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THE GENETICS OF GENIUS

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Chapter Heading - The Genetics of Genius[1]

> *'Since each individual produced by the sexual process contains a unique set of genes, very exceptional combinations of genes are unlikely to appear twice even within the same family. So if genius is to any extent hereditary, it winks on and off through the gene pool in a way that would be difficult to measure or predict. Like Sisyphus rolling his boulder up to the top of the hill only to have it tumble down again, the human gene pool creates hereditary genius in many ways in many places only to have it come apart in the next generation.'* -- E. O. Wilson 1978

Psychologists once thought, simplistically, that genius was nothing more than high general intelligence, the capacity measured by the *intelligence quotient* or IQ. IQ scores of 140 and above, attained by perhaps four in every thousand youngsters, were classified as in the 'genius range.' Stanford University's Lewis Terman, who was responsible for revising and standardizing the first individually-administered IQ test, the Stanford-Binet, identified some 1500 gifted children with IQs in this range and Terman's gifted group have now been followed through middle age. Most of them have led relatively successful lives but none of them, so far as I am aware, would be classified as geniuses today.

At the other end of the IQ scale, a rare few of retarded or autistic persons, known as *savants*, can quickly specify the day of the week on which any date in history fell or, although unable to read music, can play on the piano any composition after just a single hearing. These highly specialized abilities seem all the more remarkable in people whose general intelligence may be so low that they are dependent on others for their care and sustenance. Autistic savants are not geniuses either, of course, but these remarkable people seem to me to illustrate an important fact about the structure of mind.

À Autism and the modular brain

Autism was first described in 1944 and is extremely variable in its manifestations. Some autists seem to be profoundly retarded and never develop language. Others, often labeled Asperger's syndrome, have normal or superior IQs. One common theme in autism is an extraordinary lack of social motivation and social intelligence. Most autistic children are unresponsive to people, even to their mothers, and dislike being held or fondled. Unlike normal children, they do not seem to see other members of their species as especially interesting, to be studied and imitated. This may explain why even high-level autists tend to be slow in language development and why, in spite of sometimes high general intelligence, they remain insensitive to social cues. Asperger children seem to be unable to identify with other persons and therefore unable to anticipate how others will react to what they do. Another rare congenital abnormality, Williams' syndrome, presents the antithesis of autism. Children with Williams' syndrome are verbally and socially precocious, they 'often appear exceptionally self-possessed, articulate, and witty, and only gradually is their mental deficit borne in on one.' (Sacks 1995, p. 223)

A normal child has an innate fear of snakes and spiders, a reaction not shown to guns or electric sockets although the latter are more dangerous. Evolutionary psychologists point out that human toddlers back in the Pleistocene who instinctively avoided snakes and spiders were somewhat more likely in consequence to live to maturity and to become our ancestors. Since natural selection works slowly, such a reaction to electric sockets has not yet evolved. In a similar way, it was adaptive for ancestral infants to be fascinated by their mother's faces, to recognize an affinity with other creatures like themselves, to study and imitate them. This special-purpose 'mental module' facilitated learning language and the other skills required for social living. It would appear that this social-intelligence module is well-developed in Williams' syndrome, in spite of low general intelligence, but poorly developed in Asperger's syndrome even when general intelligence is normal.

Retarded or autistic savants seem to betoken the existence of other special-purpose modules that are capable of efficient functioning even in the presence of a low IQ. Neurologist Oliver Sacks describes some of these prodigies, such as Jedediah Buxton, a simpleminded laborer, who was a prodigious calculator. 'When asked what would be the cost of shoeing a horse with 140 nails if the price was one farthing for the first nail, then doubled for each remaining nail, he arrived at the figure of 725,958,096,074,907,868,531,656,993,638,851,106 pounds, 2 shillings and 8 pence.' (Sacks, p. 191). When asked to square this number, he produced the 78-digit answer after 10 weeks' time during which he did his work, held conversations, lived his life, while his astonishing calculating engine continued to grind away at the problem. A savant studied by Sacks personally could recite the entire nine volumes of Grove's 1954 *Dictionary of Music and Musicians* which had been read to him once by his father.

'Blind Tom', a slave child, was born in the 1850s nearly blind and he was unable to speak until age five or six, yet from the age of four, 'seated at the piano, he would play beautiful tunes, his little hands having already taken possession of the keys, and his wonderful ears of any combination of notes they had once heard.' (Sacks, p. 189). Tested at age 11 by musicologists, who played for him two entirely new compositions, 13 and 20 pages in length, Tom 'reproduced them perfectly and with the least apparent effort.' Like Mozart, Tom could perform on the piano with his back to the keyboard and his hands inverted. It is important to understand that the gifts of these autistic prodigies seem to go far beyond extraordinary rote memory. Leslie Lemke, a modern 'Blind Tom', who also is congenitally blind and retarded, 'is as renowned for his improvisational powers as for his incredible musical memory. Lemke catches the style of any composer, from Bach to Bartok, after a single hearing, and can thereafter play any piece or improvise, effortlessly, in that style.' (Sacks, p.224). The autistic man who could recite all of *Grove's Dictionary* was also a musical prodigy. Martin, although retarded, 'had a musical intelligence fully up to appreciating all the structural rules and complexities of Bach, all the intricacies of contrapuntal and fugal writing; he had the musical intelligence of a professional musician.' (Sacks, p.222).

Sacks also describes artistic prodigies such as Nadia, who 'suddenly started drawing at the age of three and a half, rendering horses, and later a variety of subjects, in a way that psychologists considered 'not possible.' Her drawings, they felt, were qualitatively different from those of other children; she had a sense of space, an ability to depict appearances and shadows, a sense of perspective such as the most gifted normal child might only develop at three times her age.' (Sacks, p.194). Stephen, a profoundly autistic child, was consigned at age four to a London school for the developmentally disabled. When he was five, Stephen began drawing, primarily cars and sometimes 'wickedly clever' caricatures of his teachers. At age seven, he began to specialize in drawing buildings, such as St.Paul's Cathedral 'and other London landmarks, in tremendous detail, when other children his age were just drawing stick figures. It was the sophistication of his drawings, their mastery of line and perspective, that amazed me---and these were all there when he was seven.' (Sacks, p.199). Steven could draw from memory a complex scene (e.g., a construction site) viewed only for a few seconds but he also had an intuitive grasp for artistic and architectural style. Repeated drawings from memory of Sacks' house over the period of a year varied considerably in detail but not at all in style. Similar repeated renderings of Matisse paintings varied also, proving that he was not 'merely' faithfully copying a vivid visual memory but, rather, that he was improvising à la Matisse.

