David Suzuki Foundation

BIOTECHNOLOGY:

A GENETICIST'S PERSONAL PERSPECTIVE

by David Suzuki

> "Dr. Faustus, Dr. Frankenstein, Dr. Moreau, Dr. Jekyll, Dr. Cyclops, Dr. Caligari, Dr. Strangelove. The scientist who does not face up to the warning in this persistent folklore of mad doctors is himself the worst enemy of science. In these images of our popular culture resides a legitimate public fear of the scientist's stripped down, depersonalized conception of knowledge – a fear that our scientists, well-intentioned and decent men and women all, will go on being titans who create monsters."
>
> **Theodore Roszak**

A Personal History

I would like to begin by providing some history and context that may inform you on where my perspective comes from. I was born in Vancouver, B.C., in 1936. Both of my parents were born in Vancouver about 25 years earlier. In 1942, my Canadian-born and raised family was stripped of all rights of citizenship, our property and assets were seized and sold at fire sale prices, our bank accounts were frozen and ultimately looted and we were incarcerated for three years in primitive camps located deep in the Rocky Mountains. Our crime was sharing genes with Canada's enemy, who were also our enemy because we were Canadians. As World War II was drawing to an end, we were confronted with two choices: renounce citizenship and receive a one way ticket to Japan or leave B.C. by moving east of the Rocky Mountains.

Pearl Harbor and our subsequent evacuation, incarceration and expulsion, shaped the lives and psyche of all Japanese-Canadians. For me, those events created my hang-ups (about my slitty eyes) and drive to prove my worth to fellow Canadians. And the results of the war left me with a lifelong knee-jerk aversion to any hint of bigotry or discrimination and a passion for civil rights.

Falling in Love with Genetics

All my life, nature was my touchstone, my life, my passion. As a boy, my love of fish and fishing led to a hope of becoming an ichthyologist. Later, when my mother sewed me a net for collecting insects, my dreams were transformed to a life of entomology. After moving to Ontario at war's end, I was fortunate in receiving a generous scholarship to Amherst College where I did an honours degree in biology and fell madly in love with the elegance and precision of genetics. I declined my acceptance to medical school in order to pursue a degree in genetics at the University of Chicago. After spending a year as a postdoctoral fellow at the Biology Division of Oak Ridge National Laboratory in Tennessee, I decided to leave the racism of the southern U.S. to return to Canada.

My first academic position was as an assistant professor in Genetics at the University of Alberta. As the most junior faculty member, I was assigned to teach genetics to second-year agriculture students. To my delight and surprise, it was the most wonderful class I ever taught. The students asked questions about plant and animal breeding, about cloning and the future of genetic engineering - questions I hadn't studied or thought much about. So I had to do a lot of reading. When I took a position in Zoology at the University of British Columbia a year later, my classes consisted largely of pre-medical students. Again they asked questions about hereditary disease and medical genetics that I was not prepared for and had to read up. And it was in the reading to answer student questions that I encountered the grotesque intersection between two great passions of my life: civil liberties and genetics!

Genetics' Dark History

I discovered that the genetics I had been taught had been expunged of much of the history of the young science. I found that early in the 20th century, biologists were justifiably enthralled with discoveries of principles of inheritance and their broad applicability from plants to insects to mammals. There was a sense that with these laws of heredity, scientists were acquiring the capacity to control evolution and shape the biology of organisms, including humans, at will.

Extrapolating from studies of petal colour in flowers, wing shape in fruit flies and fur patterns in guinea pigs, geneticists began to make pronouncements about the role of genes in human heredity and behaviour. A new discipline, eugenics, was created, the science of human heredity. Eugenics was supported by leading scientists of the time and taught as a discipline in universities. There were Eugenics journals and textbooks and

Eugenics societies. At last, it was believed, here was a solid basis on which human evolution could be directed. Positive eugenics was the increase of desirable genes in a population while negative eugenics was decreasing the incidence of undesirable genes. Not surprisingly, those traits deemed desirable were disproportionately exhibited by upper middle class Caucasians while those that were undesirable were expressed in Blacks, the poor and criminals.

Characteristics for which hereditary claims were made included: syphilis, tuberculosis, drunkenness, sloth, indolence, criminality and deceit. The prestige of eminent scientists backed eugenics. For example, Edward East, a Harvard Professor and President of the Genetics Society of America, states in his Eugenics text: “In reality, the Negro is inferior to the White. This is not hypothesis or supposition; it is a crude statement of actual fact.” The problem of course, is that “inferior” is not a scientifically meaningful category. Like “superior,” “better” and “worse,” it is a *value judgement*. In their enthusiasm and zeal for the exciting discoveries in genetics, scientists like East confused their own personal values and beliefs with scientifically demonstrated “fact.”

