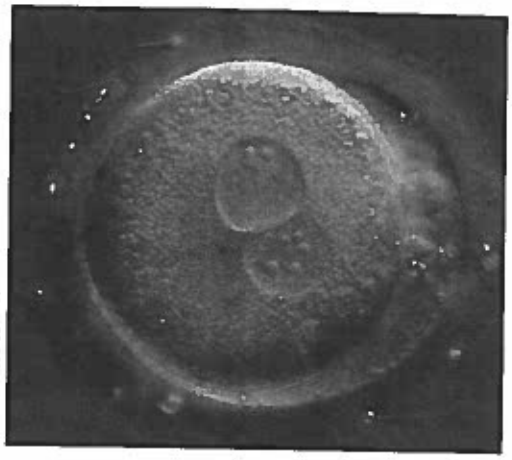


LENNART NILSSON/CAMERA

The Moment of Conception This ovum is about to become a zygote. It has been penetrated by a single sperm, whose nucleus now lies next to the nucleus of the ovum. Soon, the two nuclei will fuse, bringing together about 20,000 genes to guide development.

Life Begins

Every person starts life as a single cell, called a **zygote.** Each zygote is distinct from any other human cell ever created, yet that cell contains genes that have been passed down for hundreds of thousands of years. The first hours of development are a compelling example of both the universal and the unique characteristics of each human.

Genes and Chromosomes

First, the universal. All living things are composed of cells that promote growth and sustain life according to instructions in their molecules of **DNA (deoxyribonucleic acid)** (see Figure 2.1). Each molecule of DNA is on a **chromosome.** Chromosomes contain units of instructions called **genes,** with each gene located on a particular chromosome.

With one important exception, every cell of a normal human being has a copy of that person's 46 chromosomes, arranged in 23 pairs. That one exception is the reproductive cell, called a **gamete.** Each gamete—*sperm* in a man and *ovum* in a woman—has only 23 chromosomes, one from each of a person's 23 pairs.

At conception, the genes on each of the 22 non-sex chromosomes from the sperm pair up with the genes on the same 22 chromosomes from the ovum. For instance, an eye-color gene from the father on chromosome 15 connects with an eye-color gene from the mother on the zygote's other chromosome 15.

If the match between the two genes is exact (as it usually is since most genes are identical for every human), the person is said to be *homozygous* (literally, "same zygote") for that trait.

However, some genes come in slightly different versions, as is obvious for eye-color genes. Each version is called an **allele.** Genes that have various alleles are called *polymorphic* (literally, "many forms"). If the allele of a particular gene from the father differs from the allele of that gene from the mother, the person is said to be *heterozygous* (literally, "other zygote").

zygote
The single cell that is formed from the fusing of two gametes, a sperm and an ovum.

DNA (deoxyribonucleic acid)
The molecule that contains the chemical instructions for cells to manufacture various proteins.

chromosome
One of the 46 structures made of DNA (in 23 pairs) that almost every cell of the human body contains and that, together, contain all the genes. Other species have more or fewer chromosomes.

gene
A small section of a chromosome, the basic unit for the transmission of heredity. A gene consists of a string of chemicals that provide instructions for the cell to manufacture certain proteins.

gamete
A reproductive cell, that is, a sperm or an ovum that can produce a new individual if it combines with a gamete from the other sex to form a zygote.

allele
Any of the possible forms of a gene. Genes with various alleles are called polymorphic.

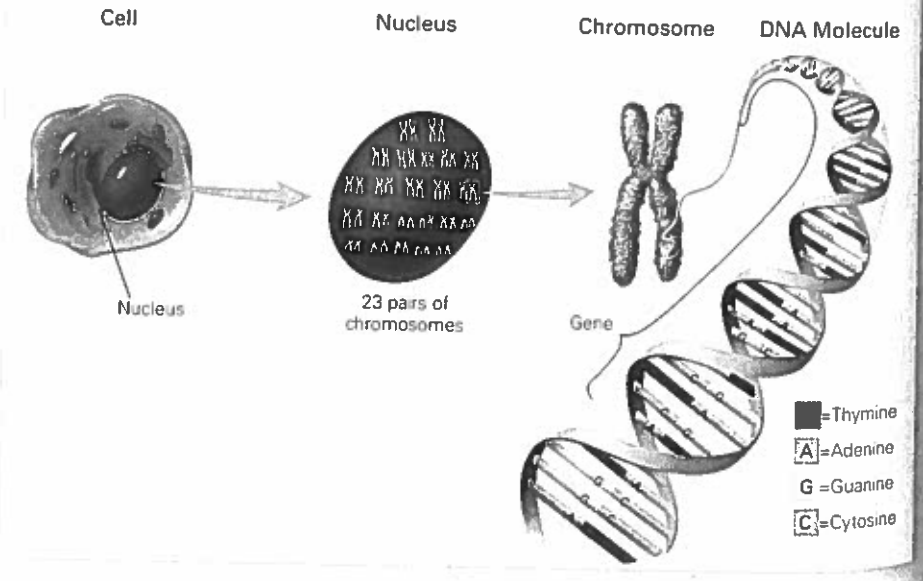


FIGURE 2.1 How Proteins Are Made The genes on the chromosomes in the nucleus of each cell instruct the cell to manufacture the proteins needed to sustain life and development. The code for a protein is the particular combination of four bases, T-A-G-C (thymine, adenine, guanine, and cytosine).