Examples like these have led psychologists to postulate the existence of numerous special intelligences which are seen in these savant cases in especially stark relief against a background of general intellectual poverty. It is of great importance to realize that such savant-like talents can also co-exist with high intelligence and in the absence of autism. The young concert pianist, Evgeny Kissin, "the most phenomenal prodigy of our time" (Solomon, 1996, p. 113), at 11 months, spontaneously sang an entire Bach fugue that his older sister had been practicing. At 30 months, "Genya sat down at the old Bechstein on which his mother taught and picked out with one finger some of the tunes he had been singing. The next day, he did the same again, and on the third day he played with both hands, using all his fingers...Chopin's ballades he would play with those little hands, as well as Beethoven sonatas and Liszt rhapsodies." (p.115). The literary genius, Vladimir Nabokov, possessed 'a prodigious calculating gift, but this disappeared suddenly and completely, he wrote, following a high fever, with delirium, at the age of seven.' (Sacks, p.226). The intellectually normal Chinese artist, Yani, displayed her artistic powers as early as did Nadia or Stephen and Sacks describes another gifted young man, now doing fundamental research in chemistry, who could read fluently and with comprehension at age two or repeat and even harmonize with any melody at the same age, and who did remarkable drawings with perspective at age three. Thus, it does not seem to be the case that savant-like gifts result from the conscription of all intellectual resources in the service of a single function.

This idea of a modular intelligence contrasts with the view of the brain as merely a general-purpose computer. the power of which can be assessed just by a single number, the IQ. Yet general intelligence is both real and important. Its role may be like that of the conductor of an orchestra in which the brass, percussion, strings, and woodwinds are the special-purpose modules. Like the best orchestral conductors, the computer-intelligence knows all of the parts but cannot play the flute as well as the flutist can; the conductor's function is to evaluate and to coordinate. Temple Grandin, a highly intelligent autistic woman and a college professor, learned to use her general intelligence to compensate for her deficient social sensitivity (Grandin 1986).

There is a useful analogy between the domains of mental and physical talent. Each Olympic sport makes different demands on different muscle groups, reaction times, gross or fine motor coordination, and so on. Because of their different genetic endowment, it is unlikely that any world-class distance runner could have become instead a world-class sprinter or weight-lifter or gymnast. Yet all world-class athletes have an unusual degree of general athletic ability. That is, if we were to construct a series of special tests designed to tap each athlete's special abilities, it is likely that the scores on all these tests would intercorrelate positively---would form what is called a 'positive manifold', both for the mixed group of world-class athletes and also for people in general. If we were to construct a soccer team of Olympic runners, sprinters, pole-vaulters, gymnasts, and boxers, they would likely beat any other scratch soccer team---except one comprised of potential world-class soccer players.

If we were to construct special tests for each of the several varieties of savant, tests designed to quantify their remarkable special abilities, we can be confident that, when administered to a sample of the general population, scores on these tests also would form a positive manifold. Good tonal memory would tend to go with good visual and conceptual memory as well as with the ability for mental computation (this correlation among the strengths of the mental modules is far from perfect, however; I know people no smarter than I am who have much better memories, for example). Retarded savants are remarkable not just because of a particular gift but also because of the absence of the related gifts that normally go with it.

Every acknowledged human genius seems to have had at least a good general intelligence *together with* an assortment of other gifts or attributes which, in mutually facilitating cohabitation, led to the extraordinary achievements that are the ultimate basis for classification into this special category. One of the ingredients in the recipe for genius, and which I believe may be as essential as general intelligence, is an exceptional degree of mental energy, permitting protracted periods of intensely focused concentration on the project in hand. Our question in this chapter has to do with the origins of these interacting attributes. Is it true that 'genius must be born and never can be taught', as Dryden claimed? Or, can genius be achieved? Is genius something that a doting parent can 'thrust upon' an otherwise ordinary child?

First, however, we need to address the curious fact that there are many people, including social scientists, even some geneticists---highly educated people who ought to know better---who believe that the human nervous system, unlike that of any other mammal, is unaffected by the same heritable variation that is obvious in the body's morphology. It follows from this postulate of *radical environmentalism*[2] that every normal human infant, however distinctive in size, shape, and appearance, must arrive equipped with a brain that is essentially identical in structure and capacity with every other new brain, just as all new Macintosh computers are essentially identical when they arrive from the factory. What differences in intellect, interests, character, or personality are to be found later in the adult must, in this view, be attributable solely to differences in subsequent experience or programming.

A Radical environmentalism

During the middle half of the 20th century, most social scientists and many intellectuals came to 'hold these truths to be self-evident, that all men are created equal...' and to interpret this fine phrase to mean biological equality. The fact is, however, that Jefferson modeled this first sentence of the American *Declaration of Independence* after the language of the constitution that had just been drafted for the state of Virginia. That document read like this: 'That all men are born equally free and independent and have certain inherent rights...' Jefferson kept the music but changed the words slightly for rhetorical effect. No practical man of that period would have given credence to the notion that all humans are biologically equal.

Charles Darwin (1809--82) was a scientist and scientists have to be practical people because they study the world of nature rather than the mistier realm of philosophy. Darwin knew that the offspring tend to resemble the parents. The great controversy over Darwin's *Origin of Species and ... the Descent of Man* was not about whether people's physiognomy and character tended to reflect their ancestry; like the invention of the wheel, the origins of that idea date back to prehistory. Animal breeders well knew that temperament, as well as running speed in horses or milk production in cows, reflected the animal's parentage and every dog fancier was aware that terriers were aggressive and sheep dogs inclined to herd things and that these behavioral traits tended to breed true.

Throughout most of human history, people have assumed that the same thing is true of our species, that smart parents tend to have smart children, that the offspring of athletes tend to enjoy sports, that mean parents often have mean offspring. But certain European philosophers, not being practical men, did entertain the notion, following John Locke (1632--1704), that the minds of human babies begin as identical blank slates to be written on solely by experience. One important radical environmentalist was the British philosopher John Stuart Mill (1806--73), a contemporary of

Darwin.

C John Stuart Mill

Mill was the eldest child of James Mill, a brilliant Scots historian and philosopher, and James educated his firstborn son himself. Little John Stuart was reading by the age of three, he was reading Greek at five, and by the age of eight he had read all of Herodotus and all of Plato's Dialogues in the original. By the ripe old age of 12, John Stuart had mastered algebra and Euclid's geometry; he had read all the standard Greek and Latin classics in those languages, and he was beginning the serious study of Adam Smith, Ricardo, and other political economists.

It is perhaps not surprising that, in his later life, Mill was inclined to attribute his own intellectual achievements to that extraordinary and intensive early training. What Mill failed to take into account, however, was that he had benefited, not only from his father's determined and ambitious educational efforts, but also from having received a half-helping of his brilliant father's genes.

It was not until the 20th century, however, that large numbers of intellectuals took up radical environmentalism as an article of faith. They arrived at this common delusion from different starting points and for a variety of reasons.

B Marxism

Karl Marx wanted to refute the prevailing assumption that the existing class structure of society was somehow preordained by God or human nature. Like many non-Marxist economists of today, he saw human individuals as interchangeable pawns at the mercy of economic forces and his utopian vision required that these same pawns, arrayed on a different board with different rules, would all behave alike and in their mutual interest. Lamarck's (1744--1829) belief that acquired characteristics might be passed along genetically from parent to child provided what appeared to be a mechanism for achieving a new world order and became a part of neo-Marxist dogma. The Marxist scientists who still lead the attack on what they regard as the hereditarian heresy are too sophisticated to espouse Lamarckian ideas, but they cling to the egalitarian dream because they cannot imagine achieving the greatest good for the greatest number unless that dream is true.[3]

B Liberalism

Political liberals, too, were concerned about the evils of oppression, both political and economic, and they believed that the achievements of the privileged classes were largely a consequence of that privilege rather than of some innate superiority. They reacted especially against Herbert Spencer's (1820--1903) *Social Darwinism* and his claim that the structure of Victorian society reflected the 'survival of the fittest,' the workings of a natural law which we cannot change and with which we should not tamper. Upper class white males took for granted the genetic superiority of their race and gender and considered their dominant social position to be a birth right. The liberals believed, quite reasonably, that, with better living conditions and equivalent education, many children from the lower classes could excel in life's race over many scions of the aristocracy.