Racism Justified by Science

With such enthusiasm and grand claims being expressed by scientists, it is not surprising that politicians would notice and begin to use these ideas to justify their own prejudices. A.W. Neill, a British Columbia member of Parliament stated in 1937: “To cross an individual of the white race with an individual of a yellow race, is to produce in nine cases out of ten, a mongrel wastrel with the worst qualities of both races.” While not quite a Mendelian ratio, Neill actually put a number to his claims. In February, 1941, Neill told the Prime Minister: “We in British Columbia are firmly convinced that once a Jap, always a Jap.” In other words, it didn’t matter that there were second and third generation Canadians who had been born and grew up in Canada. If they were Japanese genetically, Neill and others in B.C. believed all the traits of treachery, untrustworthiness, etc were genetically encoded. This attitude was reflected by General John deWitt who was charged with the evacuation of Japanese-Americans during World War II and said in February, 1942:

> “...racial affinities are not severed by migration. The Japanese race is an enemy race and while many second and third generation Japanese born on United States soil, possessed of American citizenship, have become “Americanized”, the racial strains are undiluted ... It therefore follows that along the vital Pacific Coast over 112,000 potential enemies, of Japanese extraction, are at large today.”

Our evacuation was justified by the claims of the scientific community about the significance of their discoveries. To my horror, I discovered as well that genetics flourished in Germany before the war. It was scientists who helped shape some of the “progressive” legislation of the Nazi government including the “Race Purification Laws” that resulted in the Holocaust. The infamous Josef Mengele was a human geneticist who held two peer-reviewed grants to carry out his study of twins at Auschwitz. By the end of World War II, revulsion at the revelation of Nazi death camps shifted the predominant opinion of geneticists to the notion that human intelligence and behaviour were shaped primarily by the environment (nurture) rather than heredity (nature). The important point to remember is that this shift occurred with no significant new insight or breakthrough in science!

Biological Determinism Again

The belief in the over-riding influence of nurture held until 1969 when Arthur Jensen, an Educational Psychologist at Berkley, published “How Much Can We Boost IQ and Scholastic Achievement?” in Harvard Educational Review. This massive study pulled together many reports of differences in IQ test scores between black and white populations. To geneticists, the question of what an IQ test actually measures is not an issue. The distribution of scores in both populations forms the familiar bell shaped curve, but repeatedly, the two curves have a mean difference of about one standard deviation – the white means always being higher than the black means. Using extensive mathematical analyses, Jensen purported to show that the difference in means was determined primarily by heredity. His study was immediately cited by politicians like Mississippi Governor George Wallace and President Richard Nixon to justify reducing programs like Operation Headstart designed to help disadvantaged children.

Jensen was not a geneticist. Oxford’s Walter Bodmer and Stanford’s Luca Cavalli-Sforza are eminent population geneticists and wrote the most definitive treatise on the issue of race and IQ (W. Bodmer and L. Cavalli-Sforza 1970 Intelligence and Race. Scientific American 223:19 – 29). If we use a less emotive illustration than race and IQ, say the height to which bean plants grow, it can be demonstrated that there is a hereditary component in the familiar bell shaped curve of the distribution of plant height grown from a population of seeds. That is, seeds taken from short plants, will on average grow up on the short side, seeds from tall plants will be taller and seeds from the centre will fall in between. So there is a strong component of heritability determining plant height.

If we then take one handful of seeds and plant them in moist, fertile soil and another handful in sandy, dry soil, we will get different results. There will be a bell-shaped distribution from both plots, and in both populations we can show seeds of short ones will grow up short, seeds of tall ones taller and those in the middle will be in between. So in both populations, there is a strong factor of heritability in plant height. But it is absolutely incorrect to conclude that the difference in mean height between the populations reflects a component of heritability because the only difference between them is the environment in which they are grown.

Bodmer and Cavalli-Sforza conclude that only when society is completely colourblind - that is, being black or white makes no difference in the way children will be seen or treated - can one even begin to try to compare IQ scores with a view to determining the component of heritability. Despite that definitive conclusion, a number of scientists – none of them geneticists – began to suggest that human intelligence and behaviour have a large genetic component. Psychologist Hans Eysenck and Nobel Prizewinning biochemist Hans Krebs began to publish papers purporting to show that criminality has a high component of heritability. Harvard's Richard Herrnstein claimed that social class in a meritocracy like the U.S. is far more likely to reflect genes than work habits. In Canada, a President of the Canadian Medical Association suggested that before receiving a welfare check, people should be sterilized to keep their genes from being perpetuated in future generations.

