The Critical Collaboration between Art and Science: *An Experiment on a Bird in the Air Pump* and the Ramifications of Genomics for Society

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ABSTRACT

Inspired by a famous 18th-century painting by Joseph Wright, the author discerns similarities between issues relevant then and the public's current reception of scientific ideas from modern biology in the wake of the Human Genome Project. She proposes educational and scientific initiatives and advocates more positive and balanced portrayals of scientific themes in the arts to help engage the public in a discourse about the ramifications of genomics science and technology for our lives.

We especially need imagination in science. It is not all mathematics, nor all logic, but is somewhat beauty and poetry.

—Maria Mitchell

Science is emphatically an important part of culture today, as scientific knowledge and its applications continue to transform the world, and condition every aspect of the relations between men and nations.

—Vannevar Bush

The Need for a Modern Lunar Society

In the 50 years since the description of DNA's double helix structure, we have witnessed a revolution made possible by the marriage of science and technology. Variously referred to as the DNA, Genomics or Modern Biology Revolution, its discoveries and advances over the past 50 years have changed virtually every aspect of our lives, from health to law to society. As we embark on the 21st century, the challenges that have emerged from this technology cover political, medical, ethical and legal territories.

I pondered this state of affairs recently while immersed in a dusty, oversized library book about the life and work of the 18th-century British artist Joseph Wright of Derby (1734–1797). Wright was part of an elite scholarly clique called the Lunar Society (so named for their monthly Monday meetings near times of the full moon), passionately devoted to learning and discussing the latest developments in science, engineering and industry. The group, which included industrial ceramics pioneer Josiah Wedgwood and Erasmus Darwin, a scientist, poet and grandfather of the evolution pioneer Charles Darwin, sought to dispel notions remaining from the Dark Ages, such as religious superstition and political and social intolerance, by promulgating a liberal worldview based on rational thought and advocating an open, intelligent society. Wright's meticulously executed works include many paintings and sketches that convey the depths of human emotions and the beauty of landscapes. Notable also are his complex interdisciplinary works that demonstrate the impact of the new scientific movement on society.

Wright's dramatic 1768 painting *An Experiment on a Bird in the Air Pump* (Fig. 1) strikingly anticipates our current predicament involving applications of the biological sciences as perceived by the general public. In the painting, a longhaired scientist demonstrates to an audience of men, women and children that air is vital to life; inside an instrument devoid of air a delicate cockatoo hovers between life and death; the bird's fate will be determined by the demonstrator, who can open the air passage. The curious observers offer a window on society. They experience this scientific demonstration with various emotions: awe, fright and anxiety, but also admiration and hope. The recent quantum advances made possible by the revolution in modern biology can similarly help us to advance as a society, but the consequences of many applications are also associated with sacrifice, fear and the need for change.

We are challenged similarly today to define new rules and limits for the usage and application of our newly conceived science and technology. Because today's general public is arguably less knowledgeable about contemporary science and technology than were the educated sectors of 250 years ago, general confusion, denial or dread about scientific developments must be alleviated so that we do not err on the side of unnecessary caution. Scientists and artists can help spread a balanced, informed view of scientific and societal dilemmas to address current manifestations of the modern biology revolution. A modern incarnation of the 18th-century Lunar Society is needed, in which our efforts should promote a positive global mission with a vision that transcends world factions, just as the Apollo space program (1961–1969), which dawned as the world grappled with the Cold War, culminated in the triumphant expedition to the moon.

The Modern Biology Revolution: No Longer Science Fiction

There is a pleasing symmetry in the key biological developments of the 20th century, which began in 1900 with the discovery (in fact a re-discovery) of Gregor Mendel's pioneering

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Fig. 1. Joseph Wright of Derby, *An Experiment on a Bird in the Air Pump*, 1768. (© National Gallery, London.)

laws of genetics [1] and ended with publication of the first draft of the human genome. An opportunity for reflecting on the current state of affairs came in April 2003 with the 50th anniversary of Watson and Crick's report of DNA's structure [2] (see Fig. 2 for a computer rendering of the basic model). This birthday was celebrated worldwide through meetings; dedicated journal issues (from *Science* to *Nature* to *Seed*); library, art and photography exhibits; theater performances; and much more. "Like a genetically manipulated virus," wrote S. Mawer, "DNA has now escaped the laboratory and infected the whole world. We are in the midst of a pandemic" [3].

