Leadership in SCIENCE and TECHNOLOGY

A REFERENCE HANDBOOK

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Case Studies

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Human Dimensions of Biology

Jane Maienschein

Human dimensions of biology is not a single discipline, nor a well-known entity that we all easily recognize. Yet the phrase has taken on important meaning and captures several different things that add substantively to our understanding of how biological sciences act in society. Sometimes the phrase is "human and social dimensions of science and technology" or related terms. Nonetheless, there is an emerging understanding of the cluster of different types of research that make up the human dimensions of biology. These types all ask about intersections of humanistic and social sciences that seek to understand the biological sciences as they are carried out in the world. Among the historical, philosophical, and social science dimensions to such studies are four main different approaches.

First is the most traditional study of the internal workings of science itself. This study of the *history and nature of science* recognizes that there are human dimensions to the way science is carried out. For example, human choices are made about which questions are asked, which techniques used, and which organisms are studied and about interpretations. The disciplinary fields of history and philosophy of science have concentrated on understanding these aspects of science. Sociology, anthropology, and psychology of science also add to our understanding, with focus on social and cognitive aspects of scientific work. This first approach therefore focuses on the fact that humans are doing the science and on the ways that human activity shapes the science itself.

Second is the closely related external study of the development of *science in society*. Here the focus is on external factors that shape which science is done, by whom and for whom it is done, and where it is done. A simple distinction would note that the first approach focuses on how science is done, whereas this approach focuses on how it is used, and on the choices and reasons for choices made about the use. Of course, historians and philosophers will point out that these two are not clearly distinct and that they usually overlap. Yet there is value is looking at both the internal and the external, the getting done and the getting used aspects of science. They are interconnected, but not always inextricably so.

In this second approach, for example, bioethical considerations may come into play, or questions about how legal and policy factors shape the science. In this case, factors outside of science itself are demonstrably influencing the scientific work done—for example, when public policy dictates that some nations will not do stem cell research or that it is not legal to do research on human subjects under various conditions.

These first two approaches look at the science itself and the way it is shaped by factors internal and external to the science itself, but the other two approaches look at humans as part of natural systems. The third approach considers the implications of biology for understanding humans, by looking at *humans as biological beings*. That is, how do general biological principles, laws, and interpretations apply to humans? Humans are results of evolutionary forces that affect all aspects of our lives from sexual reproduction to behavior to genetics and disease. To understand human nature, then, requires an extension of general biology to humans as biological organisms. We have to move beyond the idea that humans are sometimes different from (and perhaps even better than) other biological organisms and to see ourselves as the material evolved beings that we are.

Fourth is the importance of understanding humans as inextricably and interactively part of nature, that is as both part of nature and as agents who are acting on and thereby changing aspects of the very biological nature they are studying. In part, this is a matter of *putting humans into nature*, as in the sense of putting them into our understanding of ecosystems or as affecting global biodiversity.

Another sense involves putting humans into nature through human genetic engineering, synthetic biology, or through development of cultured or stem cell lines, for example. Each of these engineered results would not have occurred without human action, and yet the products are now rightfully part of the new natural systems that biological sciences study. Studying the biological aspects of engineered life is as much a part of the human dimensions of biological sciences as is studying humans within ecosystems, therefore.

Each of these approaches will become clearer through selected illustrative examples, followed by a sense of the implications of appreciating the importance of the human dimensions of biology and by a summary and ideas for further exploration. Of course, there are many other examples as well, but this overview should offer a sense of the range of human dimensions work and perspectives.

According to Google, as of July 24, 2010, there is just one established program in "Human Dimensions of Biology," in Arizona State University's School of Life Sciences. Here faculty members from widely divergent backgrounds ranging from history and philosophy of science to economics, immunology, paleobotany, and other areas come together so that the group "encompasses perspectives, research, and education on: human interactions with nature and the environment (such as conservation biology and urban ecology); the science of humans (including human behavior and evolution); science as a human endeavor (through history and philosophy of science); and the interplay of science and society (in the context of education, public policy, law, and daily life)." Collectively, the group embraces all four of the approaches mentioned here.