B Anthropology and Margaret Mead

American cultural anthropology, led by Franz Boas (1858--1942), 'declared war on the idea that differences in culture derived from differences in innate capacity.' (Degler, p. 62). By 1915, Alfred Kroeber, one of Boas' leading students, was asserting that: 'heredity cannot be allowed to have acted any part in history.' (Degler, p.84). This position was most clearly articulated by another Boas disciple, Margaret Mead, whom he sent as a graduate student to the South Pacific with the aim of demonstrating that adolescence was less stormy and stressful in Samoa than in the United States because of cultural differences and, in particular, because of the greater sexual freedom allegedly enjoyed by young Samoans. Mead's (1928) book, *Coming of age in Samoa*, the most widely read anthropological treatise ever published, propelled her into the front rank of social thinkers and her views were strongly stated and widely influential. 'We are forced to conclude,' she wrote later, 'that human nature is almost unbelievably malleable, responding accurately and contrastingly to contrasting cultural conditions.' (Degler, p.134). In her book *Male and female*, Mead explicitly asserted the radical environmentalist credo: 'Learned behaviors have replaced the biologically given ones.' (Mead 1949, p. 216).

Part of the impetus for Mead's work throughout her distinguished career was her conviction that prevailing assumptions about psychological sex differences were mistaken and that cultural stereotypes, rather than innate genetic factors, play an important (she would say a decisive) role. We now know that Mead's Samoan research was superficial and that her conclusions were based largely upon innocent deceptions practiced upon her by her young female Samoan informants (Freeman 1992). On the other hand, there is no doubt that there are marked differences in sexual attitudes and practices across human cultures and Mead was assuredly correct in insisting upon both the malleability of human culture and the important role that the culture plays in affecting human behavior. Her mistake, it seems to me, was in conflating human culture, which is relatively easy to change, with human nature, which is not.

B Behaviorism

The middle half of the 20th century was the heyday of behaviorism and many behaviorists tended to be radical environmentalists. One obvious reason for this tendency was the reluctance of behaviorists to theorize about mental mechanisms; if there are no theoretical constructs referring to the brain or mind, if one deals only with S--R (stimulus-response) relationships rather than with S--O--R relationships (where O stands for the organism or person), then it is difficult to account for individual differences, much less genetically determined differences. The founder of the movement, J. B. Watson, is famous for his claim:

> *'Give me a dozen healthy infants, well formed, and my own specified world to bring them up in and I'll guarantee to take any one at random and train him to become any type of specialist I might select---doctor, lawyer, artist, merchant-chief, and, yes, even beggar-man and thief, regardless of his talents, penchants, tendencies, abilities, vocations, and the race of his ancestors.'* (Watson 1924, p. 128).

Nearly 60 years after Watson, the geneticist, Richard Lewontin, made an even more extravagant claim:

> *'Our genetic endowments confer a plasticity of psychic and physical development, so that in the course of our lives, from conception to death, each of us, irrespective of race, class, or sex, can develop virtually any identity that lies within the human ambit'* (Lewontin 1992, from author's précis on the book jacket).

By claiming nearly limitless plasticity for both psychic and physical development, Lewontin suggested that ambitious parents can make their child not only into a doctor, lawyer, or, no doubt, a genius, at will, but also into a tennis champion or a basketball superstar, if that is what the child aspires to. Watson had only hubris and wishful thinking to back up his assertions. Lewontin's challenge was greater because he had 60 years' accumulation of data to contend with, most of it adverse to his startling hypothesis. That he chose to state it anyway is a triumph of ideology over reason and evidence. If it were true, Lewontin's claim would impose a heavy burden of guilt on the parents of children who fail to achieve whatever 'identity' they hoped for; because it is not true, it seems to me that Lewontin's claim is a kind of scandal.

B Nazi Racism

The views and deeds of Adolf Hitler may have had more influence on the nature--nurture question than Marx or Mead or any other thinker. Nazi notions about racial differences and Aryan superiority, the cruel experiments on twins conducted by Dr. Mengele and, above all, the barbaric 'final solution' for the millions alleged to be genetically inferior, made it difficult for an entire generation of civilized people to be dispassionate about the role of heritable differences in human affairs. Radical environmentalism was no longer just an arguable scientific hypothesis but, rather, it became an article of antifascist faith, no longer debatable in politically correct society, not even on University campuses.

B The Decline and Fall of Radical Environmentalism

The long night of radical environmentalism seems, however, to be coming to an end. Throughout the period, occasional studies appeared showing that adoptees resembled psychologically their biological parents more than they resembled the adoptive parents who reared them. Twin and family studies accumulated, showing that the degree of resemblance of pairs of related individuals tends to parallel their degree of genetic relatedness. In recent years there has been a crescendo of twin and adoption studies with mutually corroborative results, and the pendulum of informed public opinion seems to be swinging in the direction toward which these findings point.

It is once again possible for reasonable, educated people to acknowledge not only that we humans differ remarkably from one another in nearly every way imaginable but, moreover, that life would be unbearable, perhaps impossible, if this were not so. 'Individual differences are what make horse races' as Mark Twain pointed out and of course he meant 'horses races' as a metaphor for all of social living. There are still some elderly survivors of the Long Dark lurking about; geneticist Lewontin, psychologist Leon Kamin, and paleontologist Stephen Gould are three of the better known examples. The dawn light hurts their eyes and they want to cling to the old egalitarian dream. They might finally awaken if they were to try seriously to imagine a world populated exclusively by genetic clones of themselves. If every other person had precisely my own innate gifts and limitations I know that life would be hell. In a world comprised of Gould's, or Kamin's, or Lewontin's clones---of anyone's clones---not just the state but civilization itself would wither quickly away. Our species since the earliest times has been dependent for its survival upon a division of labor within social groupings; an organization of specialists being more efficient than a mere congeries of individuals, the extended-family bands formed by our ancestors were therefore greater than just the sum of their component members. Our humanoid division of labor, in turn, has been especially successful because of our within-group differences in talents and interests,

Then caste system is true!