Indeed, the DNA code describes in 3 billion letters important instructions for human life through its specification of gene products (such as proteins and RNA regulators) that ultimately determine human traits. United States President Bill Clinton described DNA in a 2000 speech as "the language in which God created life." Of course, we now also appreciate the wealth of other processes aside from our genotype that influence our phenotype, such as environmental factors and RNA editing, examples of "epigenetic" factors (those not encoded in our DNA) that determine gene products, such as proteins and RNA, and human behavior [4].

This biological goldmine, coupled with computer technology now in use, suggests new opportunities for society in many areas. Thus, among the "ten hottest jobs" predicted by *Time* magazine on 22 May 2000, five involved such products of computers and biology: *tissue engineers* (designers of organs on petri dishes), *gene programmers* (creators of customized genes), *pharmers* (developers of genetically engineered crops that produce therapeutic proteins such as vaccine-laden potatoes), *Frankenfood monitors* (watchdogs of dangerous engineered creations) and *data miners* (developers of tools for extracting knowledge from biological information).

This range of jobs indicates the breadth of the public's response to modern biology research. It also suggests why DNA and scientific subjects have become attractive for artists. DNA has stimulated designers such as Eric Harshbarger to build Lego models of it (Fig. 3) and artists to portray it as the *Mona Lisa* of Science [5]. Artists whose work revolves around genetics include, for example, Brandon Ballengee [6], Bryan Crockett [7] and George Gessert [8].

DNA is a regular presence in Hollywood film—the movies *Spider-Man* and *Gattaca* have mentioned and featured it. In related contexts, DNA figures prominently in science-fiction literature, such as in the works of Robin Cook (*Outbreak, Chromosome 6, Vector*), Michael Crichton (*Jurassic Park, Timeline*) and John Darnton (*The Experiment*).

In the theater, "DNA is God!" is the declaration of one of the exonerated death-row inmates in a recent New York off-Broadway play, *The Exonerated* [9]. DNA also appears as a harbinger of ethical or social dilemmas, as in Jonathan Tolins's play *The Twilight of the Golds.* Even in the hit Broadway musical *Avenue Q,* a puppet refers to another's sexual orientation by saying, "It's in his DNA" [10].

Moving beyond these expected venues, DNA has been used to coin business or product names because its association with the "core" of a person is exploited to imply a core brand (an original source). Examples include a San Francisco disco (DNA Lounge) [11], a skateboard brand developed by Syndrome Distributors in California [12], the name of a web design company in the United Kingdom (DNA) [13], a specialty nursery in Alberta, Canada (DNA Gardens) [14], a Greek magazine (*DNa*) [15], a vitamin supplier in England (DNA Vitamins) [16] and a gay men's magazine in Australia (*DNA*) [17].

Indeed DNA's information is central to numerous everyday procedures. The practical applications of DNA and modern biology techniques in medicine, archaeology, crime and forensics are well known. For example, DNA analysis is used in medical diagnoses to identify gene origins for cancer, schizophrenia and Parkinson's disease. For historical analysis, archaeologists and scientists can team up to identify gene signals in human populations to discern human origins, evolutionary changes in whales, or even the lineage of modern wines [18].

Examples of DNA profiling in crime conviction and forensics are abundant today in the press; the requisite analysis has provided important work for mathematicians and statisticians who must translate the results of DNA sequence comparison to probabilistic terms. Since the first prisoner in the United States was exonerated in 1993 because of DNA evidence, dozens of death-row inmates have also been exonerated. DNA profiling has also implicated individuals in murders or trysts based on DNA extracted from clothing (e.g. O.J. Simpson's black glove and Monica Lewinsky's dress).

Studies of DNA have been important in identification of remains following tragedies like the September 11 attacks on the World Trade Center and the Pentagon. The same science is useful in paternity suits.

How far, however, can and should this technology be carried? Scott Adams's comic strip *Dilbert,* 9 July 2000 [19], shows the pointy-haired bête noire boss being briefed on a new software that can "create human simulations from DNA samples." This cartoon underscores the urgent need for the general public to receive more education in science so as to be able to separate science from fiction. Indeed, the announcement in spring 2003 by Clonaid, part of the peculiar Raëlian movement [20], that humans had been cloned caused confusion and controversy, soon to be replaced—for some—by disappointment.