History and Nature of Science

Consideration of the "History and Nature of Science" has been a central piece of science education since the mid-1980s. The American Association for the Advancement of Science (AAAS), which calls itself the world's largest general scientific society, began Project 2061 in 1985 in response to growing calls for increased scientific literacy. The AAAS project brought many thousands of colleagues into the development and review process that led to *Science for All Americans* in 1989 to lay out the principles and guidelines for what students in K–12 education should learn. In 1993, *Benchmarks for Science Literacy* brought, as the title indicates, more specific learning objectives and benchmarks. Project 2061 has continued, with additional volumes, more specific guidelines and "Atlas" materials, and with considerable impact and valuable resources for teachers and states working to develop state science standards.

Responding to the same forces, the National Research Council (NRC) report *National Science Education Standards* was published in 1996 to inspire reform in education at the K–12 level after concerns that students in the United States were in danger of falling behind other developed countries in the education of scientists and engineers. Long before the No Child Left Behind Act of 2001, the NRC had joined AAAS, the National Science Foundation, and other U.S. organizations and agencies in recognizing the importance of scientific literacy for all Americans and in seeking to give every child a chance to learn science.

Both AAAS and NRC have seen education as beginning with an understanding of what science is, building on a foundation of learning about the history and nature of science. The NRC "Framework for Science Education" draft report circulated for comment in July 2010 reflects the same thinking but makes it even more explicit. The authors of this report continue their public process of soliciting input and details may change, but the intention is clearly to provide a strong and clear framework on which states can draw as they develop revised science standards.

All of these leading reports lay out principles that make clear that science is to be understood as a process carried out through time, done by people like you and me, and taking place in the context of the real world that sets constraints and makes possible some work more than others. Science is logical and systematic, indeed, reassuringly so, and not a mysterious process that only nerdy geniuses can do. Also, science works through developing ideas and then trial and error to test their fit with the natural world. Hypothesis development to explain phenomena goes along with empirical observation and testing of ideas, with the understanding that "hypotheses" may include careful summaries of observations or models, and testing may include field observations, computer simulations, or other than laboratory "wet-lab" experimentation. There is a process to science, and any of us can explore nature and come up with ideas, develop them into coherent explanatory and often predictive theories, then learn to test them.

In addition, science changes over time. It is not that somebody discovers something about nature and that remains our understanding of nature forever. Aristotle was an extremely creative man in the fourth century BC, and we agree with many of his ideas about how to study the world. But we have moved beyond his interpretations in many ways. At any given time, scientists necessarily make some assumptions about how the world works because we cannot ask about everything at once and have to start with some solid assumptions. What was once "known" can be completely set aside, and new knowledge is established through a consensus of the scientific community.

History and philosophy of science examine how underlying assumptions have worked in the past, and how they have changed over time. For example, scientists assume that the natural world is in fact natural—not supernatural or controlled by mysterious forces or special gods. It obeys laws and is predictable so that if the sun goes around the earth in a particular direction and comes up in one area of the sky every day we have experienced, it will keep coming up in that direction in a predictable way. Or if elephants grow a certain way because of cell division and give rise through sexual reproduction to other elephants, we can predict that the next elephant will do the same under natural conditions.

Understanding the history and nature of science tells us some things about methods of science and how they change over time. Scientific textbooks have often mentioned "the scientific method" as if there were only one and we know exactly what it is. This is not strictly accurate, as the new NRC "Framework" explains in draft chapter 5, because there are actually many aspects of the way we do science. Studies in the field work differently from those carried out in the laboratory, and one type of lab will differ from others. The biological sciences sometimes call for different approaches than do aspects of the physical sciences, as scientists seek to understand the organisms that are very complex systems, each of which has arisen by adaptation through evolution. Some problems call for reductionistic approaches, whereas others require complex systems analysis and in some cases understanding of adaptive systems. Therefore, those who study the history and nature of science examine epistemological assumptions about the nature of knowledge, the balance of theory and experimental and field practices.

Some historians have begun working closely with biologists to ask different questions than either would have done alone. For example, historian/biologist Manfred Laubichler and developmental biologist Eric Davidson have taken a new look at the pioneering experimental studies of cell biologist Theodor Boveri that revealed that chromosomes are the carriers of hereditary information. Among other things, Laubichler and Davidson (2008) focused on the 70-year history of one specific experimental design and the controversies surrounding the interpretations of its results. Such an approach reveals epistemological assumptions as well as methodological and technical constraints that substantially affect the course of science, then as well as today.