A The human genome

The human genome, the book of instructions for the fabrication of an individual, consists of some 100,000 pairs of genes strung out rather like beads along the DNA molecules packed within each of our 23 pairs of *chromosomes*. This complete genetic blueprint is contained within the nucleus of nearly every cell of the body. Genes serve as patterns for making enzymes and other proteins. Each cell is like a chemical factory in which the enzymes are the chemists that synthesize the special molecules required for life. Most of the genes in the human genome are identical in all normal persons; they constitute the instructions that caused us to develop into Homo sapiens rather than into chimpanzees or butterflies or toadstools. Perhaps one-fourth of our genes are *polymorphic*; from one person to another in the human population there may be two to 20 or more slightly different genes, different *alleles* that can occupy the locus of a given polymorphic gene. For example, there is one pair of genes, located on homologous loci of one of the 23 pairs of chromosomes in the human genome, that primarily determines eye color and there are two different alleles that can occur in that polymorphic locus. If both of your eye-color genes are of the blue type, then your eyes will be predominantly blue (although other genes will influence the particular shade of blue). If either or both of your eye-color genes are of the brown type, then your eyes will be predominantly brown.

The brown-eye gene is said to be *dominant* over the blue type.

Most traits that are of psychological interest, however, are metrical traits that vary in degree from person to person, as stature does. Metrical traits such as stature are *polygenic*, which means they are determined by the combined activity of many polymorphic genes. Your stature is the sum of the lengths of your head, your neck, your trunk and the long bones of your legs. Each of these components is designed by a different group of genes, some of them polymorphic, so that people differ from one another genetically in the lengths of each component part. Other polymorphic genes, such as those that determine the manufacture of the pituitary's growth hormone, influence the length of all the parts so that the components are correlated in respect to size; people with long heads tend to have long femurs also. For these reasons, we say that stature, which is the sum of these component lengths, is determined by the additive action of many different polymorphic genes. As we shall see, most metrical psychological traits also owe an important portion of their variation among people to polygenic variation within the breeding group.

C The great genetic lottery

At conception, the mother's ovum contains in its nucleus one gene more-or-less randomly selected from each of the approximately 100,000 gene pairs in her genome. The fertilizing sperm similarly contains some 100,000 single genes, one from each of the father's complete set of gene pairs. At fertilization, these two random halves of the two parents' genomes combine to form the genome of the child. If only 1000 of the 100,000 gene pairs in the human genome were polymorphic, the number of different, genetically unique offspring from all possible matings would exceed 10 followed by more than 600 zeros (2^{1000} x 2^{1000}). From this we can safely conclude that each child produced by the great lottery of conception possesses a genetic blueprint that differs in at least some respects from any heretofore seen on earth.

B Twins

On the other hand, fortunately for science, there are twins. After conception, the fertilized ovum divides into two identical daughter cells each of which then divides again, and those four daughters again divide---beginning the embryological process that will lead to the creation of a human fetus. About four times in every 1000 conceptions, at one of these early cell divisions during the first two weeks or so, the embryo splits into two equal and separately viable parts. These two half-embryos will continue to develop into separate fetuses and, ultimately, two separate children who, because they began as a single *zygote* or fertilized egg, are known as *monozygotic* (MZ) twins. Because of their origins, MZ twins share the same genome and are genetically identical.

Dizygotic (DZ) or fraternal twins occur when, for reasons still as obscure as the causes of MZ twinning, the mother produces more than one fertile ovum in the same ovulation period. When two (or more) ova are present, each can be fertilized by a different sperm and begin to develop into pairs (or more) of siblings who are genetically related just like ordinary siblings, each of them possessing different random halves of each parent's genome so that, on the average, they will share about half of their polymorphic genes. DZ twins, like ordinary siblings, can share many more than half of their parent's polymorphic genes and thus be remarkably similar, or they may share many fewer than half, and thus be genetically quite different. I have a photograph of one pair of DZ twins, young men who participated in one of our twin studies, who do not appear to be even from the same generation; one looks like the 'swinger' nephew while the other might be his twin's staid, accountant uncle.

Because of their genetic identity, we know that differences within-pairs of MZ twins must be due to environmental causes. Environmental influences, of course, begin well before birth. Indeed, when one considers the almost unimaginable complexity of the steps involved in fabricating a child, it is astonishing that the building process hews as closely as it normally does to the blueprint provided in the genome. MZ twin babies differ in size, often in handedness, and sufficiently in other little ways so that their parents and close friends can generally tell them apart---and these small differences all are due to idiosyncratic environmental differences during development. As they grow up, however, MZ twins usually prove to be remarkably similar in temperament, in aptitudes, and interests, more so than pairs of DZ twins while the latter are generally more similar, both physically and psychologically, than random pairs of unrelated people. It was Charles Darwin's cousin, Sir Francis Galton, who first realized the possibilities of using twins to study the heritability of psychological characteristics.

B Heritability

It is meaningless to ask whether Isaac Newton's genius was due more to his genes or his environment, as meaningless as asking whether the area of a rectangle is due more to its length or its width. But if a certain group of rectangles vary in width between 1 and 10 inches but vary in length from 1 to 100 inches, then we can say, for the group, that the variation in their areas is more affected by the variation in their lengths than by the lesser variation in their widths.[4] Similarly, for people in general, it is meaningful to ask whether their genetic differences are more or less important than their differences in experience in producing the variation we observe in the traits involved in genius. The proportion of the total variation in any trait that is associated with genetic variation is called the *heritability* of that trait.

It is important to understand that the heritability of most psychological traits tells us as much about the given culture as it does about human nature. It is likely (although we cannot be sure of this) that the amount of genetic variability among people within each human culture or breeding group is about the same. But environmental opportunities vary widely both within and between cultures. We would not expect to find a literary genius in a preliterate tribe in Papua New Guinea. In the Middle Ages, peasant children had much less opportunity to develop their intellectual capacities than the children of princes and the heritability of IQ then would have been decreased by this large amount of environmental variation. On the other hand, the fact that the heritability of IQ among the citizens of modern western democracies is on the order of 75 per cent suggests that these cultures have succeeded in providing environmental opportunity that is tolerably equal for all their children (at least for their white children; we are less sure about the heritability of IQ among, e.g., African Americans, for whom the relevant environmental variation may be greater).

C Estimating Heritability

As Galton anticipated, we can make use of both the social experiment of adoption and the biological experiment of twinning to estimate the heritability of traits. Children reared from infancy by adoptive parents will resemble their biological parents solely for genetic reasons. If the adoptive placements are random---if the adoptive parents are unrelated to the biological parents and are not selected to resemble them---then any similarity between the children and their adoptive parents will be due solely to environmental influences provided by the adoptive home. Twins reared together will resemble each other both for genetic reasons and because of their shared rearing experiences. If we assume that these environmental influences are the same for both MZ and DZ twins, then the greater similarity within MZ than DZ pairs must be due to the fact that MZ twins share all their polymorphic genes while DZ twins share, on average, only 50 per cent of theirs. A standard formula computes the heritability of a trait from twice the difference between the correlations of MZ and DZ twins on that trait. As explained below, however, the home environment has surprisingly little lasting effect on most traits so that a more accurate estimate of heritability is provided directly by the correlation between adult MZ cotwins.

Twins who are adopted away in infancy and reared apart represent a rare and valuable combination of Galton's two methods; apart from shared pre-natal influences, reared-apart twins resemble one another solely for genetic reasons. The correlation within pairs of MZ twins reared apart (MZA twins) on any trait is therefore a direct estimate of the heritability of that trait. It turns out that, for most traits, MZA twins resemble one another just about as much as do MZ twins reared together (MZT twins). This fact has two important implications. First, it indicates that being reared together in the same home does not usually serve to make siblings more alike psychologically when they are assessed as adults. This implication is confirmed by studies of unrelated adoptive siblings reared together who, as adults, do not resemble one another psychologically more than do random pairs of people.