Interestingly, biologist Lewis Thomas suggested over two decades ago that we should strive in the direction opposite to cloning:

> Set cloning aside, and don't try it. Instead, go in the other direction. Look for ways to get mutations more quickly, new variety, different songs. Fiddle around, if you must fiddle, but never with ways to keep things the same, no matter who, not even yourself. Heaven, somewhere ahead, has got to be a change [21].

Societal Ramifications of the Modern Biology Revolution

Clearly, many societal, ethical, economic, legal and political issues must also be addressed as this colossal research, made possible by the Human Genome Project, goes forward (Fig. 4). For example, what, if any, restrictions should there be on stem-cell research, which can potentially lead to many medical advances but utilizes precious tissue from discarded embryos? What rules should be imposed on cloning of animals, including humans, and the cross-breeding of species? Should genomics-based knowledge of human health be released to the individual, to employers, to insurers or to family members who may be directly affected? How available should our DNA imprint be to law enforcement agencies? What aspects of scientific discoveries should be privatized or patented? What restrictions should be placed on applying this scientific technology? Undoubtedly, as our scientific and technological sophistication increases, the possibilities of the practical applications increase steeply. Will our future progeny reflect a society of designer babies? Will our endless search for beauty, health, intelligence and perpetuity produce "a nursing home for sluggish Methuselahs" [22], with new possible problems and dangers?

From Copernicus's astronomy to the Human Genome Project, scientific advances are inevitable, as it is human nature to push possibilities to their limit. Accordingly, fear and anxiety are better replaced by prudent preparedness. First and foremost, this readiness requires more people to be knowledgeable about the sciences.

Multidisciplinary Science Education and Training

Two broad educational areas require substantial revision and expansion to deal with the new scientific challenges of the 21st century: within the scientific community on one hand, and between scientists and the general public on the other.

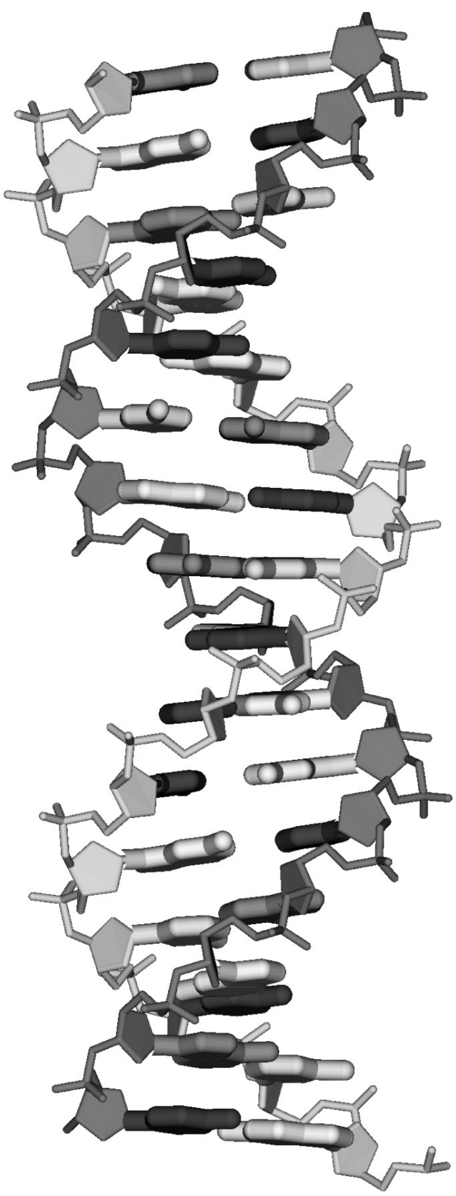


Fig. 2. A molecular model of the classic DNA double helix. (© Tamar Schlick)

Fig. 3. Eric Harshbarger's 2003 LEGO creation of a DNA helix. (© Eric Harshbarger, <www.ericharshbarger.org>.)

Training the Scientists

First, innovative multidisciplinary educational and research paradigms are required in the biological sciences. Phil Bourne, former president of the International Society for Computational Biology (ISCB), has written that computational biology, which combines biology at different scales with computer science, has recently come to earn the status of a scientific discipline. The high demand for qualified computational biologists has given rise to ISCB, which is dedicated to the advancement of scientific understanding of living systems through computations.