Variations Among People

Now, the unique. Since each gamete has only 23 chromosomes (one from each pair of the parent's 23 pairs), each man or woman can produce 2^{23} different gametes—more than 8 million versions of their chromosomes (actually 8,388,608).

When a sperm and an ovum combine, the zygote they create is a new cell in which the genes on one of 8 million possible sperm from the father interact with the genes on one of the 8 million possible ova from the mother. Your parents could have given you an astronomical number of siblings, each unique.

TRIPLET VARIATIONS More variations occur because the DNA code on those chromosomes contains about 3 billion pairs of chemicals organized in triplets (sets of three pairs), each of which specifies production of one of 20 possible amino acids. Those amino acids combine to produce proteins, and those proteins combine to produce a person. Small variations, mutations, or repetitions (called *copy number variations*) in the base pairs or triplets could make a notable difference in the proteins and thus, eventually, in the person.

And that is what happens. Some genes have triplet transpositions, deletions, or repetitions not found in other versions of the same gene. Not only do alleles affect the person, but also genes "are themselves transmitted to individual cells with large apparent mistakes—somatically acquired deletions, duplications, and other mutations" (Macosko & McCarroll, 2013, p. 564).

NOT JUNK All these variations already make each person unique, but there is more. Additional DNA and RNA (another molecule) surround each gene. In a process called *methylation*, this material enhances, transcribes, connects, empowers, silences, regulates, and alters genes. This material used to be called *junk*—but no longer. As one team explains:

> One of the most important discoveries in genetics in the last 10 years is that the vast majority of trait-associated DNA variations occur in regions of the genome that were once labeled a 'junk DNA' because they do not code for proteins. We now know that these regions harbor genetic elements that control where, when, and to what extent specific genes are expressed.
>
> *[Turey & Sethupathy, 2013, p. 705]*

Pause for a moment to consider how significant this is. Obviously genes are crucial, but even more crucial is whether or not a gene is expressed. RNA turns some genes and alleles off. In other words, a person can have the genetic tendency for a particular trait, disease, or behavior, but that tendency might never appear in that person's life because it was never turned on.

Think of turning on a lamp. Many elements must be in place before the room is illuminated. The lamp needs an unspent bulb screwed into the socket, a cord correctly plugged in, an electric bill paid, and an electricity source from the grid. Yet the room will be dark until the switch is flipped. That's RNA.

Researchers who sought a single gene for, say, schizophrenia, or homosexuality, or even a tiny detail such as memory for chemistry formulas, have been disappointed. No such single genes exist. Instead, almost every trait arises from a combination of genes, each with a small potential impact, each dependent on epigenetic factors that determine whether that gene is expressed or silenced (Ayyamathan, 2014).

GENOTYPE AND PHENOTYPE For each individual, the collection of his or her genes is called the **genotype.** It was once thought that the genotype led directly to facial characteristics, body formation, intelligence, personality, and so on, but this is much too simplistic.

genotype
An organism's entire genetic inheritance, or genetic potential.

phenotype
The observable characteristics of a person, including appearance, personality, intelligence, and all other apparent traits

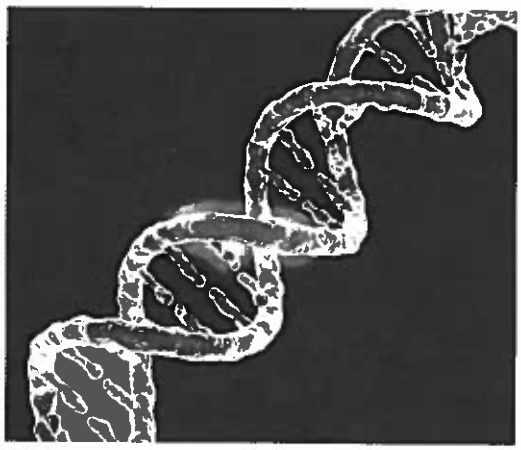
The **phenotype,** which is a person's actual appearance and behavior, reflects much more than the genotype. The genotype is the beginning of diversity; the phenotype is the actual manifestation of it, the result of "multiple interactions among numerous genetic and environmental factors" (Nadeau & Dudley, 2011, p. 1015).

Diversity not only distinguishes each person (you can immediately spot a close friend in a crowd) but also allows adaptation. We are the only species that thrives on every continent, from the poles to the equator, eating blubber or locusts as the case may be.

One of the best parts of our adaptive genes is that we teach each other. If you or I suddenly found ourselves in a climate we had never experienced, we would quickly learn how to dress, where to sleep, and what to eat by observing people who had already adapted to that place. If our descendants stayed in the new place, eventually our great-great-grandchildren would have genes slightly changed from ours, to help them thrive.

Thanks to our genetic diversity, even devastating diseases do not kill us all. For instance, a few people have alleles that defend them from HIV/AIDS (Aouizerat et al., 2011). Similarly, genotype differences allowed some of our ancestors to survive tuberculosis, malaria, the Black Death, and other scourges. In the most recent manifestation, a few people may have a genetic defense against Ebola, remaining healthy despite contact with body fluids from someone sick with that highly contagious virus (Rasmussen et al., 2014).

THINK CRITICALLY: You do not have some condition (perhaps addiction or asthma or anxiety) that troubles another member of your family. Do you credit genes or upbringing?



MEDICAL ANIMATION/SCIENCE SOURCE

Twelve of Three Billion Pairs This is a computer illustration of a small segment of one gene. Even a small difference in one gene can cause major changes in a person's phenotype.