The second implication of the fact that MZA and MZT twins are about equally similar is that, since MZA correlations directly estimate trait heritability, we can also use MZT correlations for this purpose. MZA twins are rare and very expensive to study, while there are nearly a million pairs of MZT twins in just the United States and they tend to be wonderfully cooperative about participating in research.

Estimating heritability directly from MZT correlations is not only convenient but also conservative. As we shall see later in this chapter, not all polygenic effects are additive but some, instead, are configural in the sense that the effect on the trait of certain genes may depend on the presence or absence of certain other genes. MZ twins, who share all their genes, will also share all such configural or *emergenic* traits while DZ twins, or parents and children, who share only half their polymorphic genes, may be unlikely to share the full set in the required configuration and are therefore unlikely to share the trait in question (Lykken *et al.* 1992). This means that MZ correlations, which measure the within-pair similarity of the twins, will reflect all sources of genetic similarity while DZ correlations, which reflect mainly just the additive genetic effects, will not tend to reveal the genetic basis of traits that depend on gene configurations.

A Are psychological traits influenced by genetic differences? NCTM

Nearly all psychological traits or tendencies that can be reliably measured turn out to have heritabilities ranging from about 25 to 75 per cent (e.g., Bouchard, *et al.*, 1990). That is, among persons of European ancestry---for IQ, extroversion, neurotic tendency, musical talent, creativity, scientific and other interests, even for religiousness, authoritarianism, and for happiness itself---from one to three-fourths of the variation from person to person is associated with genetic differences between those persons.

How do we know this? In the case of IQ, countless studies have shown that the correlation between pairs of related individuals is proportional to their genetic correlation. MZ twins, whose genetic correlation is 1.0, are twice as similar within pairs in IQ as are DZ twins, whose genetic correlation is .50 and the IQ correlation for DZ twins, in turn, is about four times that of first cousins, whose genetic correlation is .125. Moreover, pairs of unrelated adoptive siblings reared together, once they are grown and out of the adoptive home, correlate in IQ about zero (Bouchard & McGue, 1981). Perhaps the best evidence we have of the heritability of IQ among adults of European ancestry comes from five studies of MZA twins, done in Britain, Denmark, Sweden, and in the United States and totaling 163 of these rare twin pairs. The MZA IQ correlations in these studies (each one a direct estimate of heritability) ranged from .64 to .78 and the grand average correlation was .75 (see McGue *et al.*, 1993).

Extroversion, considered to be one of the handful of basic traits of temperament, for more than 500 pairs of adult MZT twins from the Minnesota Twin Registry, was correlated .54, indicating a heritability of at least 50 per cent. Neurotic tendency or neuroticism showed an MZT correlation of .48 in the same sample. Similar results were found in the Minnesota Study of Twins Reared Apart (Bouchard *et al.*, 1990). About half of the variance in measures of creativity has been shown by the Minnesota studies to derive from genetic variation (Bouchard & Lykken, in press). Self-rated musical talent correlated .69 among these 512 pairs of adult MZT twins but the correlation was smaller, only .44, among the Minnesota MZA twins, suggesting perhaps that this is one trait for which shared family experience does make a difference, augmenting the genetic influence. Strength of scientific interests, in contrast, correlated .45 among MZT and .57 among MZA twins. Interest in religious matters produced correlations above .50 in both groups as did a measure of commitment to traditional values (Lykken *et al.* 1993; Tellegen *et al.* 1988). Altemeyer's well-validated measure of right-wing authoritarianism produced correlations of about .60 in both MZT and in MZA twins. Finally, self-report measures of happiness or subjective well-being show a heritability approaching 50 per cent (Lykken and Tellegen 1995).

B How do genetic differences produce psychological differences?

We cannot yet begin to trace the many steps that intervene between the protein-making activities in which the genes are directly engaged and their ultimate influence upon individual differences in complex psychological traits. We assume that behavioral differences are associated with nervous system differences. Some of the later undoubtedly are 'hard-wired,' biological differences. We can imagine, for example, that some brains work faster or more consistently than others or that the inhibitory mechanisms that enable focused concentration are biologically stronger or more reliable in some brains than in others. But surely many of the brain differences that account for differences in personality, interests, and attitudes are differences in the 'software,' are the result of learning and experience. Yet, if nurture or experience is the proximal cause of individual differences in these traits, how can one explain the strong association between these differences and genetic variation (i.e., nature)?

A major insight of behavior genetics is that one important way in which the genome exerts its influence upon the brain is indirect; the genes help to determine the effective environment of the developing child through the correlation or the interaction of genes with environment (Plomin *et al.* 1977; Scarr and McCartney 1983) *Passive gene-environment correlation* is exemplified by the example of John Stuart Mill, mentioned earlier; bright parents tend to give their children both 'bright genes' and intellectual stimulation. Children reared by athletic biological parents are likely to receive strong bodies as well as athletic encouragement and example. Partly for genetic reasons, some infants are fussy and irritable whereas others are happy and responsive; these differences elicit different responses from their adult caretakers. This process, which of course continues throughout life as our (primarily social) environment reacts differentially to our innate temperament, talents, and physical appearance, is called *reactive* or *evoked* gene-environment correlation. Partly for genetic reasons, different children attend to different aspects of their environment, and seek out or create environments attuned in some way to their genetic makeup. These are examples of *active* gene-environment correlation. The first day in school or a first roller-coaster ride will be a pleasurable excitement for some children, stimulating growth and self-confidence, but a terrifying and destructive experience for other children; that is, the same fire that melts the butter hardens the egg---this is gene-environment *interaction.*

As suggested earlier, a mother's face is an instinctive source of fascination to the non-autistic infant, her smiles are gratifying, and her vocalizations stimulate an innate urge to imitate. These genetic proclivities set the occasion for the learning of language and other essential social skills. As we shall see, the great mathematician, Carl Gauss, taught himself to calculate; when only three, he was able to correct his father's sums and, at age 10, to amaze his teacher. These manifestations of his genetic gifts led the adults in little Gauss's environment to provide him educational opportunities but, even more important, we must assume that the exercise of these gifts was inherently so gratifying that it became canalized. We have as yet not a clue as to the structure of the mental module that facilitates numerical manipulation, but it is easy to see how a module as facile as Gauss's would both create the opportunity and stimulate the effort required to learn the 'software' of mathematical sophistication.

C An illustrative example[5]

A distinguished amateur ornithologist was relieved to learn, at age 11, that he was adopted; this discovery explained for him why he was so different from his parents and their relatives. His adoptive parents did not read or own books but the boy always had a library card and used it regularly. The parents had no talent for nor interest in sports but the youngster, in summer, always carried his baseball mitt with him in case of the chance for a game and won recognition for his prowess at basketball and tennis. This man's biography is a chronicle of active gene-environment correlation, and his quest for experiences compatible with his innate proclivities contrasts with his failure to respond to influences that were readily available but to which he did not resonate. One interest that the other members of his adoptive family shared was in religion but our acquaintance never joined with them in this.

