The study of genes and associated sciences has developed to the point of permitting humans to create new species of plants and animals by combining their DNA in new ways. This kind of manipulation of plant and animal life has raised many ethical questions, popular controversy, and scientific questions about long-term consequences.

ALTHOUGH HUMANS HAVE altered the characteristics of many other species over the years (most notably in plant and animal domestication), a watershed was reached in the early 1970s when biologists began to directly manipulate DNA. This “genetic modification” or “genetic engineering” involved altering, recombining, and transferring genes from disparate organisms. It is one of the most powerful technologies ever devised; it is also one of the most controversial because of the ethical, legal, political, economic, and biological issues it raises.

Even the basic vocabulary for the subject is contested. The term genetically modification first appeared in the 1970s to describe early experiments on bacteria. But by the 1990s, in response to portrayals of such creations as sinister and unnatural, some proponents began to label all domesticated crops as “genetically modified” since ancient farmers had modified the plant’s genetic makeup. The term genetic engineering, preferred by some biologists, is resented by some engineers because of the uncontrolled aspects of the process. Transgenic is often used for organisms with recombinant DNA, although it is not strictly accurate in cases where an organism’s own genes have been altered. Genetically Modified Organism (GMO) here refers to an organism containing genes that have been directly manipulated.

The biology of genetic modification traces to work in the 1950s showing that bacteria exchanged genetic material in the form of extrachromosomal rings called plasmids. In the late 1960s, biologists learned to use the “restriction enzymes” that bacteria use to cut up the DNA of attacking viruses; these enzymes could be wielded to cut specific genes out of DNA molecules. In 1972, Paul Berg succeeded in making a recombinant plasmid, or gene construct, containing cut sections of DNA. In 1973, a team led by Stanley Cohen and Herbert Boyer inserted a recombinant plasmid into an *E. coli* bacterium, making it the world’s first GMO; this allowed the production of large numbers of the plasmids, which could then be used to modify different organisms.

HISTORY OF GENETIC MODIFICATION

The subsequent history of genetic modification cannot be understood apart from the history of intellectual property rights with which it is entangled. In 1972, corporate scientist Ananda Chakrabarty had altered a bacterium by manipulating the natural process of plasmid transfer. This work was not of particular scientific importance, and did not even involve recombinant DNA, but it became the subject of a landmark dispute over the patentability of the modified bacteria. In 1980, by a five to four vote,
the U.S. Supreme Court’s *Diamond vs. Chakrabarty* decision overruled the patent office’s finding that, consistent with established legal principles, living organisms could not be patented. This ruling, combined with other decisions from around the same time, allowed private ownership of modified organisms and genes themselves. Several companies quickly began work to capitalize on the right to own genetically modified life forms, most notably St. Louis, Missouri-based Monsanto Company, which had started to build a biotechnology unit a few years before. Also in 1980, the United States passed the Bayh–Dole Act, which allowed results of federally funded research to be privatized, leading to a flow of licenses on genes and genetic technologies from universities to corporations.

Industrial uses of genetically modified simple organisms appeared quickly. One of the earliest was in cheese production: in 1981 a gene for producing chymosin (a key ingredient in the rennet used to solidify cheese) was inserted into bacteria, and in 1988 a genetically modified yeast was approved for chymosin production, allowing partial replacement of the rennet from calf stomachs. Pharmaceutical applications began at the same time, and in 1982 the U.S. Department of Agriculture approved human insulin produced by genetically modified bacteria.

Genetic modification of plants followed quickly. By 1983, parallel work at Monsanto and Washington University, both in St. Louis, Missouri, had succeeded in inserting an antibiotic resistance gene into plants, as had Belgian biologists. All had used a powerful new method of introducing foreign genes. *Agrobacterium tumefaciens* is a natural genetic engineer, a soil bacterium that inserts its genes into plants as part of its reproductive cycle. The biologists hijacked this process, replacing the genes the bacterium intended to insert with their own genes of choice. A few years later, Cornell scientists devised a second method of introducing gene constructs into plants by using a gun-like device that shot materials into cell nuclei. Still, the process by which gene constructs became integrated into the target organism’s genome remains a mystery, so biologists have to use the “brute force” method of trying to transform large numbers of cells and then isolating the genetically modified ones by killing the others. The most common way to accomplish this is to include a gene for antibiotic resistance in the construct inserted into the target organism; the cells are then exposed to antibiotics that kill off all cells except those containing the construct with antibiotic resistance gene (and therefore also the gene/s of interest). Again, developments in intellectual property law followed these scientific developments closely. The landmark Hibberd decision in 1985 extended patentability from bacteria to genetically modified plants.

