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When my friend Bill Joy wrote his now-famous article in *Wired*, I was glad that someone with impeccable credentials as a technological innovator—the father of Unix and Java, among other inventions—had explained why many thoughtful technologists feel uneasy. But I became alarmed when a seemingly well-informed journalist for a top Eastern newspaper, interviewing me about that article, seemed surprised that anyone who wasn't a neo-Luddite should worry: technological innovation's vast benefits, he opined, surely outweigh its shadow side, or we wouldn't be doing it. I realized then that Francis Bacon's enthusiastic but undiscriminating goal for science—"the enlarging of the bounds of Human Empire, to the effecting of all things possible"—could use a little tutorial about unintended consequences.

In scarcely more than a half-century, our species has developed at least four technologies that are fit, as someone gravely remarked, "for a wise, far-seeing, and incorruptible people." The first, nuclear fission, clearly had and retains the potential to annihilate humanity. Cold War terror is now history, but we are entering a more subtly dangerous period. Fifty-five years after Hiroshima and Nagasaki, fewer people remember what it means to kindle a small star over a city. Vigilance is relaxing, yet bomb-making technology has become widely available in greatly simplified forms. The only missing ingredient—fissionable material—is spreading into ever more numerous and less responsible hands. (Saddam Hussein nearly made bombs and is still trying; if he doesn't yet succeed, someone else probably will.) Some of the tens of thousands of nuclear warheads, too, seem to have gone missing. Having worked for decades on nuclear nonproliferation, I wouldn't be in the least surprised to wake up tomorrow morning and discover that nuclear terrorism, or even nuclear war, was underway. There have been near-misses. Once made, bomb materials last nearly forever. Human institutions and attention don't. Can we go on being lucky—nearly forever?

Then there's the manipulation of genes. I don't call it by the euphemism "genetic engineering," because while it moves genes, it's not about genetics, and "engineering" implies an understanding of how causal mechanisms translate action into effect, but we're far from understanding how genetic patterns turn into organisms. Unfortunately, we're also well along in changing those patterns anyhow—and thereby changing science from a way of *understanding how nature works* into a tool for *changing what nature is.*

Biotechnology is seeking to transform both the speed and the goal of biological evolution. It speeds up evolution by roughly a billionfold, from a measured pace in which innovations are rigorously pre-tested over eons (and whatever doesn't work gets recalled by the Manufacturer) to the frenetic pace of next quarter's earnings reports. At that pace, mistakes can't be detected in advance, especially by a compromised and biologically unskilled regulatory system. Then, since the products have a life of their own and are deliberately broadcast through the environment, mistakes can quickly escape and multiply.

Biotechnology also changes the *goal* of evolution from evolutionary success to economic profit—to survival not of the fittest but of the fattest. This industrialization of life, fundamentally changing the nature of the 3.8-billion-year-old life process, are carried out by people skilled in gene-splicing technique and biochemistry, but generally ignorant of key biological fundamentals—ecology and evolutionary biology. It's very clever kids with PhDs in "molecular biology," playing with dangerous stuff they don't understand.

There are already early signs of nasty surprises: transgenes spreading far beyond their intended recipients at far greater than expected speeds, herbicide-resistant superweeds, gene-spliced insecticides that kill more than their targets, protective strategies that don't work, crop yields falling short of expectations, backlash against the abuse of intellectual-property law, and more. It could get worse. Speciation may be nature's way of keeping pathogens in a box where they learn proper behavior—for example, that it's a bad strategy to kill your host. But inserting genes from unrelated organisms into random sites in the genome may let pathogens vault the species barrier, entering new realms where they have no idea how to behave.

Some theologians suggest—not from ignorance or superstition but out of deep biological wisdom—that it was not through mere carelessness that the Creator failed to put fish genes into strawberries. Biodiversity is already perfectly

adequate without our needing to create novel lifeforms, unneeded for nutrition and unwelcome in the marketplace, to correct God's lamentable oversights.