Molecular Genetics - History Repeats Itself

> "Where did the doctor's great project go wrong? Not in his intentions which were beneficent, but in the dangerous haste and egotistic myopia with which he pursued his goal. It is both a beautiful and terrible aspect of our humanity, this capacity to be carried away by an idea. For all the best reasons, Victor Frankenstein wished to create a new and better human type. What he knew was the secret of the creature's physical assemblage; he knew how to manipulate the material parts of nature to achieve an astonishing result. What he did not know was the secret of personality in nature. Yet he raced ahead, eager to play God, without knowing God's most divine mystery."
>
> Theodore Roszak

Just as eugenicists early in the 20th century became intoxicated with the discoveries being made, molecular biologists have created a climate of belief in the basic role of genes in just about every human trait. Powerful tools to isolate and manipulate DNA confer truly revolutionary powers. Almost weekly, headlines proclaim the latest isolation of a gene for a trait, from risk taking to depression, shyness, alcoholism and homosexuality. Few note that in the months after the initial claims, follow ups generally fail to corroborate the original claim or show the hereditary involvement is far more complex.

One of the big mistakes made is a confusion between correlation and causation. Take, for example, the gene controlling the enzyme, alcohol dehydrogenase (adh). There exist two different states of this gene, adh^A and adh^B. Suppose a study demonstrates that 80 per cent of alcoholics have the adh^A gene while 80 per cent of non alcoholics have adh^B. That is a *correlation*. But it is completely incorrect to conclude that adh^A *causes* alcoholism, yet the press and even scientists themselves frequently fall into that trap. Think of it this way. Suppose you study all people who die from lung cancer in Vancouver over the past ten years and discover that 90 per cent of them had stained yellow fingers and teeth. That is a correlation. Who would ever conclude that stained yellow fingers and teeth cause lung cancer? Yet it happens over and over when molecular biologists isolate fragments of DNA that correlate with traits, some as diverse and complex in expression as homosexuality.

Rapid Growth of Revolutionary Science

Genetic engineering (GE) is a truly revolutionary area of science, made possible by the incredible speed and power of newly acquired techniques. I graduated as a fully licensed geneticist in June 1961. At my graduation, someone casually asked me how soon I thought we would know how words are spelled out in DNA. I puffed up with my new PhD in hand and pronounced “Well, maybe when I’m getting ready to retire.” In December of that year, the first word had been deciphered and within four, the entire dictionary was known. I prefer to tell that story to illustrate the remarkable speed of discovery, not my ignorance and poor prognosticatory ability. When my daughter was in her last undergraduate year of university, she isolated, sequenced and compared mitochondrial DNA of three geographically separated but related plant species for a senior research project! It was breathtaking to me because such experiments were inconceivable when I graduated 40 years earlier. So I understand why there is so much excitement. I too am excited and have followed GE vicariously for many years. But in a revolutionary area where excitement abounds, history informs us there is all the more reason to encourage vigorous debate and to be critical and cautious.

Debating Recombinant DNA

By the 1970s, it had become clear to me that molecular genetics was going to revolutionize the field and have profound social ramifications. The impetus to what has become known as biotechnology, was the ability to make combinations of DNA molecules from diverse species and to test those molecules in living cells. The technique was known as "recombinant DNA." As a columnist for the National Research Council of Canada publication, *Science Forum*, I wrote in 1977:

> "For young scientists who are under enormous pressure to publish to secure a faculty position, tenure or promotion, and for established scientists with 'Nobelitis', the siren's call of recombinant DNA is irresistable…in my own laboratory, there is now considerable pressure to clone Drosophila DNA sequences in *E. coli*…My students and postdocs take experiments and techniques for granted that were undreamed of five or 10 years ago. We feel that we're on the verge of really understanding the arrangement, structure and regulation of genes in chromosomes. In this climate of enthusiasm and excitement, scientists are finding the debate over regulation and longterm implications of recombinant DNA a frustrating roadblock to getting on with the research."