In his late middle-age, this man undertook to discover his biological parentage. He found that his parents had married after he had been given up for adoption and they had produced several other children, his full-siblings, who he discovered to be well educated, active, and successful people like himself. One uncle had been Dean of my university's graduate school. This man's adoptive parents, like most parents, were 'permissive' in the sense that they did not determinedly or effectively shape his behavior nor influence him by their provocative or charismatic example. They might have prevented him from engaging in sports but they merely did not encourage these activities. Had they been readers themselves with quick minds and lively intellectual interests, they might have given different or additional directions to his reading and thought. Had their religious practices been either emotionally or intellectually stimulating, he might well have been more interested in them.

Had this man, in adulthood, found that he had an MZA twin reared by a different set of similarly 'permissive' adoptive parents in some other American town, I believe they would have discovered that they shared not only similar aptitudes and interests, but similar developmental histories as well. Had the cotwin been adopted by the father of John Kennedy or of John Stuart Mill, however, or by Dickens' Fagin, or a Mafia Godfather, then, having traveled markedly different environmental paths, the cotwins' differences might have been as interesting as their residual similarities.

A Emergenesis: Genetic traits that do not run in families

B Secretariat

Old-fashioned hereditarians used to make much of the notion of breeding, a concept that has been pushed to the extreme by exponents of the sport of horse racing. Through careful breeding in the early part of the 19th century, the Thoroughbred race horse got steadily stronger and faster and the record times recorded at old English race courses steadily fell. Along about 1900, however, this curve leveled off as the initial additive variance was bred out of the line. The modest improvements in performance over the next 70 years or so are largely attributed to better training, nutrition, and veterinary techniques.

And then along came Secretariat, a great red American stallion who lay down and took a nap on the day of his Kentucky Derby[6] and then got up and broke the course record, not by just a whisker but by seconds. He did the same thing at Pimlico and then won the Belmont---and the Triple Crown---by more than 30 lengths. Put out at once to stud, where only the most promising mares could afford his fees, Secretariat sired more than 400 foals--- most of them disappointments, none of them remotely in their sire's class. Secretariat had a distinguished lineage, of course, although none of his forebears could have run with him, but whatever he received at the great lottery of his conception could not be easily passed on in random halves. It seems a reasonable conjecture that Secretariat's qualities were configural, emergenic.

At last, in 1988, one of Secretariat's sons, Risen Star, finished third in the Kentucky Derby, won the Preakness, and then won the Belmont by some 14 lengths, albeit a full two seconds behind his sire's record pace. After more than 400 attempts, Secretariat managed to produce a winner; although emergenic traits do not 'run in families,' they are more likely to reappear in a carrier family than in a random lineage. No doubt Risen Star's dam contributed key elements of the emergenic configuration.

Although running speed is, of course, a metrical variable, Secretariat so far exceeded the limits of the normal distribution as to suggest a qualitative difference, a new natural class or taxon. The arena of human achievement appears to offer many similar examples, singular individuals whose accomplishments so far exceed the norm that we classify them separately from the common herd. An important example of such an emergenic class includes those people we call 'geniuses.'

A Genius

> *'How did it come about that a man born poor, losing his mother at birth and soon deserted by his father, afflicted with a painful and humiliating disease, left to wander for twelve years among alien cities and conflicting faiths,... suspected of crime and insanity, and seeing, in his last months, the apotheosis of his greatest enemy---how did it come about that this man, after his death, triumphed over Voltaire, revived religion, transformed education, elevated the morals of France, inspired the Romantic movement and the French Revolution, influenced the philosophy of Kant and Schopenhauer, the plays of Schiller, the novels of Goethe, the poems of Wordsworth, Byron, and Shelly, the socialism of Marx, the ethics of Tolstoy, and, altogether, had more effect upon posterity than any other writer or thinker of that eighteenth century in which writers were more influential than they had ever been before? Here, if anywhere, the problem faces us: what is the role of genius in history...?'*

In this celebrated first sentence of their *Rousseau and revolution*, Will and Ariel Durant (1967) pose as well the psychological problem of genius itself, its mysterious irrepressibility and its ability to arise from the most unpromising of lineages and to flourish even in the meanest of circumstances.

Human genius has always been a problem for both environmentalists and hereditarians to understand. There have been families of genius, of course, the Bernoullis and the Bachs, the Darwins and the Huxleys, the musical Marsalis family; but it is the solitary genius, rising like a great oak in a forest of scrub and bramble, who challenges our understanding. Carl Friedrich Gauss, ranked with Archimedes and Newton as one of the 'Princes of Mathematics,' had uneducated parents, his mother was illiterate, yet the boy had taught himself to read and to do simple arithmetic by the time he was three years old (Buhler 1981). When Gauss was 10, the village schoolmaster thought to keep his large class occupied by computing the sum of the integers from one to 100. Moments later he was startled to see little Carl at his desk with just a single number on his slate; 'there 'tis,' said the boy and then sat with his hands folded while the rest of the class toiled on. In the end, only Carl had the correct answer (Dunnington 1955). The boy had at once perceived that the problem reduced to $(1+100) + (2+99) + ... + (50+51) = 50(101) = 5050$. To believe that some extraordinary accident of experience created this Prince out of ordinary clay is to believe in magic.

The great Hindu mathematician, Srinivasa Ramanujan, whom Mark Kac called a 'magical genius' (Kolata 1987), was reared in a one-room adobe hut in southern India and his mathematical education consisted primarily of two books, both in a foreign language (J.Borwein and P.Borwein 1988). In 1913, with the help of a better-educated friend, Ramanujan wrote from Madras to the great G.H. Hardy at Cambridge, asking his opinion of some 120 theorems which were enclosed. Hardy reports that some of these were classical though obscure; others were in Hardy's own area and he managed to prove them himself:

> *'though with a good deal more trouble than I had expected.... The formulae 110--113 are on a different level and obviously both difficult and deep.... I had never seen anything the least like them before. A single look at them is enough to show that they could only be written down by a mathematician of the highest class. They must be true because, if they were not true, no one would have had the imagination to invent them.'*-- G. H. Hardy 1940

Suppose that Gauss or Ramanujan had been born with a healthy MZ twin who was spirited away to be reared by some country parson in Oxfordshire. Barring cholera or other accident, is it not likely that the parson's surname too would now be immortal? Ramanujan died young without offspring; his parents and one brother apparently were unexceptional. Although Gauss provided rich stimulation and opportunity for his six offspring (by two different and highly cultivated wives), none of them distinguished themselves.[7] But if the genius of these men was prefigured in their genes, why was it never manifested elsewhere in their lineage? The answer is, I think, that genius consists of unique configurations of attributes that cannot be transmitted in half-helpings. What are these ?