More on Shared and Divergent Genes

The entire packet of instructions that make a living organism is called the **genome.** There is a genome for every species, from *Homo sapiens* to the smallest insect, even for every kind of plant. A worldwide effort to map all the human genes led to the *Human Genome Project,* which was virtually completed in 2003.

genome
The full set of genes for a certain species

SURPRISES FROM THE HUMAN GENOME PROJECT Until 2001, scientists thought humans had about 100,000 genes, but that turned out to be a gross overestimate. The Human Genome Project found only about 20,000 to 23,000 genes.

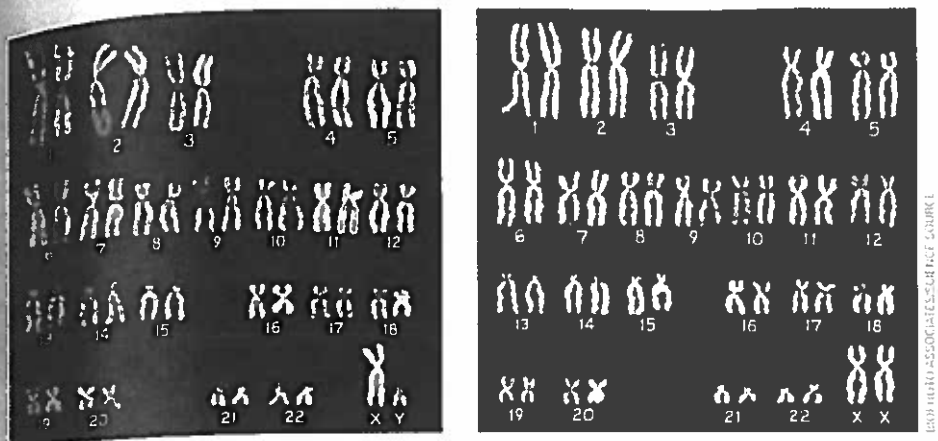
Genomes from other creatures led to more surprises: Dogs and mice have more genes than humans, and mice have several times more. The precise count is still unknown, partly because of another surprise: It is not always clear where one gene ends and another begins.

Another surprise is that any two men or women, of whatever ethnicity, share 99.5 percent of their genetic codes. Not only are all humans much more alike than some thought, but also humans are much more similar to other mammals than most people imagined.

The genetic codes for humans and chimpanzees are 98 percent the same (although chimp genes are on 48, not 46, chromosomes), and the genomes for every other mammal are at least 90 percent the same as for people. All these shared genes allow scientists to learn about human genetics from other creatures, especially mice, by transposing, deactivating, enhancing, and duplicating their genes.

Although human similarities are astounding, differences that seem minor are significant, too. Some alleles are relatively common, detectable, and understood. For example, the apoE4 allele, unlike apoE2, renders a person more susceptible to AIDS, heart disease, and Alzheimer's disease.

But many alleles have unknown effects, or perhaps no effects. And some polymorphisms are very rare: Each of us probably has one or two alleles that only one person



Uncertain Sex Every now and then, a baby is born with "ambiguous genitals," meaning that the child's sex is not abundantly clear. When this happens, a quick analysis of the chromosomes is needed, to make sure there are exactly 46 and to see whether the 23rd pair is XY or XX. The karyotypes shown here indicate a normal baby boy *(left)* and girl *(right)*.

in a million has. We have learned a lot about genes, and that makes us realize how much we do not know.

Research on breast cancer, for instance, has found two relatively common genes, named BRCA1 and BRCA2, that make it likely a woman will develop breast cancer if she lives long enough. Less than a fourth of the women who develop breast cancer carry one or the other of those genes. Perhaps another fourth have one of ten other known alleles that increase the risk, although how much and in what way is "ambiguous" (Kean, 2014, p. 1458).

That omits half of the millions (estimated at one woman in eight) who will develop breast cancer. Their disease is caused by a combination of genes, alleles, mutations, diet, and other epigenetic factors—but no one knows what and how. If we knew, millions of lives might be saved.

THE 23RD PAIR The difference between one person and another—and between one species and another—begins with the genes, but it is much more epigenetic than genetic. Consider sex differences, which originate from one gene on one chromosome, the Y, which is half of the 23rd pair.

In females, the 23rd pair is composed of two large X-shaped chromosomes. Accordingly, it is designated **XX.** In males, the 23rd pair has one large X-shaped chromosome with many genes and one quite small chromosome, with only a few genes, which is Y-shaped. That 23rd pair is called **XY.**

XX
A 23rd chromosome pair that consists of two X-shaped chromosomes, one each from the mother and the father. XX zygotes become females.

XY
A 23rd chromosome pair that consists of an X-shaped chromosome from the mother and a Y-shaped chromosome from the father. XY zygotes become males.

Because a female's 23rd pair is XX, every ovum contains one X or the other—but always an X. Because a male's 23rd pair is XY, when his 46 chromosomes divide to make gametes, half of his sperm carry an X chromosome and half carry a Y.

The Y chromosome has a gene (SRY) that directs the developing fetus to make male organs. Thus, the sex of the developing organism depends on which sperm penetrates the ovum—either an X sperm, which creates a girl (XX), or a Y sperm, which creates a boy (XY) (see Figure 2.2).

At conception, there are about 120 males for every 100 females, perhaps because Y sperm swim faster and reach the ovum first (remember, they carry fewer genes, so they are lighter than the X sperm).

However, male embryos are more vulnerable than female ones (because of fewer genes, again?), so they are less likely to survive prenatally: At birth the boy/girl ratio is about 104:100.

