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the CODE of LIFE

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Understanding
heredity

by Lexi Krock

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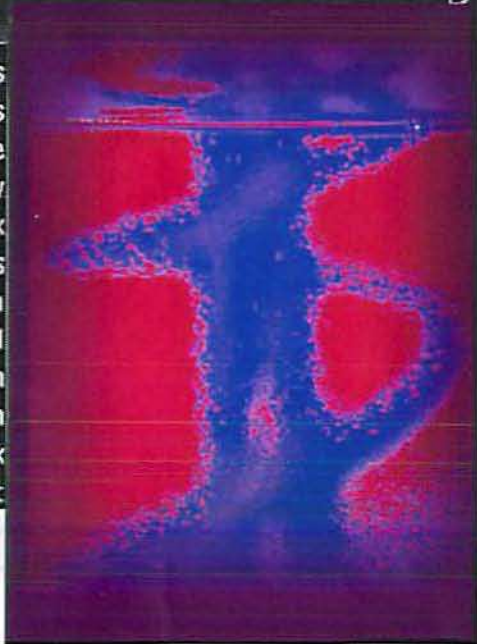
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Strand of DNA

Introduction

Of all the branches of science, genetics is the most self-reflective; not without coincidence, it is also the most universal. We all like to think about who we are, where we came from, and how we are related to others, sometimes even a little too much. All of this thinking (at least on the part of scientists) has paid off. Today, with the Human Genome Project slated to release a complete sequence of our genetic code by 2003, we are closer than ever to answering many questions that have dogged thinkers for thousands of years and many that we've never even posed before. In this feature, take a closer look at a sequence that stretches almost as far as the code itself -- the checkered


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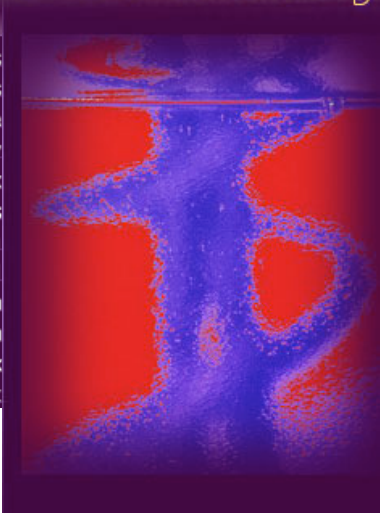
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c. 580-500 B.C. Pythagoras

Pythagoras surmised that all hereditary material came from a child's father. The mother provided only the location and nourishment for the fetus. Semen was a cocktail of hereditary information, coursing through a man's body and collecting fluids from every organ in its travels. This male fluid became the formative material of a child once a man deposited it inside a woman.

Pythagoras, Greek philosopher and mathematician

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c. 490-430 B.C. Empedocles
Pythagoras' theory of heredity could not readily explain the obvious occurrence of shared physical traits between a mother and her child. Empedocles, another Greek thinker, accounted for Pythagoras' oversight by asserting that semen blended with female sexual fluid found inside a woman's body. An embryo, he believed, resulted from the mixing of male and female hereditary material found in these sexual fluids.

An excerpt from Empedocles' ancient text on heredity

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384-322 B.C. Aristotle
Aristotle's understanding of heredity, clearly following from Pythagorean and Empedoclean thought, held wide currency for almost 2,000 years. The Greek philosopher correctly believed that both mother and father contribute biological material toward the creation of offspring, but he was mistakenly convinced that a child is the product of his or her parents' commingled blood. Semen, Aristotle held, was a man's purified blood, which could engender a child when coupled with menstrual blood inside a woman's body.

Aristotle's blood-centered understanding of heredity probably spawned the terms "bloodline" and "blueblood" (from the color of veins), which refer to lineage.