A year later, having encountered little support within the scientific community to engage in critical discussion about the social, moral and ethical implications of recombinant DNA, I tried to explain the reluctance in *Science Forum*:

> "I can appreciate the pressures that are brought to bear to stifle dissent within the scientific community. Peer approval brings with it invitations to give lectures, to speak at symposia and honorary positions in scientific organizations. The driving priorities of young scientists are to get and keep good sized grants and achieve recognition, tenure and promotion. Therefore, outspoken criticism is understandably rare in this group and they depend on people higher up in the scientific hierarchy to set their objectives…What am I saying? Not that scientists are evil, malicious or irresponsible - rather that our personal priorities, membership in a vested interest group, ambitions and goals prevent us from objectively weighing the social against personal consequences of our work."

A Personal Moratorium on GE

My own personal experience with the consequences of well-intentioned but scientifically unjustified claims and the insights I had gained while trying to answer my students' questions had made it clear to me that there was a very important need for scientists to engage in public discussions about the significance and implications of their work. Because I wanted to be able to participate credibly in this discussion, I declared in a 1977 column in *Science Forum*:

> "Can the important questions be addressed objectively when one has such high stakes in continuing the work? I doubt it. Therefore, I feel compelled to take the position that…no such experiments [on recombinant DNA] will be done in my lab; reports of such experiments will not acknowledge my grants; and I will not knowingly be listed as an author of a paper involving recombinant DNA."

I had achieved far more in science than I ever dreamed or hoped. It had been the joy of research that absorbed me for a quarter of a century. I loved the excitement and camaraderie of the lab. I was proud of our group, at one time the largest in Canada, and the work we did. But it was the muddy area of extrapolation of scientific insights to broader society that concerned me because there were numerous examples of individuals making claims far beyond their scientific legitimacy. I felt that some of us whose careers and reputations were not in jeopardy had to forego this work in order to take part, as scientists, in the discussions of the moral and ethical questions free from the bias of vested interest in the work. Scientists working for the nuclear, tobacco and petrochemical industries, either as employees or recipients of research grants, speak from a perspective of with a stake in continuing income and research support, and therefore it's natural that they would tend to deflect criticism rather than discuss it openly. There was no reason to suppose that scientists in biotechnology would be any different. Eventually I stopped taking government grants altogether because grants are awarded by peers, almost all of whom are promoters of research without regard to social or ethical concerns. I didn't want to be dependent on, and thus vulnerable to, the influence of outside agendas.

Damned if I Do, Damned if I Don't

As a popularizer of science through newspaper columns, television and radio, I am able to survey a far broader range of topics and questions than I ever did as a research scientist. Rather than losing my interest in the field of biotechnology and all of its implications, I have a broader perspective to reflect upon and have written extensively on the subject over the years. In 1986, I discussed moral and ethical issues of genetics in my autobiography, *Metamorphosis: Stages in a Life*. I wrote syndicated columns on genetics that became chapters in the bestselling books, *Inventing the Future and Time to Change*. In 1988, science writer Peter Knudtson and I coined the term "genethics" and co-wrote *Genethics: The Ethics of Engineering Life* that became a bestseller and continues to be widely used in university courses.

So it has been puzzling to me when individuals, some not even scientists, but spokespeople for the biotechnology industry, call my credibility into question. I deliberately gave up the day-to-day excitement of scientific research in order to remain a credible discussant on the moral and ethical implications of the new genetics. But I didn't forget all I'd learned and practiced as a scientist. At the very least, all of us who participate in the discussion ought to be forthright about the sources of our funding, position in companies and any other factors that might influence our perspectives and bias our statements.

Biotechnology is Here

Today products of biotechnology are being rammed into our food, onto our fields and into our medicines, without any public participation in discussions and with the complicity, indeed, the active support and funding of governments. But there are profound health, ecological and economic ramifications of this activity. At the heart of biotechnology is the ability to manipulate the very blueprint of life, removing and inserting segments into diverse species for specified ends. While plant and animal breeding over the past 10 millennia have built the agriculture we depend on, biotechnology takes us far beyond the crude techniques of breed and select. It behooves us therefore to examine the underpinnings of the claims, potential and limits of this young field.