Laubichler's work with historian Jane Maienschein and vascular biomedical researcher William Aird provides another example. They have shown the way that the earliest studies of the endothelium, especially by Wilhelm His who introduced the term, grew out of his study of development and point to different ways to understand these inner cells of the vascular system—then and now (Laubichler, Aird, and Maienschein 2007). Meanwhile, other philosophers are working alongside systematists, for example, to study what we mean by "species"—which is particularly important when we want to understand the extent and character of biodiversity including the imperative that some people feel to save those species. In each case, the historical and philosophical approaches reveal underlying assumptions, as discussed in Jane Maienschein, Manfred Laubichler, and Andrea Loettgers's (2008) "How Can History of Science Matter to Scientists?" Making those assumptions visible helps lead to more informed future research.

In addition, as historians Naomi Oreskes and Eric Conway (2010) show, science does not always produce "certainty" in results, but produces the best understanding for now. This understanding will often include probabilistic accounts: we know that there is such-and-such probability of a particular outcome given the conditions stated. Peer review and emerging consensus in a scientific community leads eventually to acceptance of an explanation as best—but only after much testing and contesting of competing views.

As Oreskes and Conway explain, with smoking tobacco or dramatically increasing human burning of carbon-based fuels, there are questions about whether the smoking causes cancer in the first case and about whether global climate change is causing warming because of human actions. In each case, for the population and globally, we can confidently say yes. Yes, smoking causes cancer and burning carbon fuels contributes to global warming. That is true in general.

The scientific community has reached consensus about smoking and burning carbon fuels, but that does not allow us to make predictions that any particular individual will suffer cancer nor any particular place will experience warming. Science gives us both extremely precise and definite results: yes, smoking definitely causes cancer. But the science also gives us probabilistic and uncertain results for a particular case of predicting whether a particular person will develop cancer. Understanding the difference between uncertainty about a particular detail and doubt about the overall causal connections is extremely important. Oreskes and Conway do an outstanding job of demonstrating why. They show that the "merchants of doubt" they identify and discuss have had political and personal reasons for drawing on the uncertainties about particular cases to plant seeds of doubt about the big picture causal connections, where there is really no doubt. Oreskes and Conway argue persuasively that the media have not helped to make this distinction, perhaps because they do not understand it themselves or perhaps because those doubt merchants have so effectively manipulated the press.

The cases of cancer and global warming point to another aspect of the biological sciences that is changing the way researchers work. It is widely acknowledged that there is an explosion of data and that we do not have the infrastructure in place to collect, archive, compare, analyze, and make it all available. As a result, individual researchers may have access to different data sets and end up with different conclusions. Comparison across multiple sets and sharing of data in ways that are considered "interoperable" is a goal for many researchers and for agencies such as the National Institutes of Health (NIH) and the National Science Foundation (NSF). Researchers are having to learn to manage data and how to draw on available data for the most robust interpretations. We see that science works in defined and systematic ways, but is carried out by people who work within social and institutional

constraints and with particular choices and assumptions about the work they do. We turn next to ways that society affects the science done and the way it is used.

Science in Society

Practices in the biological sciences are all carried out by the people doing work in a messy social context, with its pressures and limitations and its own assumptions. Looking at who does the science, where they do it, which science gets done, and who uses the discoveries are also all part of understanding human dimensions of biology.

In addition, policies and law, as well as bioethical considerations all play a role in shaping both the science and the way the science is taken up in society. The old-fashioned view of science is that completely disinterested researchers study nature as they find it. They ask whatever their curiosity drives them to ask, using whatever methods and equipment they can find. And therefore science is insulated from the society that surrounds the human researchers doing the science.

Researchers in history and social studies of science have shown very convincingly for several decades that this has never been true. Thinkers since ancient times have had their patrons and have responded to social whims and wishes, so that, for example, the physician Galen sought to please his supporters and energetically attack his opponents, and Galileo Galilei cared a great deal about what the Medici family wanted. Today, the patrons of science are often governments and private funding agencies, so that researchers have to make their proposals conform to the defined initiatives and the standards set by the agencies. For some research, very little funding is available (as for example, detailed descriptive systematics work required for classifying all those organisms that make up the world of biodiversity or theoretical work that is neither empirical nor hypothesis-testing). This differential availability of funding should stimulate leaders to ask whether we are overemphasizing some areas and missing others, for example. Such a result would be important if it means that we do not have data we might need to make informed decisions about, say, how to respond to oil spill emergencies or a new infectious disease.