Michael Faraday, the premier experimental scientist of his generation, was the self-taught son of a humble blacksmith. Knight refers to Faraday's 'curious mixture, or perhaps we should say compound, of humility and pride.' (Knight 1985); biographers of people of genius often allude in this way to interactions or configurations of their subjects' attributes. We know that Shakespeare, too, came from undistinguished stock, that this foremost wordsmith in our history had numerous siblings and several children, none of whom left any trace---or any word ---behind them (Parrott 1938). An American genius, Benjamin Franklin, was one of a large family and sired two children of his own, all of them members of the common generality of humankind (Garfield 1982). The configurality of genius is dramatically illustrated in the life's work of another extraordinary American, Gutzon Borglum, the sculptor, engineer, inventor, entrepreneur who carved Mount Rushmore (Shaff 1985). However one evaluates the esthetic or the ecological impact of transforming a mountain into a frieze of presidential heads, this prodigious monument will survive the millennia because of the configuration of prodigious talents, each of them essential to the project, that were combined in this singular individual. One of the luminaries of 20th Century science, John von Neumann, was capable of such extraordinary intellectual feats that some of his colleagues were led to suggest that von Neumann's brain 'might be an emergent organ, of a different order of complexity than those of ordinary mortals.' (Campbell 1988, p.103). Genius of this caliber seems to be not just an abundance of one or several components such as IQ, but rather a harmony of attributes, a compound rather than merely a mixture.

A Exceptional endowment or exceptional endeavor?

On reading *Hereditary genius*, by his cousin, Francis Galton, Charles Darwin wrote: 'You have made a convert of an opponent in one sense, for I have always maintained that, excepting fools, men did not differ much in intellect, only in zeal and hard work; and I still think [this] is an eminently important difference.' Thomas Edison, too, believed that genius was ninety-nine per cent perspiration and one per cent inspiration and he 'often work[ed] as many as 112 hours a week' (McAuliffe 1995). Isaac Newton, asked how he made his remarkable discoveries, replied: 'I keep the subject constantly before me and wait until the first dawnings open little by little into the full light' (Andrade 1956).

Hardy told of a visit he made to Ramanujan 'when he was lying ill at Putney. I had ridden in taxi-cab No. 1729, and remarked that the number seemed to me rather a dull one, and that I hoped it was not a bad omen. "No," he replied, "it is a very interesting number; it is the smallest number expressible as a sum of two cubes in two different ways"' (Newman 1956). It was said of Ramanujan that every number was his friend and he had plainly thought about and stored away many interesting facts about most of the lower integers. At the age of 10 or 12 he could recite the values of *pi* and the square root of two to any number of decimal places. Because mathematics was his only interest as a boy, he had failed his scholarship examinations in India. Could it be that Ramanujan's exceptional achievements resulted, not from exceptional endowments but, rather, from the fact that, like Newton, he had kept the one subject of his interest constantly before him since his childhood?

In 1960, at the Center for Advanced Study in the Behavioral Sciences in Palo Alto, Dutch psychologist Adrian de Groot, an expert on the psychology of chess and a chess master himself, simultaneously played and defeated 20 chess duffers like myself. He was not allowed even to see one chess board presided over by two of the Center Fellows who thought themselves to be relatively accomplished players. Well into the game, after they announced the next move they had decided on, de Groot pointed out that their proposed move was impossible; although they had the chess pieces arrayed before them while he had only his mental image to rely on, they got it wrong while he got it right. De Groot himself had played---and been easily beaten---by the future grand master, Bobby Fisher, when Fisher was a boy of twelve. De Groot was careful to point out, however, that even by that early age Fisher had played many thousands of chess games and had derived from this experience a vast armamentarium of chess positions and strategy.

The late Richard Feynman frequently disconcerted physicist colleagues by interrupting their explanations of new findings, to which they had devoted weeks or months of work, and quickly scrawling on a blackboard a more general result of which theirs was just a special case. Was this lightening-like calculation or was Feynman able to draw upon a 'storehouse of previously worked-out---and unpublished---knowledge'? Feynman's biographer, James Gleick, describes a 1960s Caltech seminar at which astrophysicist Willy Fowler proposed that the recently discovered quasars were supermassive stars.

> *'Feynman immediately rose, astonishingly, to say that such objects would be gravitationally unstable. Furthermore, he said that the instability followed from general relativity. The claim required a calculation of the subtle countervailing effects of stellar forces and relativistic gravity. Fowler thought he was talking through his hat. A colleague later discovered that Feynman had done a hundred pages of work on the problem years before. The Chicago astrophysicist Subrahmanyan Chandrasekhar independently produced Feynman's result---it was part of the work for which he won a Nobel Prize twenty years later. Feynman himself never bothered to publish. Someone with a new idea always risked finding, as one colleague said, "that Feynman had signed the guest book and already left."'*

(Gleick 1992)

K.A. Ericsson (1990; Ericsson and Charness 1994; see also the chapter by Lehmann and Ericsson in this volume) has shown that remarkable feats of memory can be achieved by apparently unremarkable people after extensive practice. He has also shown, as the above examples attest, that most examples of exceptional performance, including those by people known as geniuses, are preceded by years of intense and single-minded application and practice.

Ericsson and his colleagues have amassed a truly impressive body of evidence in support of their view that it is deliberate and intensive practice---rather than differences in native ability---that separates elite performers from the rest of us. With hundreds of hours of guided practice spaced over weeks or months, ordinary college students can learn to increase their digit span---the number of digits correctly repeated after hearing them read only once at a rate of one per second---by 10 times. There are techniques of calculation with which, after extensive practice, one can accomplish feats of mental arithmetic impossible for the untrained mind. The conditioning and practice of elite athletes changes their muscle strength, aerobic capacity, the speed of their reflexes, the size of their hearts, and even the relative proportions of fast and slow-twitch muscle fibers, and it is these practice-produced effects rather than just native ability that is responsible for extraordinary athletic performance. The celebrated violinist at last night's concert almost certainly practices more intensely and consistently than the members of the orchestra's violin section. Elite performers tend to do less well as they get older but many of them also tend to practice less intensely as they age.

Ericsson believes not only that genius and exceptional performance generally depends upon intensive years of practice but, moreover, that most of us, given the same teachers and similar preparation, could do as well as these elite performers do. Ericsson and Charness (1994, p.744) are willing to acknowledge that genetic differences in temperament and 'preferred activity level' may determine which of us go for the gold but, curiously, they cling to the assumption that individual genetic differences in both physical and mental capacities are not important, perhaps nonexistent. This would require us to believe that most children could acquire perfect pitch and the ability to reproduce compositions after a single hearing if only we listened to music as long and as intently as Blind Tom and Leslie Lemke did, or draw from memory a construction site after a brief glance, as Sack's savant Steven did. We should have to suppose, as Lewontin seems to imply, that almost any of our children could become world-class athletes, given the right training and the appropriate temperament. We must also accept the proposition that little Gauss's ability to correct his father's arithmetic at three and confound his school master at ten resulted, not from extraordinary mental hardware, but from mental software acquired through self-directed practice in an intellectually unstimulating environment.

Those of us who have studied MZ twins reared apart from one another find these assumptions, which are the concept of radical environmentalism in different clothes, incredible. We cannot believe that MZA twins correlate .75 in IQ merely because, in their separate environments, their similarities in temperament led them to indulge in very similar amounts of practice on very similar topics. One set of Bouchard's MZA triplets each were on their high school's wrestling team before they ever knew of each other's existence. I think this was because they shared a configuration of genetic traits, physical and mental, that made them interested in---and good at---this particular sport. More generally, I think that one reason, although not the only reason, that most elite performers engage in the dedicated pursuit of excellence in their specialty is that they are naturally good at it from the start so that their early efforts are rewarded by early success.