The sex ratio seems to be nature, not nurture, but the environment already has an effect. The United Nations reports that the natural sex ratio at birth in most developed nations (such as the United States) is 105:100, but it is lower in the poorest nations, probably because hunger and lack of prenatal care harms more male fetuses

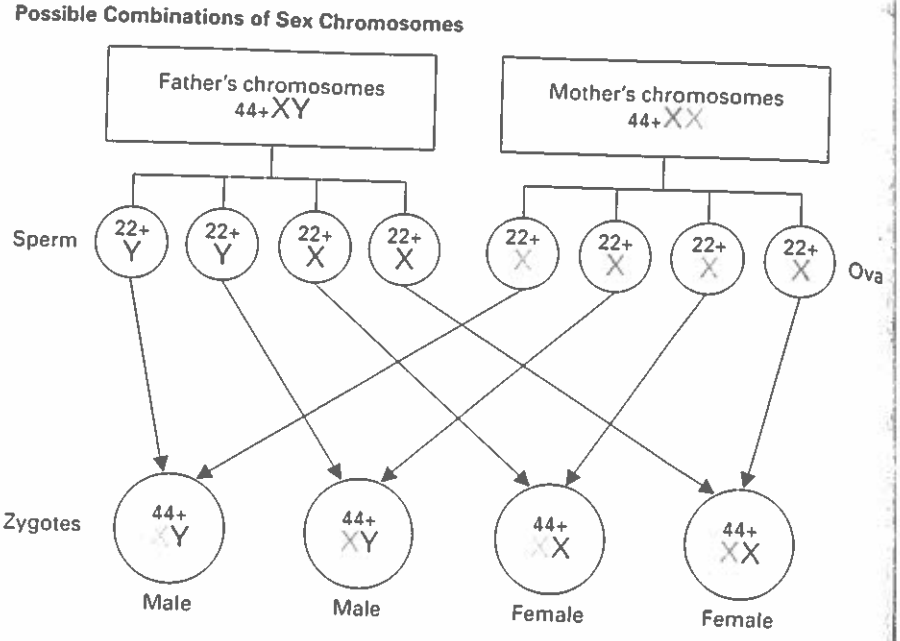


FIGURE 2.2 Determining a Zygote's Sex Any given couple can produce four possible combinations of sex chromosomes, two lead to female children and two, to male. In terms of the future person's sex, it does not matter which of the mother's Xs the zygote inherited. All that matters is whether the father's Y sperm or X sperm fertilized the ovum. However, for X-linked conditions it matters a great deal because typically one, but not both, of the mother's Xs carries the trait.

than female. In Angola, the ratio is 103:100 (United Nations, Department of Economic and Social Affairs, 2015).

Biological sex differences become cultural as soon as a newborn is named and wrapped in blue or pink. Indeed, cultural differences can begin before conception. Consider sex selection.

OPPOSING PERSPECTIVES

Too Many Boys?

In past centuries, millions of newborns were killed because they were the wrong sex, a practice that is considered murder today. Now the same goal is achieved in three ways: (1) by inactivating X or Y sperm before conception, (2) by inserting only the male or female zygotes after in vitro conception, or (3) by aborting XX or XY fetuses.

Should sex selection be illegal? It is, in at least 36 nations. It is not in the United States (Murray, 2014).

Why do some nations allow sex selection, and others not? Should governments legislate morals, or choose one culture over another? People disagree (Wilkinson, 2015).

One nation that forbids prenatal sex selection is China. This was not always so. In about 1979, China began a "one-child" policy, urging and sometimes forcing couples to have only one child. That achieved the intended goal: Severe poverty was almost eliminated.

But advances in prenatal testing, and the Chinese tradition that sons, not daughters, must care for aged parents, led many couples to want their only child to be a boy. Among the unanticipated results: (1) since 1980 an estimated 9 million abortions of female fetuses; (2) between 1980 and 2006,

MANISH SWARUP/AP PHOTO

My Strength, My Daughter That's the slogan these girls in New Delhi are shouting at a demonstration against abortion of female fetuses in India. The current sex ratio of children in India suggests that this campaign has not convinced every couple.

adoption of an estimated 200,000 newborn girls by Westerners; (3) in 2010, far more unmarried young men than women.

In 1993, the Chinese government forbade prenatal testing for sex selection. In 2007, China became much less likely to allow adoption, and the number of children from China adopted by Westerners plummeted from 14,496 in 2005 to 4,418 in 2011. In 2013, China rescinded the one-child policy. Yet the infant boy/girl ratio is still about 117:100 (United Nations, Department of Economic and Social Affairs, 2015).

Sex preferences are apparent everywhere. One elderly Indian man said, "We should have at least four children per family, three of them boys" (quoted in Khanna, 2010, p. 66). Couples of Asian ancestry in the United States also have more boys than girls (Puri et al., 2011). In some Western nations, including Germany, girls are preferred—both as newborns and as caregivers of the old (Wilhelm et al., 2013).

The argument in favor of sex selection is freedom from government interference. Some fertility doctors and many individuals believe that each couple should be able to decide how many children to have, and what sex they should be (Murray, 2014).