For biomedical research, some have pointed to the concentration on selected organisms as a human dimension of science that can distort what we know. We know that there is relatively more funding in some areas, and some analysts argue that the NIH stated priority for working on particular "model organisms" has caused researchers to miss the opportunity for valuable cross-species comparisons, for example. As sociologists Adele Clarke and Joan Fujimura (1992) have pointed out, sometimes it is true that there is a "right tool for the job" including a particular organism for addressing a particular question, but that is surely not the case because the NIH expressed a preference for that organism as a model for humans.

The NIH list includes mammals (mouse and rat), as well as nonmammalian models such as the yeast *Saccharomyces cerevisiae* and *Schizosaccharomyces pombe*, fungus *Neurospora*, amoebae *Dictyostelium discoideum*, round worm *Caenorhabditis elegans*, water flea *Daphnia*, fruit fly *Drosophila*, zebrafish *Danio rerio*, frog *Xenopus*, chicken *Gallus*, and also the plant *Arabidopsis* that is considered a targeted rather than model organism. Why these, you might ask? Partly for historical reasons, because they proved useful in the laboratory and we have learned so much about them that it is efficient to keep investing in the same organisms to learn more. And sometimes for strategic reasons because the research community has made the case that the organism in question, like the mouse or rat, are enough like humans that they stand in as a model for the human conditions that we cannot study directly.

Why does it matter? One argument a few years ago was that if we only fund research on a few organisms, we could not do genetic comparisons that would be useful for understanding diseases. As that genetic work has become less expensive, however, that argument has faded. Some worry that we are missing important aspects of biological nature because we in effect have on blinders caused by funding restrictions. The argument is that just because the very large axons of giant squid made it easy to measure action potentials, or because Eric Kandel did magic with the sea slug Aplysia and its electronic release of ink does not mean that these are excellent models for other aspects of human neural system behavior. Others note that such concentration is efficient, and philosopher of science Rachel Ankeny (2001) explains the arguments in each case.

Other social factors also shape science, of course. The social worlds of scientific work shape institutions, constrain, and enable choices. Science is carried out through teamwork, with a complex network and often a hierarchy of principal investigators, postdoctoral fellows, graduate students, undergraduates, and occasionally others. The work carried out in large funded laboratories starts with the questions and problems the principal investigator seeks to address, but this is not just a matter of following the researcher's own curiosity. In fact, much science is actually mission oriented. It is oriented toward solving problems that are considered important to society and for which federal agencies or private foundations have made funding available to solve the problem, as with specific diseases or the need to clean up an oil spill. Even with Galileo, the interest of patrons influenced his study, but his goals remained largely intellectual rather than technological. Today, we are farther beyond the individual curiosity-driven wondering and much more often mission-oriented.

Bioethics, biopolicy, and law also affect the science done in society. For example, concerns about the bioethics of embryonic stem cell research led to policy discussions about funding and laws in numerous jurisdictions in the United States and internationally to fund, restrict, and sometimes regulate research. Another example concerns cloning or genetic engineering of foods. Public fears in some areas, especially in Europe, have led to restrictions on agricultural use of cloned animals or foods derived from genetically engineered crops, but other researchers and populations are promoting research to extend food production through just those same technologies of cloning or genetic engineering.

Bioethics and law have affected the context of research, such as with regulation of human subjects research. The Nuremberg Code was established in 1947 as part of the Nazi trials, and the U.S. Congress adopted its own code beginning in 1974 to regulate research carried out by the then Department of Health, Education, and Welfare, which included NIH. This, in turn, led to a series of discussions and reports that eventually led to 45 CFR 46, based on the Belmont Report (National Commission for the Protection of Human Subjects 1978) and establishing what is called the "Common Rule." This legislation set up the Institutional Review Board policies and guidelines that have been adapted and modified numerous times since.

Some critics feel that the resulting emphasis on research subjects' informed consent has become too restrictive. Some see the rules as unnecessarily complex and as denying those who are ill the ability to participate in clinical trials. But ethicists reason that such participation can too easily become exploitative, that subjects do not fully understand the risks involved, and that they are easily misled by what is called the "therapeutic misconception," which is the mistaken impression that if somebody is doing a trial it must be because the product works. Some researchers and potential donors have complained that informed consent to donate tissue or eggs for experimentation is sometimes overly restrictive.