Unfortunately, the field's growing recognition has not translated automatically into training innovations. Although programs in computational biology and bioinformatics (certificates and graduate degrees) have been appearing, they vary widely because of the field's unique challenges.

While the interest in computational biology is growing rapidly, the transition to productive research in the field is difficult for non-biologists. There is a growing need for professionals who can translate scientific problems in biology into mathematics and computations; for such productive work, familiarity with modern scientific computing approaches, as well as key biological challenges, is essential. It is not only a matter of in-depth knowledge of biological subjects (which is itself a challenge), but also one of the ability to acquire a very different scientific perspective and approach, which may deviate from the accuracy and order that mathematicians and physicists are trained to seek. At the same time, biological scientists may lack sufficient training in mathematics, computer science and physics to perform many analyses, modeling, simulation and database systematics of biological systems. Yet a multidisciplinary approach is critically needed to merge descriptions of the functional and cellular picture (from biology) with atomic and molecular details (in chemistry), the electronic level with underlying forces (in physics), appropriate numerical models and algorithms (in mathematics), and practical implementation on high-speed and extended-communication platforms (computer science and engineering). This synergy is critical because the best computational approach is often closely tailored to the biological problem. In the same spirit, close connections between theory and experiment are essential: Computational models evolve as experimental data become available, and biological theories and new experiments are performed as a result of computational insights.

A recent report spearheaded by the Human Frontier Science Program (HFSP), with panelists from Europe, North America and Japan, presents a bold new paradigm for education and training in the natural sciences [23]. It argues that the traditional model of "pipelining"—unidirectional disciplinary tracks that produce research professors in narrow specialties—is inadequate to deal with the complex scientific, social, and economic problems of our times. It also states educational and social challenges that we must address. Among them are these needs: to develop a new scientific culture that cultivates and rewards interdisciplinary expertise; to train and reward teachers and other educational leaders; to train our science students for a wider range of career outcomes (academe, government, industry, health care, education, business, journalism, politics and law); to encourage the participation of women and ethnic minorities in the sciences; to provide ethical and career guidance, including writing and management skills; and to integrate science with society.

To achieve this transformation in scientific training, new educational programs for masters and doctoral degrees are essential to train researchers to be competent in computational methods as well as knowledgeable in biological systems. Such innovative degree programs have already been the focus of the Burroughs Wellcome Interface Program, the Sloan/Department of Energy initiative in computational biology and the (U.S.) National Science Foundation's Integrative Graduate Education and Research Traineeship Program (IGERT) institutional awards. Programs like these can prepare our future generations for successful careers in bioinformatics, biotechnology and allied fields. A blend of academic, industrial and government experience, as well as computational and experimental work, is also important to familiarize students with the multifaceted nature of biological research.

Besides this training of scholars in the requisite life-science, computational and interdisciplinary skills, the training of health professionals in hospitals and medical schools should include training in genomics, bioinformatics and allied fields. These modern fields have radically evolved since current professionals were in school, and this gap in knowledge should be addressed by devoting concerted workshop training efforts to practicing doctors on a regular basis. These programs would enable physicians and other health providers to better understand modern scientific tools, such as bioinformatics, for utilizing genomic and other available scientific data in medical diagnosis and treatment.

Training the General Public

On the second front, to prepare future generations to deal with the ramifications of science and technology, children should be introduced at an early age to the increasingly important disciplines of science, mathematics and computing. Although the level and quality of education in science, mathematics and computing varies widely across the world, many Western countries such as the United States still suffer from the lack of strong programs at the elementary and high-school levels in these disciplines, although this requirement is widely recognized. Perhaps one problem is that we emphasize rote scientific learning instead of team problem-solving—a central feature of today's interdisciplinary scientific efforts. Graduate schools are just beginning to put more emphasis on this additional level of learning, and these methods can be adapted for younger students. In higher institutions, subjects such as mathematics are so feared that professors find they need to inflate grades to retain students. As science's image improves, it should be possible to boost classroom training both by increasing the level of minimum required mathematical and computer skills and by introducing specialized workshops to familiarize young students with current scientific research in computational biology. Greater commitment of resources and effort to education, as well as enhancement of the reward system for teachers, will be required to make these tall orders a reality.