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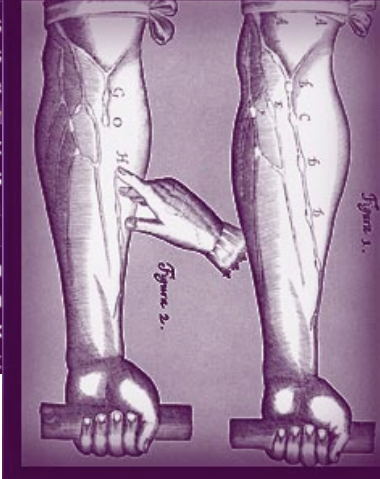
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William Harvey's research on the veins of bandaged arms led to his discovery of the correlation between the heart and the circulation of blood through the body.

1578-1657 A.D. William Harvey

The English physician William Harvey was the first to explain how our pumping hearts circulate blood. Though circulation remained the primary focus of his medical research, Harvey also studied animal reproduction, particularly in chickens and deer. Harvey came to understand that menstrual blood did not contribute to the formation of a fetus, putting Aristotle's idea to rest. Harvey also questioned the direct role of semen in reproduction. He suggested that an egg found inside a female became fertilized by means of a kind of infection set in motion by the sexual act.

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Antonie van Leeuwenhoek's microscopes, which he crafted by hand using secret methods, had powers of magnification ranging from 50 to 300 times. His microscopes allowed him to see sperm for the first time in history.

1632-1723 Antonie van Leeuwenhoek

In 1677, just twenty years after William Harvey's death, Dutch scientist Antonie van Leeuwenhoek created a microscope powerful enough to magnify the sperm found in semen. Because Harvey could not observe with the naked eye any evidence of hereditary material in semen, he became skeptical that semen made a genetic contribution to a fetus. Van Leeuwenhoek's finding, however, spawned the idea that cellular interactions generate all living things. With his microscope, Leeuwenhoek could plainly observe these interactions taking place. His discovery made him famous worldwide and debunked the then popular notion of spontaneous generation. Until Leeuwenhoek, eels, for example, were believed to spontaneously arise from dew. Leeuwenhoek investigated the generation of eels and proved that they originated, like the other animals he studied, from cellular interactions between a male and a female of the kind.

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Pierre-Louis de Maupertuis studied the polydactylic hands of a single German family in which the trait had been passed for generations.

1698-1759 Pierre-Louis Moreau de Maupertuis

In his 1751 book, *Système de la nature* (System of Nature), French mathematician, biologist, and astronomer Pierre-Louis Moreau de Maupertuis initiated the first speculations into the modern idea of dominant and recessive genes. De Maupertuis studied the occurrences of polydactyly (extra fingers) among several generations of one family and showed how this trait could be passed through both its male and female members. He even surmised that polydactyly was the result of a mutation in the "hereditary particles" of an individual and devised a mathematical means of predicting the occurrence of the trait in the family's future offspring.

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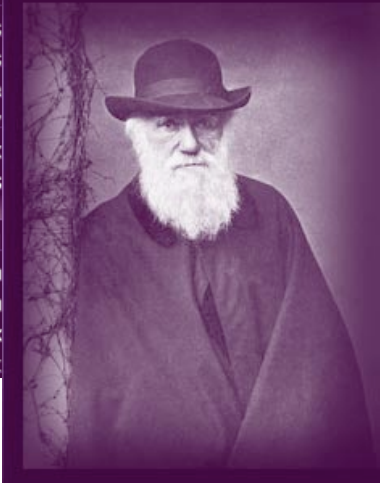
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1809-1882 Charles Darwin

Darwin's ideas of heredity revolved around his concept of "pangenesis." In pangenesis, small particles called pangenes, or gemmules, are produced in every organ and tissue of the body and flow through the bloodstream. The reproductive material of each individual formed from these pangenes was therefore passed on to one's offspring. In his early research, Darwin believed that the characteristics of one's pangenes were susceptible to change throughout life, so that offspring could inherit traits acquired by their parents during life, but he later eliminated this aspect of his theory.

Charles Darwin is best known for his notion of natural selection, which holds that those individuals within a species that are best suited to their particular environment will have better survival and reproductive success than others of their kind and will thus genetically pass those advantageous traits to their descendants.

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Gregor Mendel is widely credited with formulating the basic laws of heredity: Hereditary factors do not mix but remain segregated; some factors are dominant, while others are recessive; each parent lends only half of his or her hereditary information to his or her progeny; and different offspring of the same parents have different sets of hereditary information.