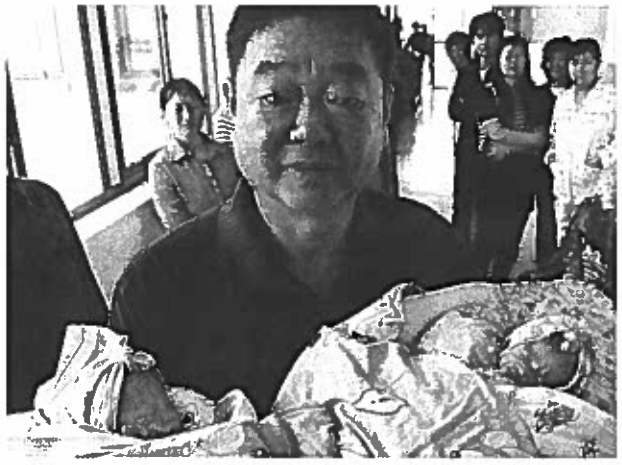
The argument against sex selection is that society might suffer. For instance, 30 years after the one-child policy began, many more young Chinese men than women die. Why? Developmental psychology suggests an answer. Unmarried young men everywhere take risks to attract women and become depressed if they remain unpartnered. That increases the risk of early death, from accidents, suicide, drug overdoses and poor health practices.

Other problems may occur that affect a society that has many males. Males have higher rates than females of learning disabilities, drug addiction, suicide, homicide (as victims and killers), and heart attacks. They are more likely to vote for wars and advocate long sentences for criminals.

But wait: Genes do not *determine* behavior. Every sex difference is influenced by culture. Even traits that originate with biology, such as the propensity to heart attacks, are affected more by environment (in this case, diet and cigarettes) than by XX or XY chromosomes. Perhaps nurture would change if nature produced more males than females.

Already, medical measures and smoking reductions have reduced heart attacks in men. In the United States in 1950, among people under age 65, four times as many men as women died of heart disease. By 2010, the rate was lower for both sexes, but especially for men, 2:1 not 4:1. Lifelong, cardiovascular deaths are now close to sex-neutral (Centers for Disease Control, 2015). Similarly, every gender difference is influenced by nurture.

Might laws against prenatal sex selection be unnecessary if culture shifted? "Might" . . . "if" . . . Critical thinking is needed; both opposing perspectives make sense.



STRDEL/AFP/GETTY IMAGES

Mama Is 60 Wu Jingzhou holds his newborn twin daughters, born to his 60-year-old wife after in vitro fertilization. Ordinarily, it is illegal in China, as in most other nations, for women to have children after menopause. But an exception was made for this couple since the death of their only child, a young woman named Tingting, was partly the government's fault.

Twins

There is one major exception to genetic diversity. Although every zygote is genetically unique, not every newborn is.

About once in every 250 human conceptions, the zygote not only duplicates but splits apart completely, creating two, or four, or even eight separate zygotes, each genetically identical to that first single cell (see Visualizing Development, page 54). If each separate cell implants and grows, multiple births occur, usually with every newborn genetically identical. This does not seem to be genetic, as the rate is similar—and rare—in every ethnic group.

One separation results in **monozygotic twins,** from one *(mono)* zygote. Two or three separations create monozygotic quadruplets or octuplets. (An incomplete split creates *conjoined twins,* formerly called Siamese twins.)

Because monozygotic multiples originate from the same zygote, they have virtually identical genetic instructions for physical appearance, psychological traits, vulnerability to diseases, and everything else. However, because nurture always affects nature, even before birth, identical twins do not have exactly the same phenotype.

monozygotic twins
Twins who originate from one zygote that splits apart very early in development. (Also called *identical twins.*)

LaunchPad

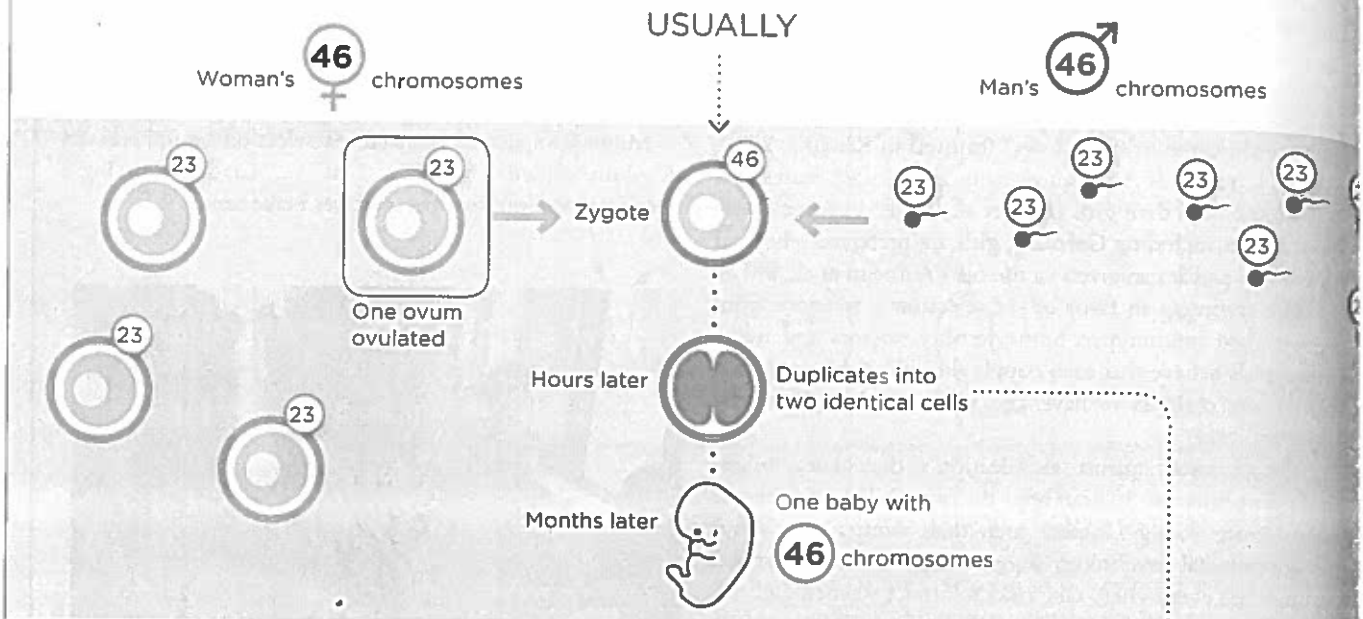
Video Activity: Identical Twins: Growing Up Apart gives a real-life example of how genes play a significant role in people's physical, emotional, social, and mental development.