In addition to such formal programs, efforts to bring science to the public's everyday life are also crucial. The Public Broadcasting Service (PBS) has recently introduced a regular science feature during the nightly "NewsHour with Jim Lehrer," and the Discovery Channel deserves credit for bringing science to all. Terry Sejnowski recently suggested that a cable science network (CSN) could also serve that purpose [24]. By providing science education—lectures by scientists, or presentations and discussion from international meetings and public conferences—we can hope to bring to everyone's living rooms pertinent information on topics ranging from global warming to biological warfare to epidemics/crises such as SARS, anthrax attacks and environmental hazards. More town hall–like meetings to discuss scientific issues in public forums, such as presidential debates, or sessions in scientific meetings that are open to the public, could also help spread good solid science and a better image for science to every city in the world.

An elevated level of scientific information in our governmental and legal sectors would make the crucial difference in closely advising the people and groups responsible for making far-reaching decisions regarding the application of scientific and technological advances. For example, the International Science and Technology Reference Forum, with the support of the United Nations, is establishing a permanent team of legal experts and scientists to mediate between science and the legal sector [25]. Another network centered at the University of Pavia, Italy, entitled European Network for Life Sciences, Health, and the Courts, has similar goals [26]. Such opportunities for marrying expertise—in this case, that of life scientists and law professionals—could be realized between other groups, for example between agriculturalists and biologists; between environmentalists or oil producers and scientists knowledgeable about pollution, ecology and the chemical industry; between military personnel and research scientists who specialize in chemical and biological warfare; or between health professionals and basic-science researchers in biomedicine. Funding for these programs could come from all levels of government and national/international public and private funds, starting from a small scale.

Art and Science Collaboration—A Necessity

Another way to help guide the application of our scientific developments and the public's understanding of science and technology is to draw the sciences and the arts closer to one another, and to do so positively. C.P. Snow argued for such connections and collaborations 45 years ago [27]. The ancient Greeks did not make clear distinctions between literature and science, and the schism that Snow refers to is a modern phenomenon. Part of the gap in knowledge is simply inevitable: the body of scientific knowledge grows so rapidly that most scientists have become so specialized that they cannot comprehend most other scientists' works.

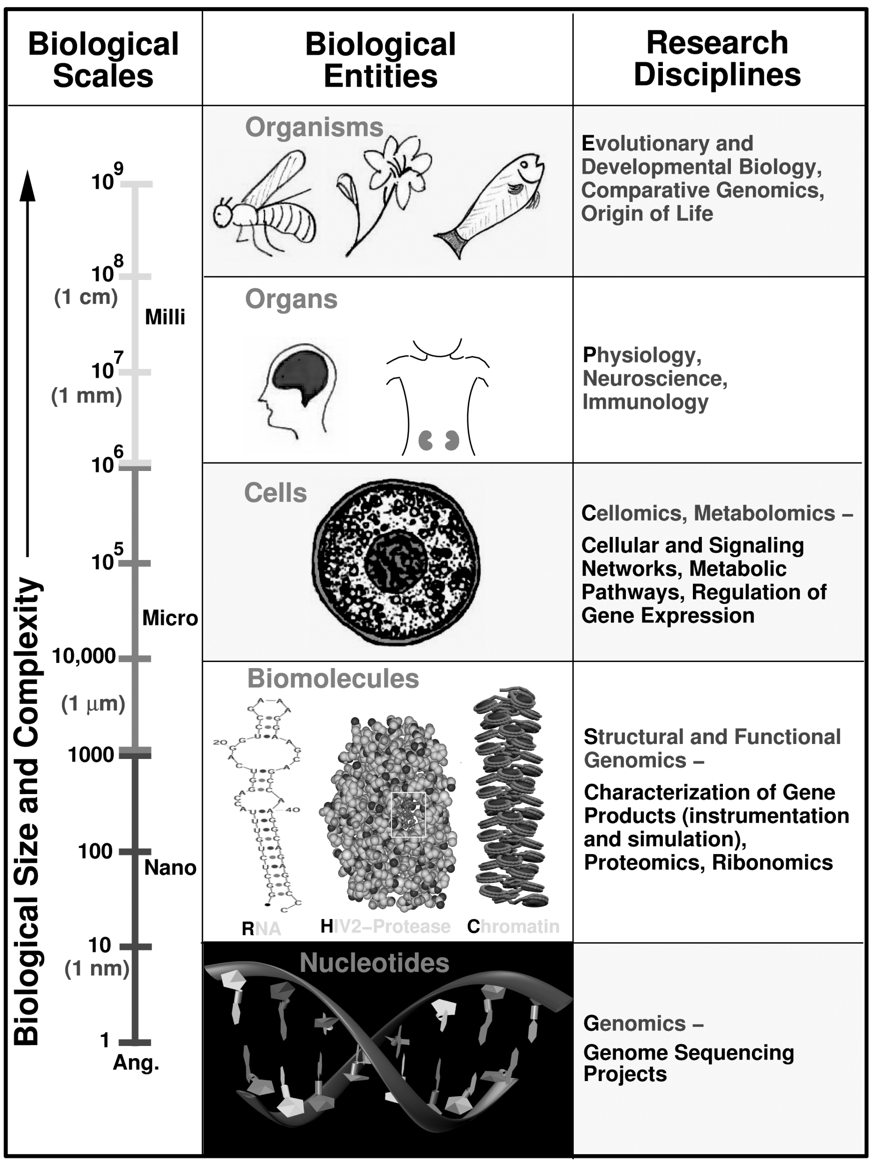
Scientists seek the truth, just as artists do, in sometimes unusual ways. To inspire my students of mathematical biology to develop computational models that incorporate details where necessary but approximations where appropriate, I recall for them Pablo Picasso's saying: "Art is the lie that helps us tell the truth." Similarly, artists such as Leonardo da Vinci, Albrecht Dürer, Victor Vasarely and M.C. Escher have borrowed from or been inspired by scientific ideas.

