The U.S. moratorium on research with

28 Even in the era of expanding neoliberalism, some regulations were adopted and honored. The 1985 Vienna Convention on Ozone Layer was followed by the more general Stockholm Convention on Persistent Organic Pollutants (including DDT), signed by 152 nations in 2001. Not ratifying as of 2018 were Brunei, Haiti, Israel, Italy, Malaysia, and the United States.

29 World Bank figures show that GDP for the G-7 countries (United States, Canada, Japan, France, Germany, Italy, and United Kingdom) declined from 62 percent of global GDP in 1980 to 46 percent in 2015.

recombinant DNA was brought to an end in the deregulation atmosphere of the 1980s. On the one hand, this enabled Genentech, a private biotechnology firm, to arise as a speculative star on Wall Street (Hughes 2011). On the other hand, implications of the study of mitochondrial DNA and human evolution were recognized rapidly as resolving long debates on human evolution and as focusing on historical study of the genome. With this result, fueled especially by the steady improvement in techniques for gene sequencing, the campaign for documenting the full human genome took hold (financed by the U.S. National Institutes of Health), and success in the project was announced in 2003.[30] At much the same time, concerns about global warming led to creation of the Intergovernmental Panel on Climate Change (supported by the UN). Its first report was published in 1990 and subsequent reports only confirmed and deepened the great concerns about environmental degradation. Although molecular biology raced ahead, it also ran into new debates. The reductionism dispute came up again as Stephen J. Gould and Niles Eldredge argued that evolution proceeded not at a regular pace, according to the hypothesis of a random frequency of mutations, but with rapid bursts (Morange 1998, 249–250). The dispute continued beyond 2000 and it deepened with research on “epigenetics,” the study of modification of gene expression rather than alteration of the genetic code itself (Tost 2008).

Meanwhile, increasing evidence arose to document the exhaustion of natural and human resources. As the century progressed, international bodies took an increasingly central role in discussions over how to safeguard humankind’s collective future.[31] Powerful movements for “conservation” arose—in response to the excesses of development—among new nations, struggling communities, and philanthropic groups. Longstanding beliefs, sometimes religiously based, in the inherent value of the natural world and the balance among its elements, gained increasing attention among those identifying new problems in environmental decay and new threats to health. The rise of systems theory, also codified in the postwar era, enabled environmental and other conservation movements to develop sophisticated and interactive arguments about the need to invest in conservation and not just in development.

Recent research on the notion of Big Science has begun to account for the place of the biological sciences, including biotech and ecological studies,

30 In an important and overlapping technical development, the U.S. National Institutes of Health released PubMed in 1997. This open-access bibliography of most English-language periodical literature in the life sciences greatly facilitated scholarly communication.

31 See, for instance, Borowy 2013.

within this category.[32] In the main, scholars first began to explore Big Science through the prism of the physical sciences through projects like the Manhattan Project and the CERN (European Organization for Nuclear Research) project in Switzerland.[33] More recently, biological research programs, such as the Human Genome Project, have received attention in this regard. In particular, historians have emphasized important differences in the application of Big Science to the life sciences, particularly the fact that these disciplines have historically attracted much less military funding than the physical sciences and have relied more on large networks of researchers than massive machinery or laboratories (Kevles 1997; Vermeulen, Parker, and Penders 2010; 2013; Parker, Vermeulen, and Penders 2010; Coleman 2010; Vermeulen 2013).

In addition to the new problems of conservation, great new challenges arose in infectious disease. The HIV-AIDS crisis expanded relentlessly for twenty years: new infections peaked in roughly 1997 and annual mortality peaked in roughly 2005 (Iliffe 2006). Overall, biomedical science was slow to rise to the occasion on research and treatment for this disease of the postindustrial age. The outcome showed the need for expanded collaboration between social sciences and biomedical science in treatment; the meagre flow of funds and personnel to Africa and the reluctance to work closely with African communities and their health specialists showed that the old hierarchies had not fully given way to the challenge of the post-human-genome outlook, with its implicitly high value on human equality.

The aftermath of devastating war, the emphasis on social welfare as much as on economic growth, the end of colonial empires, and Cold War confrontation combined at once to shape and to respond to the great postwar expansion in the practice of the life sciences. New international institutions showed the capability to tackle the grandest of scientific challenges, yet they also experienced paralysis in response to the national ambitions of their members. Political ideology could constrain research, nationalist sentiment could redirect research, but the spirit of internationalism just as commonly prevailed. By the end of the twentieth century, multiple threads of the life sciences were joining in an unprecedented exploration, biotechnology. At the same time, new understandings of ecology were put to the test in facing the rising threat of environmental degradation.

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32 For a 2010 account that treats the IBP as a "secret success" and encompasses the Long Term Ecological Research (LTER) Network, see Aronova, Baker, and Oreskes 2010.

33 Among many others, see Solla Price 1963; Galison and Hevly 1992; Capshew and Rader 1992; Rasmussen 2002; Westfall 2003.

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