Biotechnology to Feed the World

Perhaps the most frequently cited rationale to get on with genetic engineering as rapidly as possible goes like this: human population continues to increase by more than 80 million a year, most in the developing world. In order to avoid clearing more forests and draining wetlands to meet this need, proponents argue, the only option to protect nature and feed the masses is to increase yields per hectare through biotechnology. It’s an argument that carries a lot of weight despite the irony that the number of people suffering from severe malnutrition is about equal to the number of people afflicted with obesity in the rich nations. However, biotechnology is being driven by vast sums of speculative money. In order to justify those investments and to attract even more money, a product is needed. That’s why so many companies have already foundered - they’ve failed to live up to the hype. The very survival of biotech companies depends on the expectation of profits from the company’s products. Those products are made at enormous cost. But the people who are most desperately in need of food are also the poorest. James Wolfensohn, President of the World Bank, claims that 1.3 billion people exist on a dollar or less a day while three billion struggle on $2 or less daily. It would be a breathtaking reversal if free enterprise capitalists were suddenly overwhelmed with generosity and concern for those less well off and make GE products available at prices the needy can afford. Feeding the starving masses through biotech in the near future is a cruel hoax that cannot be taken seriously.

The Real Nature of Scientific Knowledge

I have no doubt there will be important products that come out of genetic engineering – but in the more distant future. It is the profit-driven rush to grow GE organisms in the open where they may contaminate other species and to introduce new products into the market that is most disturbing. My major concerns are based on simple principles. Every scientist should understand that in any young, revolutionary discipline, most of the current ideas in the area are tentative and will fail to stand up to scrutiny over time. In other words, the bulk of the latest notions are wrong. This is by no means a knock on science, it is simply an acknowledgement that science progresses by demonstrating that current ideas are wrong or off the mark. The rush to exploit new products will be based on inaccurate hypotheses and questionable benefits could be downright dangerous.

I graduated as a fully licensed (ie, with a PhD) in genetics in 1961. It was eight years after Watson and Crick's famous paper and we had learned a lot - we knew about DNA, the number of human chromosomes, the operon, etc. But today when I tell undergraduates about the hottest ideas of chromosome structure and gene regulation in 1961, they laugh in disbelief. In 2003, the best notions of 40 years earlier seem naïve and far from the mark. But those students are less amused when I suggest that 20 years from now when they are established scientists, the ideas they are excited by now will seem every bit as quaint as the ones I was excited by in my early days. In any new area, scientists make a series of observations then set up a hypothesis that makes sense of the observations. That hypothesis enables a researcher to design experiments to test its validity. When the experiment is performed and the data gathered, chances are the hypothesis will be discarded or radically altered and then further experiments are suggested. That's how science proceeds.

Not Quite Ready

When a biotechnologist can clip out or synthesize a specific sequence of DNA, insert it at a precisely specified position in a host genome and obtain the predicted expression of the inserted DNA with no other complications, then we can say that it is a "mature" discipline. Of course, when that happens, one can't publish papers on such a manipulation because it will be old hat. If you've checked biotech publications these days, you'll be amazed at their number and variety. Those reports are based on experiments where we *didn't know* what the results would be, after all that's why experiments are done and reported. Doesn't the abundance of biotech papers inform us that we still have a huge amount to learn? That suggests strongly that the discipline is far from mature enough to leave the lab or find a niche in the market.

The problem with biotechnology as it's presented today is that those pushing its benefits stand to gain enormously from it. While I believe their sincerity, they obviously start from a faith in the benefits and our ability to "manage" the GE organisms and products safely. But we've learned from experience with the tobacco, nuclear, petrochemical, automobile and pharmaceutical industries and military establishments that vested interest alone shapes a spokesperson's perspective and precludes an ability to examine criticisms or concerns in an open fashion.

Linear Science - An Illusion

Promoters of biotechnology foster a version of how science proceeds that is totally at odds with real science. They confuse the way scientists write grant requests with reality. The game scientists play in grant applications is to act as if the money will be used to do experiment A which will lead to experiment B and on to C and D and, then voila, a cure for cancer. Scientists perpetuate this illusion that science progresses this way as justification for receiving a grant. It's as if scientific discovery proceeds in a linear way - but nothing could be further from the truth. Experiment A is carried out because we don't know what the results will be, so we have no idea where the results and then subsequent experiments will lead us. That's why despite all of the hoopla over biotechnology, so few concrete products have come forth and there is considerable controversy surrounding those that have reached test plots or the marketplace.