There are many examples of the ways that society has shaped science in complex ways. An early twentieth-century example is in public health, with the eugenical calls for "good breeding" to prevent the genetically "deficient" from having children and encourage the "superior" to do so. One proponent of public health through intelligent breeding, Margaret Sanger, worked hard to provide accessible birth control options for those who wanted them with the hope of reducing the number of dangerous abortions and unwanted children. Her partnership with biologist Gregory Pincus and Catholic physician John Rock led to commercially available birth control pills in 1960.

Meanwhile, others sought ways to solve the reverse problem and to create procedures and technologies to help infertile couples have the children they so eagerly wanted. This research led in 1978 to in vitro fertilization (IVF) by biologist Robert Edwards (who had been working on mouse stem cells) and physician Patrick Steptoe and to the birth of Louise Brown, the first "test tube baby." Both the birth control and IVF movements had roots in the same social impulses, both encouraged mission-oriented science, and both led to medical and scientific results that elicited strong social reactions and that were regulated by state and federal governments.

Humans as Biological Beings

We understand that we humans are made up of matter, consisting of cells and guided by transcription and expression DNA within cells through cell-cell signaling to organize into functional, complex individual organisms. In addition, as has been widely acknowledged since the late nineteenth century, we are the product of long evolutionary processes that have left many remnants of past adaptations and relationships. Our individual ontogenetic development is very much shaped by its place in the evolutionary scheme of things, so that we are thought to have at least 96 percent of our DNA in common with apes and we have a surprising amount of DNA overlap with mice, fruit flies, and even such seemingly remote organisms as coral.

Furthermore, we are much more than a stable structured set of cells derived from neatly circumscribed development driven by inherited DNA. Estimates are that as many as 90 percent of the cells of any one of us are not human but instead microbial. These microbes have developed symbiotic relationships with humans—either in the past or at present. Biologist Lynn Margulis (1981) has explained since the 1970s that our cells are actually each small colonies of former even smaller organisms that became adapted to living and working together (in work that was initially ridiculed and eventually accepted as true and exciting). Each of us is really a colony of cells, which is fortunate because those microbes help us digest and resist disease and help in many other ways. Some of those "others" cause disease, but these are the minority of those cells that make up each of us. Even those cells that are part of "us" in a clear sense of having been derived from the original fertilized egg cell that defines us are replaced or turned over quite often, again with widely varying estimates about how often but some cell types are replaced very frequently. Estimates are that the majority of cells in the body are less than a decade old, even for the elderly, though again, this is science in process and the estimates fluctuate. Finally, this developing evolving complex system of genomes exists in an environment that exerts constant pressures and therefore effects changes.

This aspect of the third approach to the human dimensions of biology focuses on understanding normal individual development in its larger context, but we also experience many diseases and microbial assaults to our individual systems. Established endemic diseases and emerging infectious diseases both affect us, as do the wear and tear of aging and chronic diseases that result. Whether we can develop adaptive defenses against both the effects of cellular aging and against these would-be attackers is a central question affecting our survival as individuals and as populations. Therefore, understanding when and how we can develop effective defenses is one of central human dimensions of biological science. Consequently, the biology we need for understanding humans includes the interactions of ecology, evolution, and development that all contribute to making us who we are.

Probably the most dramatic change in our understanding of ourselves as natural biological beings has come with evolution. The important breakthrough by Charles Darwin and evolutionary biologists since has been to see all of human behavior as the result of material adaptive systems. For Darwin, this includes all behavior, ranging from sexual reproduction to expressions of emotions, language, and even religious beliefs: all result from adaptations to existing conditions. This biological emphasis led to so-called social Darwinism (Hofstadter 1959), which has included assumptions that evolution will lead to improvement for individuals through struggle and success (the Andrew Carnegie approach), improvement of the species through competition and selection (eugenics), and improvement of the species through cooperation and mutual aid (Pyotr Alekseyevich Kropotkin), or to decline in populations and death of individuals through struggle and loss of what was seen as the spiritual or other side of humans that made humans different from all other "merely natural" species (many critics). Edward O. Wilson's (1975) ideas of sociobiology, through which behaviors were seen in terms of genetics and selection, evoked hostile attacks even from other biologists and especially from social scientists who saw Wilson as privileging genetics and losing the social aspects of human behavior (Kitcher 1987).