I think we must agree with Ericsson, however, that works of genius tend to be the product of minds enriched by years of concentrated effort. Isaac Newton often became so caught up in cerebration that he would forget to eat or sleep. Edwin Land, inventor of the instant Polaroid camera and of a sophisticated computational theory of color vision, sometimes worked at his desk for 36 hours or more, unaware of the passage of time until he felt faint on standing up. Similar stories were told of Edison. It does not follow, however, that these were ordinary minds to begin with.

Edison, Feynman, Land, and Newton all from their boyhood had intense curiosity, an enthusiasm or zeal for discovery and understanding. Each of them was able to take seriously hypotheses that others thought to be implausible (or had not thought about at all). All four possessed a kind of intellectual arrogance that permitted them to essay prodigious tasks, to undertake to solve problems that most of their contemporaries believed to be impossible. And each of them had quite extraordinary powers of concentration. Even Darwin, plagued as he was by physical miseries that would have invalided most men, somehow mustered mental energy enough to pursue the painstaking researches that yielded the thousands of facts with which he built his theory and defended it against so many critics.

B Mental energy

Most important — motivation, interest

What is this 'mental energy' that powers minds of genius, from Newton to Mozart to Ramanujan? Surely it is partly a function of motivation. I can think longer and harder about ideas that interest me or, to phrase it differently, about problems I see to be steps toward some goal that I covet. But I cannot think long and hard about Fermat's Last Conjecture because I haven't a clue about how to solve that problem, no matter how much I should enjoy being the one to achieve that objective. If, as a boy, I had been able to run faster or kick a football further than my fellows could, I might have worked long and hard on improving those talents. But I could not and I did not. Who can doubt that one reason Bobby Fisher played so many games of chess so young was that he found from the start that he had a gift for the game? Yet, mental energy is not entirely a function of motivation and a sense of making progress. I have an eminent colleague, the psychologist Paul Meehl, who has always been able to read at least six books to my one. He does not read faster than I do nor with greater initial interest. I do not believe that he is more strongly motivated than I am to learn what the books have to teach (although, with his superior memory, he does have the advantage of knowing that more of what he reads will stay with him!). The fact is that, although I am probably his equal in physical energy, while reading technical material my eyelids begin to droop long before his do. I have spent in my life untold hours happily reading, writing, analyzing data, writing computer programs, full of the sense of enjoyable accomplishment---but never for more than four or five hours at a stretch, 10 or 12 hours in a day. It is inconceivable that I could work productively at any intellectual task for 36 consecutive hours, not if my life depended on it.

Most recognized geniuses, in contrast, seem to possess remarkable powers of concentration. Archimedes's 'awesome mathematical talent was augmented by an ability to devote himself singlemindedly to any problem at hand in extraordinary periods of intense, focused concentration. At such times, the more mundane concerns of life were simply ignored. We learn from Plutarch that Archimedes would:

> *"forget his food and neglect his person, to that degree that when he was occasionally carried by absolute violence to bathe or have his body anointed, he used to trace geometrical figures in the ashes of the fire, and diagrams in the oil on his body, being in a state of entire preoccupation, and, in the truest sense, divine possession with his love and delight in science."'* (Dunham 1990).

Multiplexing ?

Referring to Newton, John Maynard Keynes has said:

> *'His peculiar gift was the power of holding continuously in his mind a purely mental problem until he had seen straight through it. I fancy his preeminence is due to his muscles of intuition being the strongest and most enduring with which a man has ever been gifted. Anyone who has ever attempted pure scientific or philosophical thought knows how one can hold a problem momentarily in one's mind and apply all one's powers of concentration to piercing through it, and how it will dissolve and escape and you find that what you are surveying is a blank. I believe that Newton could hold a problem in his mind for hours and days and weeks until it surrendered to him its secret. Then being a supreme mathematical technician he could dress it up, how you will, for purposes of exposition, but it was his intuition which was pre-eminently extraordinary---"so happy in his conjectures", said de Morgan, "as to seem to know more than he could possibly have any means of proving."'* -- J. M. Keynes 1956

Psychologists are not yet able to measure individual differences in mental energy, independent of motivational factors, but there can be no doubt at all that some people have more of this resource than others do and I am confident that these are differences in native endowment. If I seem to be claiming here to know, like Newton, more than I possibly have any means of proving, let me explain how I do know it. There is no doubt that now, at age 67, my own stores of mental energy---my poor 'muscles of intuition'---are considerably weaker now than they were at 27. In his *A Mathematician's Apology* (1969), G.H. Hardy remarks that 'mathematics, more than any other art or science, is a young man's game...I do not know an instance of a major mathematical advance initiatied by a man past fifty.' (p.78). It seems a reasonable postulate that powers which vary within an individual at different times must also vary between individuals at any time. Quoting Hardy again, Newton's 'greatest ideas of all, fluxions and the law of gravitation, came to him about 1666, when he was twenty-four.' (p.78). Surely Newton's mind, at fifty, was even more enriched by years of concentrated effort than it was at twenty-four, yet he had given up mathematics by age fifty, presumably because some power(s?) of mind, already in full flood at twenty-four, had ebbed.

If Edison, Fineman, Gauss, and Newton had all been intensely tutored from the age of three by brilliant parents, as J.S. Mill was, then I might at least consider the possibility that my own mental muscles might have been stronger if my own parents had been more demanding. But they were not and I will not. 'When you see [Edison's] mind at play in his notebooks, the sheer multitude and richness of his ideas makes you recognize that there is something that can't be understood easily---that we may never be able to understand.' (historian Paul Israel, quoted in McAuliffe 1995). I think what lies at the heart of these mysteries is genetic, probably emergenic. The configuration of traits of intellect, mental energy, and temperament with which, during the plague years of 1665--6, Isaac Newton revolutionized the world of science were, I believe, the consequence of a genetic lottery that occurred about nine months prior to his birth, on Christmas day, in 1642.

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[1] Portions of this chapter were modified, with permission, from: Lykken et al., (1992) and from Lykken (1995).

[2] Although radical environmentalism often is adopted for political or ideological reasons, "radical" in this context is used in the sense of "extreme."

[3] For a sophisticated modern assertion of the Marxist opposition to "biological determinism" see Lewontin, Rose, and Kamin (1984).

[4] The question about Newton would be meaningful if we had measures, in standard score form that

permits comparisons with people in general, of his genetic potentials and of his environmental influences.

[5] This man, an acquaintance of my colleague, J.J. Bouchard, Jr., was kind enough to provide our research group with an outline of his autobiography.

[6] The Kentucky Derby, the Pimlico, and the Belmont Stakes comprise the three great annual events---the "crowning" events---of American Thoroughbred flat-racing

.[7] Gauss's second son, Eugene, emigrated to the United States in 1830, enlisted in the army, and later went into business in Missouri. Eugene is said to have had some of his father's gift for languages and the ability to perform prodigious arithmetic calculations, which he did for recreation after his sight failed him in old age.