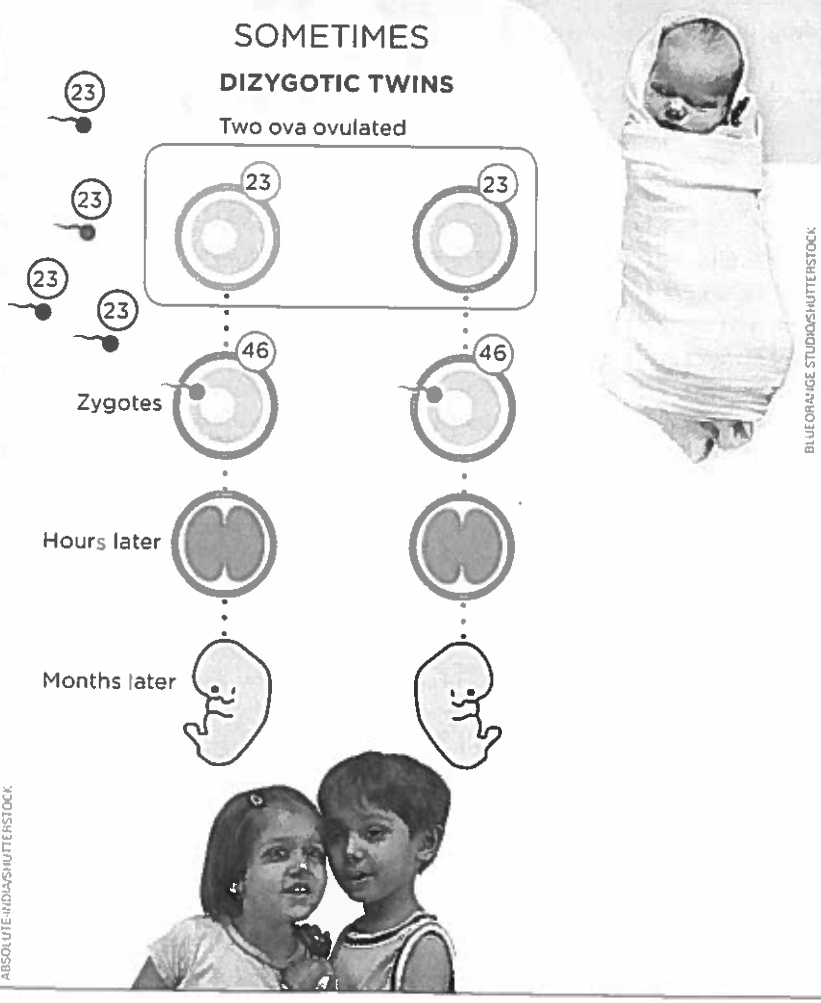
MANISH SWARUP/AP PHOTO

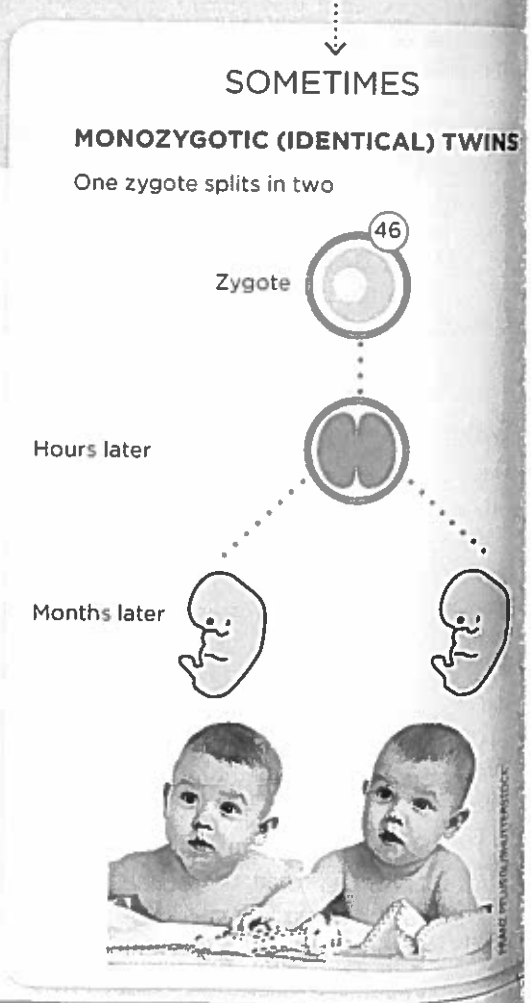
VISUALIZING DEVELOPMENT

One Baby or More

Humans usually have one baby at a time, but sometimes twins are born. Most often they are from two ova fertilized by two sperm (*lower left*), resulting in dizygotic twins. Sometimes, however, one zygote splits in two (*lower right*), resulting in m zygotic twins; if each of these zygotes splits again, the resu monozygotic quadruplets.