The great strength of science is in *description*. We discover things wherever we look because despite the enormous growth of science in the 20th century, our knowledge of how the world around us works is still miniscule. Scientists like University of Victoria biologist Tom Reimchen use powerful analytic tools to reveal astonishing secrets in nature. Thus, it has long been known that salmon need the forest to keep river water cool and spawning gravels free of silt; because when forests along watersheds are clearcut, salmon populations plummet or disappear. But Reimchen has used the relative abundance of the isotope N^{15} in the ocean in contrast with its rarity on land, to trace N^{15} brought by salmon through the forest community. He has shown that salmon flesh is consumed by dozens of species including wolves, eagles, bears, flies, slugs and salamanders, and spread through the forest in their excrement. Examining cores of trees along salmon rivers, Reimchen can correlate the width of tree growth rings with both the size of runs and amount of N^{15}. This is descriptive science at its best, teasing secrets from nature and revealing that in the real world, everything is connected to everything else. And that is what the remarkable tools of biotechnology promise as well, an opportunity to dissect out nature's secrets at the cellular level.

DDT - A Case Study

The fatal weakness of science is in *prescription* of solutions. A classic example is DDT, a complex ring molecule first synthesized in the 19th century that Paul Mueller in the 1930s found kills insects. The power of chemistry to control a scourge that had plagued humankind since the beginning of time was trumpeted widely. At the time Mueller made his discovery, geneticists knew enough to have suggested that using an insecticide would simply select resistant mutants that would eventually replace the sensitives and thereby set farmers onto a treadmill of requiring an endless string of different pesticides. Ecologists of that time could have suggested that of all animals in the world, insects are the most numerous and diverse, and play critical ecological roles like pollination, predation, and feeding other species. Perhaps one or two insect species per thousand species are pests to human beings. Using a broad-spectrum insecticide to get at the one or two species that are a nuisance to humans seems analogous to killing everyone in a city to control crime – pretty crude and unacceptable.

But in the exuberance over the power of chemistry, geneticists and ecologists failed to raise concerns, millions of kilograms of DDT were manufactured and used and Paul Mueller won a Nobel prize in 1948. Years later, bird watchers began to notice that birds, expecially raptors like hawks and eagles, were declining. Biologists tracked it down and discovered that although the pesticide was sprayed at concentrations of parts per tens of millions, the molecule was absorbed by microorganisms. They in turn were eaten by larger organisms and at each trophic level up the food chain, DDT was concentrated many fold. At the top of the chain, in the fatty tissue of birds' shell glands or women's breasts, DDT was concentrated hundreds of thousands of times! This is known as biomagnification, a widespread biological phenomenon that was only discovered when eagles began to disappear. Our knowledge of how the world works is still very primitive because it is so huge, complex and interwoven.

It is of more than passing interest to note that in 1962 when Rachel Carson raised the alarm over pesticides in her seminal book, *Silent Spring*, it was Monsanto that led a scurrilous attack against her credibility. The company, now the world's leading promoter of GE crops, still aggressively attacks its critics, apparently having gained little concern for ethics from that experience. The history of DDT and later, CFCs, reveals that we are very clever at applying scientific insights for specific purposes, but the repercussions in the real world (ie, biomagnification and ozone depletion) could not be predicted beforehand and were only discovered after widespread use. There is absolutely no reason to think GE organisms and products will be free of such unexpected consequences.

A Clockwork Universe

Ever since Isaac Newton and Rene Descartes, scientists have assumed the cosmos is like an immense mechanical construct whose components can be examined piece by piece. If this is the case, then in principle, we can focus on parts of nature and eventually, upon acquiring knowledge of enough of the fragments, we could put them all together to recover a picture of the whole by the sum of the parts. Biologists have been particularly critical of any suggestion that the whole is greater than the sum of its parts, seeing it as an expression of Vitalism, a discredited notion that living organisms possess a kind of vital essence absent in non-life. Biologists don't seem concerned with the problem that life arose from the aggregation of non-living matter, but the state of aliveness cannot be anticipated from the properties of the non-living components.

Reductionism, the focusing on parts with the goal of understanding the whole of a mechanistic universe, has been a productive methodological approach. Thus, scientists focus on a subatomic particle, an atom, a gene, cell or tissue, separate it from everything else, control everything impinging on that fragment, measure everything within it and thereby acquire profound insights - into that fragment. But physicists learned early in the last century that parts interact synergistically so that new properties emerge from their combination that could not be anticipated from their individual properties. After defining all of the physical properties of atomic hydrogen and atomic oxygen, physicists would be at a total loss to anticipate the properties when two atoms of hydrogen are combined with one oxygen to make a molecule of water. Biologists and doctors have yet to internalize that understanding. Thus, it was long assumed that by studying a chimpanzee in a cage, for example, one could learn everything there was to know about the species. It was only when Jane Goodall went out into the field and studied chimps in their natural habitat that she discovered a completely different animal. Biophysicist, Brian Goodwin, has shown that the collective behaviour of ants within a colony cannot be explained by the sum of the behaviour of individuals of each caste.