1822-1884 Gregor Mendel

Gregor Mendel, an Austrian scientist who lived and conducted much of his most important research in a Czechoslovakian monastery, established the basis of modern genetic science. He experimented on pea plants in an effort to understand how a parent passed physical traits to its offspring. In one experiment, Mendel crossbred a pea plant with wrinkled seeds and a pea plant with smooth seeds. All of the hybrid plants produced by this union had smooth seeds. During years of painstaking research, Mendel bred more pea plants with different select traits, such as blossom color, pod color and shape, and pod position.

After studying the data from these experiments, Mendel concluded that physical traits are passed to offspring through genetic factors called alleles. Each parent had not one but two alleles for each trait. Two alleles (one from each parent) interact to produce the final physical characteristics of an offspring. While previous conceptions of heredity suggested that specific characteristics from each parent blend together in the offspring, Mendel deduced that heredity depends on contributions from both parents, which compete randomly for expression in the offspring. Mendel's research proved that each of the two alleles for a given trait that parents transmit to their offspring can be either dominant (a trait certain to appear if one or both alleles are dominant) or recessive (a trait that is masked unless both alleles are recessive).

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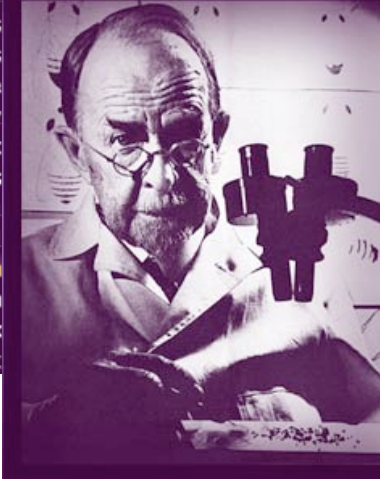
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Thomas Hunt Morgan in his laboratory

1866-1945 Thomas Hunt Morgan

Thomas Hunt Morgan began experimenting with *Drosophila*, the fruit fly, in 1908. He bred a single white-eyed male fly with a red-eyed female. All the offspring produced by this union, both male and female, had red eyes. Morgan then bred these male and female siblings, which resulted in some offspring with red eyes and some with white eyes. All of the flies with white eyes were males. From these and other results, Morgan established a theory of heredity that was based on the idea that genes, arranged on the chromosomes, carry hereditary factors that are expressed in different combinations when coupled with the genes of a mate. In 1933, Morgan won the Nobel Prize for his discovery of "hereditary transmission mechanisms in *Drosophila*."

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Shown shortly after winning the Nobel Prize in 1962, Harvard biology professor James Watson displays a model of DNA in his laboratory.

b. 1916 Francis Harry Compton Crick

b. 1928 James Dewey Watson

British biophysicist Francis Crick and American geneticist James Watson undertook a joint inquiry into the structure of DNA in 1951. Geneticists already knew that DNA held the primary role in determining the structure and function of each cell in the body, but they did not understand the mechanism for this or that the structure of DNA was directly involved in the genetic process. Employing X-rays and molecular models, Watson and Crick discovered the double helix structure of DNA. Suddenly they could explain how the DNA molecule duplicates itself by forming a sister strand to complement each single, ladder-like DNA template. Watson and Crick's groundbreaking research paved the way for all of the major genetic discoveries of the last half-century. They received the 1962 Nobel Prize for Physiology or Medicine.

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Barbara McClintock, more than 40 years after her research on corn pigmentation, receives the Nobel Prize from King Carl Gustav of Sweden.

1902-1992 Barbara McClintock

Though American botanist Barbara McClintock conducted the research that led to her discovery of mobile genetic elements in the 1940s, it was not until decades later that scientists began to take her work seriously. McClintock experimented with variation in the colors of corn kernels on a single cob. She tracked pigmentation changes in the corn and observed through microscopic evidence that two transposable genes called "controlling elements" were influencing the corn's pigmentation according to where their ever-changing position was on the corn's chromosomes. Whichever genes became the genetic neighbors of these controlling elements in a given generation of corn accounted for the changes in pigmentation McClintock observed. In 1983, McClintock became the first female recipient of the Nobel Prize for Physiology or Medicine. Scientists today believe "jumping genes," or transposons, may be linked to some genetic disorders such as hemophilia, leukemia, and breast cancer, and may have played critical roles in human evolution.