ABSOLUTE INDIA/SHUTTERSTOCK

BLUE ORANGE STUDIO/SHUTTERSTOCK

FRANZ PFLUEGL/SHUTTERSTOCK

Usually, monozygotic twins develop their own identities while enjoying twinship. They might both have inherited athletic ability, for instance, but one chooses basketball and the other, soccer. One monozygotic twin writes:

> Twins put into high relief *the* central challenge for all of us: self-definition. How do we each plant our stake in the ground, decide how sensitive, callous, ambitious, cautious, or conciliatory we want to be every day? . . . Twins come with a built-in constant comparison, but defining oneself against one's twin is just an amped-up version of every person's life-long challenge: to individuate—to create a distinctive persona in the world.
>
> *[Pogrebin, 2010, p. 9]*

Dizygotic twins, also called *fraternal twins,* are born three times as often as monozygotic twins. They began life as two zygotes created by two ova fertilized by two sperm. (Usually, the ovaries release only one ovum per month, but sometimes two or more ova are released.) Dizygotic twins, like any offspring from the same two parents, have half their genes in common. Their phenotypes may differ (about half are male–female pairs) or they can look quite similar, again like other siblings.

dizygotic twins
Twins who are formed when two separate ova are fertilized by two separate sperm at roughly the same time. (Also called *fraternal twins*.)

The incidence of multiple ovulation is influenced by genes, and thus is more common in some ethnic groups than others. For example, about 1 in 11 Yorubas in Nigeria is a twin, as are about 1 in 45 European Americans, 1 in 75 Japanese and Koreans, and 1 in 150 Chinese.

Age matters, too: Older women more often double-ovulate. Not all twin conceptions result in twin births. Sometimes an early sonogram reveals two developing organisms, but later only one embryo continues to grow. This *vanishing twin* phenomenon may occur in about 12 percent of pregnancies (Giuffrè et al., 2012).

Because genes endure lifelong, if a woman has one set of twins, she is more likely to have another set (Painter et al., 2010). Her daughters also have a 50/50 chance of inheriting her twin-producing X, and hence they are likely to have twins themselves. Her sons are not likely to have twins because they do not ovulate. But her son's daughters may have twins because their X is from his mother, and half the time it is the multiple-ovulation X.

Genetic Interactions

No gene functions alone. Thus, almost every trait is *polygenic* (affected by many genes) and *multifactorial* (influenced by many factors). Almost daily, researchers describe new complexities in multifactorial interaction. Here we describe some of those complexities.

Genetic Mix Dizygotic twins Olivia and Harrison have half their genes in common, as do all siblings from the same parents. If the parents are close relatives, who themselves share most alleles, the non shared half is likely to include many similar genes. That is not the case here, as Mother (Nicola) is from Wales and Father (Gleb) is from the nation of Georgia, which includes many people of Asian ancestry. Their phenotypes, and the many family photos on the wall, show many additive genetic influences.

additive gene
A gene that contributes to the phenotype, usually with other additive genes.

dominant–recessive pattern
The interaction of a pair of genes in such a way that the phenotype reveals the influence of one (the dominant gene) more than that of the other (the recessive gene).

carrier
A person whose genotype includes a gene that is not expressed in the phenotype. Such an unexpressed gene occurs in half the carrier's gametes and thus is passed on to half the carrier's children.

X-linked
A gene carried on the X chromosome. If a male inherits an X-linked recessive trait from his mother, he expresses that trait because the Y from his father has no counteracting gene. Females are more likely to be carriers of X-linked traits but are less likely to express them.

Most genes are **additive genes.** Their effects *add up* to make the phenotype. When genes interact additively, the phenotype may reflect all the genes that are involved. Height, hair curliness, and skin color, for instance, are influenced by additive genes. Indeed, height is probably influenced by 180 genes, each contributing a very small amount (Enserink, 2011).

Less common are *nonadditive* genes, which do not contribute equal shares. In one nonadditive form of heredity, alleles interact in a **dominant–recessive pattern,** in which one allele, the *dominant gene,* is far more influential than the other, the *recessive gene.* When someone inherits a recessive gene that is not expressed in the phenotype, that person is said to be a **carrier** of that gene: The recessive gene is *carried* on the genotype.

Most recessive genes are harmless. For example, blue eyes are determined by a recessive allele and brown eyes by a dominant one, which means that a child conceived by a blue-eyed person and a brown-eyed person will usually have brown eyes.

"Usually" is accurate, because sometimes a brown-eyed person is a carrier of the blue-eye gene. In that case, in a blue-eye/brown-eye couple, every child certainly has a blue-eye gene from the blue-eyed parent and has a 50/50 chance of having another blue-eye gene from the carrier parent. Half the children of this couple will have blue eyes, half brown, on average.

Sometimes both parents are carriers. Then their children have one chance in four of inheriting the recessive gene from both parents. A blue-eyed child can be born to brown-eyed parents. A word to the wise: When a child looks like neither parent, do not question paternity (see Figure 2.3).

A special case of the dominant–recessive pattern occurs with genes that are **X-linked** (located on the X chromosome). If an X-linked gene is recessive—as are the genes for most forms of color blindness, many allergies, several diseases (including hemophilia and Duchenne muscular dystrophy), and some learning disabilities—the fact that it is on the X chromosome is critical (see Table 2.1).