A synergy between the sciences and the arts can be achieved by featuring science in artistic narratives in supportive ways—as in films such as *Good Will Hunting* and *A Beautiful Mind*, or in stage productions such as Michael Frayn's *Copenhagen* (on Bohr and Heisenberg), David Auburn's *Proof* (on the authenticity of a mathematical proof by a young woman), Peter Parnell's *QED* (on physicist Richard Feynman's life and work), Jacquelyn Reingold's *String Fever* (on string theory), Tom Stoppard's *Arcadia* (on a young mathematical genius), Gabriel Emanuel's *Einstein: A Play in Two Acts* (on the eccentric and brilliant physicist), or John D. Barrow's *Infinities* (about the great paradox of mathematical infinity, presented with aspects of philosophy, science and theater). A list of approximately 100 plays written on scientific topics was assembled by Brian Schwartz and Marvin Carlson of the Graduate Center of the City University of New York [28].

Notable from the 19th century is the British clergyman Edwin A. Abbott's book *Flatland* (1884), a whimsical tour of basic geometry. In the 1990s, physicist George Gamow introduced readers to an amateur science enthusiast, C.G.H. Tompkins, whose initials were chosen after fundamental physical constants (the speed of light, the gravitational constant and Planck's constant). Since the 1960s, prominent scientists such as Carl Djerassi, Stephen Jay Gould, Roald Hoffman, Alan P. Lightman, Dan Lloyd, Christos H. Papadimitriou, Carl Sagan, Lewis Thomas, James D. Watson and Steven Weinberg have helped public audiences appreciate, and become more excited about, science.

However, not all portrayals of science by artists are positive, and some skeptical or antagonistic views may spread unfounded fears about scientific technological practices. The works of art featured in the exhibition Paradise Now: Picturing the Genetic Revolution, curated by Carole Kismaric and Marvin Heiferman [29], include some positive renderings of products associated with genetic research, but pieces such as *The Farm* by Alexis Rockman depict potential horrors of bioengineering by portraying in an imaginary soybean field plants and animals altered to suit commercial interests, such as flat tomatoes and featherless chickens. Other works by Bryan Crockett, Mark Dion, Laura Stein and Eva Sutton also depict the horrors of transgenic cross-breeds and genetically modified organisms.

Fig. 4. The outgrowth of numerous scientific disciplines stemming from The Human Genome and other sequencing projects. (© Tamar Schlick) In the progression from DNA constituents (the nucleotides) to cells to organisms, many scientific disciplines are traversed, and so are the possible applications.