Missing the Whole by Focussing on Parts

In focussing, we lose sight of the rhythms, patterns, cycles and context that make the object of study interesting in the first place. Biotechnology is the ultimate expression of reductionism, the faith that the behaviour of individual pieces of DNA can be anticipated by studying them individually. Richard Strohman is an eminent scientist and former Chair of the Department of Molecular and Cell Biology at Berkeley who stated the problem this way:

> “When you insert a single gene into a plant or an animal, the technology will work…you'll get the desired characteristic. But you will also…have produced changes in the cell or the organism as a whole that are unpredictable…Genes exist in networks, interactive networks which have a logic of their own…And the fact that the industry folks don't deal with these networks is what makes their science incomplete and dangerous…We are in a crisis position where we know the weakness of the genetic concept, but we don't know how to incorporate it into a new, more complete understanding.”

Biotechnologists assume all pieces of DNA can be removed and inserted as if they are equivalent. But as Strohman points out, genes don't exist as independent entities, they exist within complex sets of networks. From the moment of fertilization, whole suites of genes are turned on and off in an orchestrated sequence that leads to the development and differentiation of an individual. It is ultimately the total expression of that sequence and suite of genes, that produces the phenotype of the organism, and that is what natural selection acts upon. So the genome should not be seen as a bunch of individually functioning and selected genes, they act in concert. Biotechnologists assume that they can simply take a gene from a flounder, for example, and stick it into a tomato plant where it will function and produce a predictable result. But that strikes me as comparable to taking Bono out of U2, sticking him into the New York Philharmonic Orchestra and asking him to play his music while the other musicians play theirs. They will all be playing music, but how it will all sound together cannot be anticipated.

Unknowing Participants in an Experiment

The growth of GE plants over vast areas of the prairies is already a fait accompli. Pressured by companies like Monsanto, the Canadian government has acted as cheerleader for the biotech industry, approving new strains with little regard to the urgent questions that have been raised. Unlike chemical pollutants or radioisotopes which degrade or decay, GE plants and animals reproduce and mutate, so once released into nature, they cannot be recalled. The impressive feature of life on Earth has been its tenacity. Despite all the changes - the Sun is 30 per cent warmer now than it was four billion years ago, ice ages have come and gone, continents have collided and generated mountains and oceans, magnetic poles have reversed and re-reversed - life has persisted and flourished over 3.8 billion years. Once it has a hold, life is incredibly tenacious. Wind, insects, rains, rivers, many factors can act as a vehicle for GE organisms to spread their genes. Lavern Affleck, a Saskatchewan farmer testified before a New Zealand committee examining the benefits and hazards of GE crops:

> “Canada has gone blindly into broad scale experimentation with the Canadian land base. It is an experiment which cannot be retracted, and was entered into without sincere reflection as to possible ramifications. In our experience, crops (and weeds) are spread in so many ways (wind, the waterways, on the roadside, on farm machinery and trucks) that it is impossible to prevent accidental releases into unwanted areas. We now have some degree of GE crop contamination across our entire Canadian Prairie land base.”

Lacking an understanding of the complex relationship between scientific research and its application, governments sporadically commit money to specific areas in the hopes of stimulating economic benefits. In my opinion, they are doomed to failure for a number of reasons, however, that is not the point of this essay. Federal and provincial governments have already latched onto the life sciences, promoting biotech companies and their products. Unfortunately, molecular biology is an arcane discipline that few non-specialists can decipher. Biotechnology companies and scientists doing molecular research are aggressively proclaiming the benefits of their work. In their zeal, objections and concerns are brushed aside as trivial or baseless, just as the tobacco industry dismissed health concerns about smoking. But how can society deal with new discoveries and applications in ways that will minimize hazards to people and ecosystems?

In my view, universities are places where these issues should be openly discussed and debated. University scientists straddle the scientific disciplines, speaking the arcane language of science while communicating with students and the larger society in non-jargon vernacular. A university is a very special institution in society – a community of scholars and students exploring ideas at the very cutting edge of human thought. Many of these ideas are perceived as dangerous to society and thinkers are often viewed as threats to the established order. To ensure the freedom for scholars to pursue their work and protect them from outside interference, universities confer the privilege of tenure. Tenure brings with it the responsibility to share knowledge and speak out on issues where a scholar's field impinges on society.