There are also misuses of biological ideas. We see this in some uses of evolutionary psychology, for example, where exaggerated claims about human nature have led to arguments that we might predict criminal behavior based on chromosomes or particular genes. More recently, we have seen claims about behavior made on the basis of brain imaging, where proponents claim to be able to "see" defective brain activity that is taken as explaining the resulting behavior. There is room for appropriate use of biological knowledge about human behavior, and some of the efforts in economics to develop more realistic accounts of the collective actions of human agents have begun to show what we can gain by doing so.

Informed development of social and political models for action based on understanding of human individual and social behaviors does have the potential to shape social and political decision making. It is therefore all the more important to make sure that the biological science on which leaders are drawing is well established and accepted by the scientific community rather than representing the eager hopes of a few enthusiasts.

Putting Humans Into Nature

Humans exist on a planet full of microbes, fungi, plants, and animals. It might therefore seem obvious that humans exist in nature and we should not have to put them there. Traditionally, however, society in general and natural scientists in particular have thought (and continue to think) of nature as something "out there" and as humans acting like exogenous vectors on nature. This thinking pervades discussions of climate change, where the language is typically dominated by ideas of climate as going along on its own, and then of humans as recently having started to disturb the natural. Or, alternatively, ecosystems experience degradation and human engineering makes the system healthier. Both are seen as impacts of the external humans acting "on" nature.

This vision of humans as outside nature is just wrong. We have always been part of the natural world. By the Middle Ages, as Jean Gimpel (1976) explained compellingly, human "civilization" had led to serious pollution of water and air in many places in Europe. Humans were already very much shaping the natural world of which they were a part. This is the challenge that historians and ecologists have tried for decades to get society to accept: to see ourselves as part of the natural world and to understand just how inextricably our actions make that world what it is. Just as the actions of every other living being and every physical system make up nature, so do our decisions and actions. Again, this may seem obvious. But fully understanding what this means and embracing the consequences takes real courage and leadership.

Leadership is required because, as humanists note, humans are social beings with a strong moral sense that affects the social worlds in which we live. This has led to various versions of environmental ethics, each with its strengths and limitations. One approach with great promise is that of philosopher Ben Minteer in collaboration with evolutionary ecologist James P. Collins (2008). They call for an "ecological ethics" that starts with a scientific understanding of ecological systems that include humans as central components and building an ethical framework that goes beyond the traditional approach of environmental ethics. Traditional applied ethicists focus on such considerations as the intrinsic or utilitarian value of nature, whereas ecological ethicists work with systems that include science, values, and practical needs such as conservation and other applied interests. This approach involves a new understanding of ways to put humans into nature and to value them as part of nature.

Ecologists have taken a lead in embracing this understanding. For decades, the Ecological Society of America (ESA), for example, had insisted that it was an organization of scientists whose commitment had to be to doing the best science. This was taken to mean science as "pure and objective as possible," as former ESA president Jane Lubchenco once put it. But Lubchenco and other ecological leaders came to understand that if they were the ones with the scientific knowledge, they needed to be the ones to educate scientists about policy making and to help communication among all the relevant groups. The ESA started the Leopold Fellows Program, works with the American Association for the Advancement of Science Policy Fellows Program and the Sustainable Biosphere Initiative, and has become a leading group advocating development and use of the best possible science for social good.

But what is the best science related to understanding humans in nature? It is hard enough to understand ecosystems if we treat them as if they were neatly bounded phenomena with resources moving in and out in definable ways. Human behavior is messy, so adding understanding of humans as part of nature will take collaborations between social and life scientists. Scientists alone cannot, as Wilson (1998) seems to suggest, carry out their own "consilience" of all the sciences and thereby offer wise social and political leadership. It takes a collaborative process that draws from multiple disciplines. It also takes serious social scientific understanding of how humans value nature, including through economic analysis of what are called *ecosystem services* that consist of features of some ecosystems such as fresh water and fresh air but also the harder to define services such as singing birds and beautiful flowers (Perrings, Mooney, and Williamson 2010).

The National Science Foundation's new National Ecological Observatory Network (NEON) program, as well as the decades-old Long-Term Ecological Research (LTER) network of sites including two urban models, promises advanced research and data collection and management. At least this is true insofar as the programs collect social as well as traditional ecological data.