The Human Genome Project is apparently stimulating more and more artists to address issues of social responsibility and the profound implications of our newly found discoveries in biology for many aspects of our lives. At the time of this writing, a traveling museum exhibit entitled Gene(sis): Contemporary Art Explores Human Genomics, curated by Robin Held, is on view at Northwestern University [30]. The exhibit's 60 works by 24 artists contain disturbing representations of transgenic species, such as Eduardo Kac's fluorescent albino rabbit (created by splicing a jellyfish's bioluminescence gene into a rabbit), which challenges us to ponder the limits of our technology, the influence of science on art and the ethics of biotechnology. Still, such exhibits encourage the general public to become more engaged in the applications of the biological sciences and to appreciate the complex scientific and societal implications of genomic research. Caryl Churchill's provocative play *A Number* prods us to consider the nature-versus-nurture debate and the advantages versus the dangers of genetic engineering through a thriller about three sons, the original and two clones, of a man who suffered loss as a young father; the ending is a stunner that shatters our expectations and our view of the playwright's stance.

Indeed, we must encourage artistic expressions that depict science and scientists positively. In addition to the theater and film examples above, Lynda Williams aims to popularize physics in her stage persona, the Physics Chanteuse, through songs with pro-science lyrics (for example, an adaptation of Madonna's "Material Girl" titled "Hi-Tech Girl" [31]). Organizations such as ASCI (of New York) and Ylem (in the San Francisco Bay Area) have long brought scientists and artists together, and organizations such as the Sloan Foundation and the Wellcome Trust have funded initiatives to encourage artists to tackle scientific topics.

A successful Science and the Arts series was recently developed by the Graduate Center of the City University of New York [32]. The program presents dance, theater, music and art with science as the theme and spreads their products to other locations such as Brookhaven National Laboratory and the New York Academy of Sciences, and to an audience of non-scientists of all ages. Among the program's notable events was an exhibition titled Genomic Issue(s): Art & Science. Other events include a rock opera in tribute to the planned termination of the Jupiter-circling spacecraft *Galileo*;

plays about Feynman and the Curies; and a discussion with author Israel Horovitz on his new play on bioethics revolving around one biologist's struggle between altruism and financial rewards. Also, on the first Sunday evening of the month, at the Cornelia Street Café in New York's West Village, chemist and Nobel laureate Roald Hoffman hosts an innovative science-and-art evening program [33].

These positive presentations of science and exposure to scientific dilemmas achieve the crucial goal of making the audience curious about and engaged with science and technology. This engagement is a prerequisite to our mutual development of modern and prudent compromises to address problems at the frontiers of the revolution in modern biology.

Conclusion

A scientifically literate and appreciative society could make the crucial difference between the abuse of science and scientific breakthroughs for the betterment of society. A revamped scientific training and educational infrastructure that emphasizes interdisciplinary approaches to complex problem solving rather than rote learning is also essential to addressing the multidisciplinary and global challenges of our 21st century. Indeed, the recent multidisciplinary Euroscience Open Forum 2004 in Stockholm, Sweden, made clear that science has become truly global in nature. However, it also revealed that the U.S. climate for science following the attacks of September 11 has led to a major shift of priorities in the support of science favoring defense and homeland security at the expense of many other domains. These dilemmas underscore the complex relations between science and national politics and ideology, requiring highly informed, open-minded and forward-looking leadership to exploit scientific talent and technology.

With attention to urgent scientific fronts such as the quality of our environment, alternative energy sources, genomics-based health care systems and exploration of life beyond Earth, we could become the admirers and beneficiaries of our labors, like the scholars in Wright's painting and the Lunar Society. Prudence and devoted embrace of our science and technology will give us the wisdom needed to manage our wondrous possibilities. Whether we choose to live until the age of 600—if ever possible—or compromise between what science offers and the lives we want to live—as Odysseus did in choosing to be with his wife Penelope for a short period rather than being immortal without her [34]—we can make well-informed and open-minded decisions if artists and scientists collaborate on scientific themes in a supportive manner.

> *The proper and immediate object of science is the acquirement, or communication, of truth.*
>
> —Samuel Taylor Coleridge

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