Sadly, universities have compromised this position by entering into extensive partnerships with the private sector. In their search for funds, university administrators have found sources in corporations and now actively encourage faculty to establish companies that will provide royalties to the university. The consequences can be seen at the University of British Columbia Faculty of Forestry where the foyer of the building is filled with plaques acknowledging the contribution of forest companies. While environmentalists have for decades decried B.C.'s clearcut logging practices as both destructive and unscientific, UBC's forestry faculty has largely toed the industry line. Supporting the forest industry seems to have become more important to the forestry faculty than reasoned debate. (Interestingly, the recent growth in numbers of women in the faculty has been accompanied by more genuine interest and debate over alternative forestry practices.)

The same promotion of industry perspectives occurs in those faculties receiving money from pharmaceutical, chemical and military sources. Students are presented with one-sided information about the potential benefits of these areas with little balance from those with concerns. Indeed, most faculty members who do have reservations seldom dare to speak out, or if they have the courage to risk the approbation of their peers, suffer all manner of indignities. In my experience, merely questioning the activity or suggesting possible hazards is to invite strong disapproval and accusation of being “anti-science” or “emotional and non-scientific.” It is a sad state in a so-called community of scholars where dissent or difference of opinions is supposed to be valued. One way to raise important issues without being overwhelmed by pro-biotech lobbying would be through a Royal Commission to examine the broad societal, health, ecological and economic implications of genetic engineering.

In Europe where a “slow food” movement has sprung up as a counter to North American fast food, GE crops and food have been kept out of the continent. They have applied the Precautionary Principle that demands convincing evidence of both a need for the product and its safety before acceptance of a new technology. Europeans tell me they are watching Canadians for evidence of hazard or safety because we “are doing the experiment.” Canadians have been eating GE food for more than five years without being informed or provided information on labels.

Over recent decades, scientists have been revealed to have carried out experiments on unwitting human subjects until the 1960s. A few examples: patients infected with syphilis were deliberately denied treatment in order to follow the full course of the disease; inmates of mental asylums were administered the hallucinogen, LSD, to determine the effects; and people judged mentally or physically handicapped for genetic reasons were sterilized. Out of these examples of excessive scientific exuberance, scientists have accepted the conditions for carrying out tests with humans: prospective subjects must first be fully informed of what is to be done and the subjects must give approval before the study is carried out. Convinced by the biotech industry that GE foods are “substantially equivalent” to non-GE food, governments have demanded little in large-scale studies of the long-term effects of ingesting GE food. (One study by Dr. A. Putszai showed deleterious consequences of feeding GE potatoes to rats. It was peer reviewed and published in the prestigious medical journal, *Lancet*, but remains controversial. Putszai’s experiments are still the only GE feeding study published.) So, in Canada, large numbers of people are being subjected to a massive experiment without providing informed consent. At the very least, all Canadians should be able to see what food is genetically engineered so they can make their own choice.

A Future for Biotechnology?

As a geneticist, I continue to take enormous vicarious delight at the incredible technological dexterity being gained and acquisition of answers to basic biological questions I never thought I would live to see solved. The exuberance of geneticists is understandable, especially when there seem to be such opportunities to engineer life according to our specifications. I have no doubt there will be important uses of these techniques and insights in the future. But as the proliferation of scientific papers and journals attest, there is still an enormous amount we have to learn. The reason we do experiments and then report them is because we don't know what the result will be. Already, there are reports and experiences with GE crops in open fields and in our food that suggest there are valid reasons to proceed with greater caution.

It behooves every scientist to remember the experience of the nuclear industry. During World War II, allied scientists rushed to build an atomic bomb before the enemy succeeded in building its own. Once the bomb was built, the Allies learned the enemy was not in the race. Atomic bombs represented a radically new weapon that not only increased the scale of destruction but induced genetic alterations that would be perpetuated indefinitely in the genomes of future generations. Nevertheless, the use of these revolutionary weapons was justified by the potential to save lives by completing the war more quickly. Years after atomic bombs were created and used, scientists discovered new phenomena: radioactive fallout and bioaccumulation of radioisotopes; electromagnetic pulses of gamma rays that incapacitate electrical connections; and vast ecological consequences of nuclear winter. There is absolutely no reason to suppose that biologists know enough to anticipate the ecological and health ramifications of a revolutionary technology such as genetic engineering. Governments must resist the economic pressures and show leadership and concern for the long-term health of people and nature. And scientists involved in this exciting area should learn from history and welcome free and open discussion about ecological, health and social implications of their work.