This follows from what you already know. Since the Y chromosome is much smaller than the X, an X-linked recessive gene almost never has a dominant counterpart on the Y. Therefore, recessive traits carried on the X affect the phenotypes of sons more often than those of daughters. The daughters are protected by their other X chromosome, which usually has the dominant gene.

This explains why males with an X-linked disorder inherited it from their mothers, not their fathers. Because of their mothers, 20 times more boys than girls are color-blind (McIntyre, 2002).

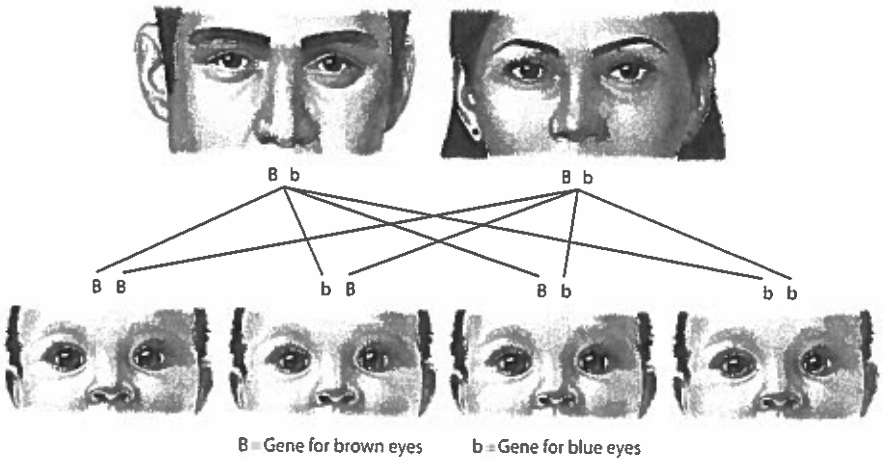


FIGURE 2.3 Changeling? No. If two brown-eyed parents both carry the blue-eye gene, they have one chance in four of having a blue-eyed child. Other recessive genes include the genes for red hair, Rh-negative blood, and many genetic diseases.

TABLE 2.3 The 23rd Pair and X-Linked Color Blindness

23rd Pair	Phenotype	Genotype	Next Generation
1. XX	Normal woman	Not a carrier	No color blindness from mother
2. XY	Normal man	Normal X from mother	No color blindness from father
3. XX	Normal woman	Carrier from father	Half her children will inherit her X. The girls with that X will be carriers; the boys with her X will be color-blind.
4. XX	Normal woman	Carrier from mother	Half her children will inherit her X. The girls with her X will be carriers; the boys with her X will be color-blind.
5. XY	Color-blind man	Inherited from mother	All his daughters will have his X. None of his sons will have his X. All his children will have normal vision, unless their mother also had an X for color blindness.
6. XX	Color-blind woman (rare)	Inherited from both parents	Every child will have one X from her. Therefore, every son will be color-blind. Daughters will be only carriers, unless they also inherit an X from the father, as their mother did.

Note: On this chart, the red X means that it contains the gene for color blindness.

The final complexity is *epigenetic*, not solely genetic. All important human characteristics are influenced by nurture, including diseases known to be inherited, such as cancer, schizophrenia, and autism (Kundu, 2013; Plomin et al., 2013).

Diabetes is a notable example. People who inherit genes that put them at risk for type 2 (non-juvenile) diabetes do not always become diabetic. However, their lifestyle—especially body fat and exercise—might activate their genetic risk. Then epigenetic changes make diabetes irreversible (Reddy & Natarajan, 2013).

One intervention—bariatric surgery to dramatically reduce weight—leads to remission of the diabetes in most (72 percent) patients, but diet and exercise remain crucial. In more than half of those 72 percent, diabetes returns: Epigenetic changes can be controlled but not erased (Sjöström et al., 2014).

The same may be true for other developmental changes over the life span. Drug use—cocaine, cigarettes, alcohol, and so on—may produce epigenetic changes that make addiction likely, even if a person has stopped using the drug for years (Bannon et al., 2014). The addict can never use the drug again as an unaffected person might.

Some environmental factors that suppress or release genes are cognitive, not biological. For example, if a person feels lonely and rejected, that feeling can affect the RNA, which allows genetic potential for heart disease or social anxiety to be expressed (Slavich & Cole, 2013). Note that it is the *feeling* of loneliness, not the objective number of friends or social contacts, that has significant epigenetic influence.

Sisters, But Not Twins, In Iowa
From their phenotype, it is obvious that these two girls share many of the same genes, as their blond hair and facial features are strikingly similar. And you can see that they are not twins. Lucy is 7 years old and Ellie is only 4. It may not be obvious that they have the same parents, but they do—and they are both very bright and happy because of it. This photo also shows that their genotypes differ in one crucial way. One of them has a dominant gene for a serious condition.

OBSERVATION QUIZ
Who has that genetic condition? (see answer, page 58) ▲

WHAT HAVE YOU LEARNED?

1. What is the relationship among DNA, chromosomes, and genes?
2. Why is it said that your parents could have given you millions of different siblings?
3. What surprises came from the Human Genome Project?
4. How is the sex of a zygote determined?
5. How do monozygotic twins, dizygotic twins, and nontwin siblings differ?
6. How could a child inherit a disease neither parent has?
7. How is diabetes both genetic and not genetic?