And of course the technology is prone to abuse. Any high-school kid can now buy a gene-splicing kit for basement experiments with recombinant DNA. It's not unduly difficult to splice deadly toxins into common bacteria: some amateurs have already been caught doing so, and some countries (if not also non-national terrorist groups) employ teams of amoral but skilled scientists to create dreadful new plagues. That's dangerous to do, but even more dangerous to use. It's also far easier, cheaper, and more concealable than developing nuclear bombs. It will be a pleasant surprise if no designer epidemics are unleashed on the world, accidentally or deliberately.

Genetic manipulation, far from being the pinnacle of industrial modernity, is actually the last gasp of industrial primitivism, applying a reductionist and mechanistic mindset to living systems that don't work that way. It's the biggest intellectual collision since the Reformation: Descartes meets Darwin. Yet it's astonishingly devoid of compelling social or economic rationale. Perhaps its most striking feature (just like nuclear power) is the insubstantiality of its actual benefits. We are assured that biotech is the only way to feed the world, just as we were told that nuclear power is the only way to keep the lights on. The reality is just the opposite. Both technologies cost more and work worse than well-established alternatives outside the commercial orthodoxy—alternatives that are better buys for customers but less profitable for input suppliers.

Nuclear power, for example, has died of an incurable attack of market forces, suffering the greatest collapse of any industrial enterprise in world history. In the U.S. it has absorbed more than a trillion dollars, yet delivers less energy than biomass, or $1/20^{th}$ as much as energy efficiency. It is the world's slowest-growing energy source today, while efficiency and renewables are the fastest. Similarly, genetic manipulation, after 20 years' commercialization, has no proven example and little promise of beating the yields, resilience, or economics of biologically informed agriculture that seeks not to supplant but to imitate nature. On the contrary, genetically modified crops are trading at a discount and unmodified crops at a premium—the spread equaling the profits the promoters had hoped to capture—and the market values Monsanto's life-science business at approximately zero. Such sad ends to good intentions are inevitable when technologies are deliberately shielded from market and political accountability so that they get no feedback. Systems without feedback are stupid by definition.

The third of Bill Joy's four horsemen is nanotechnology—the emerging technique of making self-replicating machines at molecular scale. This holds promise of "desktop manufacturing" that could assemble anything, one atom at a time, very cheaply, with no waste. On the other hand, roughly comparable materials and energy efficiency is already available from other techniques described in our recent book with Paul Hawken, *Natural Capitalism*, and in Janine Benyus's book *Biomimicry*. Those techniques, however, lack nanotechnology's scary potential for microbe-sized, self-replicating antipersonnel weapons.

I'm far less qualified than Bill Joy to comment on his fourth worry—where artificial intelligence is taking us. But as one of the world's most capable computer scientists, he deserves to be taken seriously when he asks whether this art, too, may change for the worse not only what we can do but also who we are.

My purpose in summarizing these concerns (explained elsewhere in detail) is not to scorn my colleagues in technological innovation, nor to sow panic, nor to gripe about the general goal of progress. As a technologist whose lifeswork is innovation to create a more secure, prosperous, and life-sustaining world, my questions are about means, not ends. My purpose here is rather to invite us all to use our critical faculties and our market and political responsibilities to create the sort of world we want. When the most powerful force we know in the universe—six billion human minds wrapping around a problem—is harnessed, it should create happiness and satisfaction rather than suffering and injustice. Our new tools are so sharp, doubled-edged, even deadly, that we need to be sure they won't injure us. If we can't be confident about that, then we should lay them down and choose safer ones.

The coming decades will be our species' graduation test, when we discover whether this opposable-thumbs-and-large-forebrain experiment was a good idea. The search for intelligent life on earth shows promise, but is now entering its most critical stage. Let's not mess it up now by blandly assuming that whatever is possible is also wise.