Although this emphasis on ecological systems including humans is the typical way scholars think of "putting humans into nature," another centers on literally putting pieces of humans and in particular human cells into nature. For example, human cells are cultured or created in the laboratory and then "put into nature" in the sense that researchers are creating new life forms that were not there before and that in some cases, are being found mixed with other human cells where they are not intentionally introduced. Genetically modified human cells and tissues, laboratory chimeric combinations of human and animal cells, cell lines including HeLa cells taken from Henrietta Lacks (Skloot 2010), and cultured stem cell lines: all produce new life forms based on human cells and carry the potential to alter other organic materials. So-called synthetic biology introduces yet another approach, taking inorganic matter chemicals and a framework and producing new functional cells.

This biological engineering, or what Jacques Loeb a century ago enthusiastically described as controlling life (Pauly 1987), introduces possible biomedical opportunities, and new questions. The point is not that this is necessarily a problem, but rather that it has been a surprise to researchers, and the phenomenon raises questions about these particular human dimensions of biological research. It will take new research, drawing on the biological and social sciences and the humanities, to understand the challenges raised by putting humans into nature in all these senses. And it will take wise and informed leadership to guide our reactions.

Conclusion

Communication and understanding are important for wise leaders. Too often policy makers feel pressures to react quickly to a particular moment or event rather than with reflection and perspective. What is clear is that there are many human dimensions of biology, and that biological sciences do not give us a neatly insulated body of knowledge separate from society. It will take work to build understanding of the interactions of science and its human dimensions, and wisdom to shape decisions taking us forward.

The human dimensions of biology do not make up a single tidy discipline or any one circumscribed community but, rather, call for a way of thinking about larger questions related to humans in nature and humans doing science in the world. This work requires the working together of biological and social scientists, along with other scientists, engineers, and public thinkers. It needs informed and interested leaders willing and able to work alongside those scientists to make sure that the mission-oriented research we need done to address real world problems is getting done. We need different ways of organizing knowledge and approaches to knowledge, embracing interdisciplinarity, collaborating across different boundaries, and increasingly sharing credit and responsibility for the results of the research.

To reiterate, human dimensions of biology play out in four main ways. First through the fact that science is carried out by humans who themselves exist in a constrained environment. Science education that draws on the history and nature of science to help reveal underlying assumptions and bring together multiple perspectives should help produce a community of scientist-citizens able to explain their research to others. In theory at least, citizens and policy leaders informed about the workings of science should act rationally and should be able to interpret and use the best available research results, calling for mission-oriented research when it is needed to address real-world problems and questions.

Second is the way that science exists in society, where there are real-world social problems demanding solutions and real-world constraints and opportunities growing out of funding decisions. It is important to look at who does the science, where they do it, which science gets done, and who uses the discoveries. All of these are part of understanding the human dimensions of biology. Many of these decisions are political and all are social, so essays in this volume on research groups, scientific career choices, peer review, and many others will inform understanding of this important set of human dimensions.

Third is understanding of humans as "natural." Understanding human life-nature helps give us a way to see human actions as influenced by adaptations to our evolutionary past as well as material responses to our current existence. Policy makers and biomedical decision makers should be careful not to be misled by those overly enthusiastic about their particular interpretations of the biological evidence and what it means. Just because a certain machine detects a certain pattern of brain waves does not mean that courts should jump to bring those machines as evidence for biologically based deviant behaviors. Building scientific consensus requires careful research, testing, and retesting of alternative hypothetical interpretations about causes. Correlations do not themselves make causes, and bringing together knowledge of the way science works and what we can understand about human nature calls for care.

The fourth area involves putting humans into nature: into ecology in the sense of the scientific understanding of ecosystems that include humans as component parts, and also in the sense of literally creating and putting human cells into nature where they did not exist before. Both provide opportunities and challenges to our understanding of the science—and even greater challenges to our understanding of the social and human implications.

All of science has human dimensions, though not all precisely the same as the life sciences. Exploring those dimensions, recognizing the ways that they demand increased understanding of life in terms of complex adaptive and interactive systems, and becoming more explicit about these complexities will lead to better science. This, in turn, will help inform better decision making and better policy. Strong and clear leadership in the sciences and the use of scientific research to solve problems has made and will continue to make a tremendous difference.

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