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Understanding heredity

by Lexi Krock

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- Genome Project

1990 Human Genome Project

The Human Genome Project is an international research effort to decode the human genome, the complete genetic instructions for a human being. Project leaders originally estimated the work would take 15 years, but with the help of supercomputers and adrenaline, they now expect to sequence the complete human code by 2003. With the final sequence in hand, scientists, doctors, and students will have the use of all the DNA information that is key to understanding even the most complex biological systems in our bodies. The possibilities for applications of this information in research are innumerable. At the very least, authorities expect the human code to revolutionize our understanding of human disease. For more information about the Human Genome Project, see [Genome Facts](#).

When Human Genome Project researchers have completed their task, they will have mapped and sequenced three billion nucleotide base pairs.

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Genome Facts

With the flurry of media attention surrounding the race to sequence the genome, it often seems as if the myriad genome facts and news items floating around could fill up a couple of telephone books. If you feel bombarded, imagine how the decoders feel: If written out, a human genetic code would fill the pages of 200 1,000-page New York City telephone directories. Though we can't compile all the facts here, this list of mind-boggling facts and figures will get you started. For more basic information about genes, visit the [Glossary](#).

- A rough draft of the human genome was completed in June 2000. Efforts are underway to complete a final draft of the human genome, expected sometime in 2003.
- Since it began in 1990, the Human Genome Project is estimated to have cost \$3,000,000,000.
- The entire human genome requires three gigabytes of computer data storage space. (One million base pairs of sequence data equals one megabyte of storage space; the human genome has three billion base pairs.)
- Every second, Human Genome Project computers decode 12,000 letters.
- For the Human Genome Project, researchers collected blood (female) or sperm (male) samples from a large number of donors. Only a few samples were processed as DNA resources, and the source names remain confidential, so neither donors nor scientists know whose DNA is being sequenced.
- The human genome sequence generated by the private genomics company Celera was based on DNA samples collected from five donors who identified themselves only by race and sex.
- The vast majority of DNA in the human genome -- about 97 percent -- consists of non-genetic sequences with unknown function, sometimes called "junk DNA."
- Human DNA is 98 percent identical to chimpanzee DNA.
- The average amount of genetic difference between any two chimpanzees is four or five times more than the average difference between any two humans, which is 0.2 percent, or one in 500 letters. (This takes into account that human cells, unlike chimpanzee cells, have two copies of the genome.)
- If two different people started reciting their individual genetic code at a rate of one letter per second, it would take almost eight and a half minutes before they reached a difference.
- Humans have approximately 30,000 genes.
- The roundworm has 19,098 genes.
- The fruit fly has 13,602 genes.
- Yeast has 6,034 genes.
- The microbe responsible for tuberculosis has approximately 4,000 genes.
- There are 100 trillion (100,000,000,000,000) cells in your body.

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- There are three billion (3,000,000,000) base pairs in the DNA code within each cell.
- If unwound and tied together, the strands of DNA in one cell would stretch almost six feet but would be only 50 trillionths of an inch wide.
- If all the DNA in your body was put end to end, it would reach to the sun and back over 600 times (100 trillion times six feet divided by 92 million miles).
- It would take a person typing 60 words per minute, eight hours a day, around 50 years to type the human genome.
- If all three billion letters in the human genome were stacked one millimeter apart, they would reach a height 7,000 times the height of the Empire State Building.

For more information about genes, visit the [Glossary](#).

Sources: (1-5, 7, 15-21) National Human Genome Research Institute Web site; (2) NOVA "Cracking the Code"; (8-10, 13-14) New York Times; (11-12) Oak Ridge National Laboratory Web site; (6) Celera Genomics Web Site.

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