Genetic modification of animals followed a different trajectory. By the late 1960s, biologists were able to inject embryonic cells from one organism into the blastocyst (early embryo) of another, and by 1980 several labs had succeeded with the direct microinjection of purified DNA into the pronuclei of fertilized mouse eggs. Following the Chakrabarty decision, academic biologists applied for a patent on a modified oyster; the ruling in 1987 by the Board of Patent Appeals and Interferences affirmed that animals too could be patented (although not humans—the rationale being that the 13th Amendment banned ownership of humans). The next year, the United States issued its first animal patent for the “Oncomouse,” a mouse with an inserted gene predisposing it to mammary cancer (the patent was issued to Harvard University and promptly licensed to DuPont). Other countries have been more wary of animal patents; Canadian courts rejected the Oncomouse patent, while the European patent office issued conflicting rulings, eventually settling on a restricted patent.

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The U.S. Agricultural Research Service was the first in the world to genetically engineer barley.

Therefore, by 1988, both plants and animals could be genetically modified; the resultant organisms could be privately owned; and findings from government-sponsored basic research could be licensed or sold to corporations. Numerous academic labs and corporations were experimenting with a wide range of genetic modifications of life forms. This was a historic juncture in science, and also in the industry–university relationship. It was also a juncture long anticipated in speculative fiction, which had pointedly asked whose interests would dictate what life forms would be created. In Aldous Huxley’s *Brave New World* (1989), life forms were developed according to the interests of corporate sales and state control (as exemplified by the worker caste designed to love only those sports that required them to pay for transportation and sporting equipment). Development of GMOs is still in its early stages, but important patterns have emerged reflecting the interests controlling the technology.

In plants, world area of genetically modified crops was up to 90 million acres by 2005. The vast majority of genetically modified seeds were soybean, maize, canola, or cotton. By far, the most common plant modification has been herbicide resistance: a gene is inserted to counteract the effects of a particular herbicide, which can then be sprayed without affecting the crop. Herbicide resistant crops accounted for 71 percent of the global genetic modification area. By far, the most common genetically modified species is soybean, which accounted for 61 percent of the global genetic modification area. The Monsanto Company dominated global sales of GMOs with its soybean resistant to its own Roundup herbicide, and the main customers were commercial farmers who found the herbicide resistance convenient. The second most common genetic modification was insertion of a gene from *Bacillus thuringiensis* (Bt), which causes the plant to produce an insecticide. This replaced or augmented more environmentally toxic insecticides that have in some areas lost effectiveness to insect resistance. Again, most customers were large commercial farmers, but there was a growing
market for Bt cotton among small farmers in India and China. After this there is a very sharp drop-off to the third-most widely used genetic modification technology, which induces virus resistance in produce in a small number of fruits and vegetables.

Development of genetically modified animals has progressed less quickly. The first commercial genetically modified animal in the United States, in 2003, was an aquarium fish made to fluoresce (banned in California as a life form genetically altered to amuse customers). Efforts are also underway to modify salmon to grow faster in fish farms.

Thus the first dozen years of GMO development have been heavily dominated by commercial interests; since GMO’s require multiple genes and technologies, most of which are now owned by corporations, this situation is bound to continue. Yet much of the public discussion of GMO’s centers on uses of the technology to improve nutrition in developing countries. There is a striking gap between voluminous media on theoretical humanitarian applications and the actual development of crops for such purposes. For instance, GMO-producing firms spent tens of millions of dollars advertising “Golden Rice,” but years later, neither this nutritionally enhanced rice nor any other humanitarian crops had made it into farmers’ fields. Humanitarian GMO’s, which generally offer no major benefits to corporations except for public relations, have encountered serious problems with funding, biosafety testing, and intellectual property.

Nevertheless, laboratories continue to experiment with a wide range of genetic modifications reflecting the potential of the technology—bacteria to detoxify the environment and prevent HIV and perhaps cancer. The theoretical benefits of the technology are enormous, as is the question of whether these benefits will ever be realized.

SEE ALSO:
Genetic Diversity; Genetic Patents and Seeds; Genetics and Genetic Engineering.

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