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Science Literacy

Genetics:
Why are living things different from one another?



Science Literacy Student Reader



Chromosome replication



Genetic variation in plants



Genetic variation in animals

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Genetics

Science Literacy Student Reader



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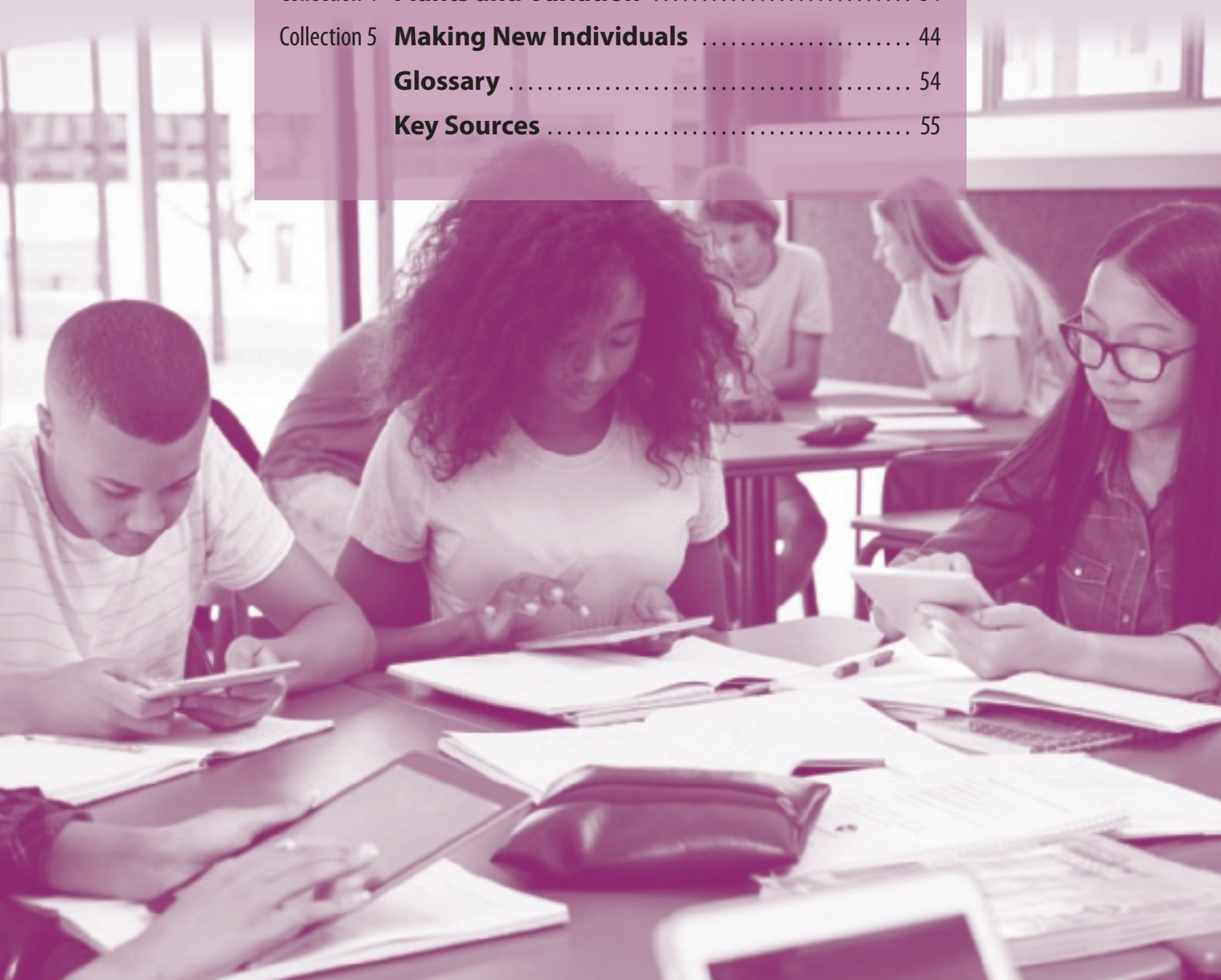
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Genetics

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Put Yourself in This Scene

Isaiah and Gabe are at the local basketball court. Both are in the tenth grade and motivated to keep playing competitive basketball through high school and possibly beyond. After shooting for an hour, they are now taking turns leaping up toward the basket and trying to dunk the ball. Gabe is just inches away from succeeding. Isaiah, who is shorter, jumps about as high off the ground as Gabe. But with a shorter body and arms, he's not as close to getting the ball over the rim.

"I'm telling you," Gabe says. "Get the VertiCalisthenics app on your phone. It's just $9.99 per month. I've already seen gain in just a few weeks!"

Isaiah rolls his eyes. "Come on, man. Don't fall for that stuff. You're almost dunking because you're growing like an inch a week. You can almost touch the net without jumping! All we have to do is keep playing, jump a lot, do some leg exercises, and it'll work out however it's gonna work out. At least for you. I'm probably maxing out at 5'10", so I may never get there."

"You're wrong," Gabe replies. "The app provides a daily exercise regimen that's based on studies from real vertical leap scientists! They've got the data to back up their claims: testimonials from tons of people like us who are now dunking with ease."

Isaiah drips with sweat and sarcasm. "Vertical leap scientists! Wow. Sorry, but that isn't a thing."



Gabe shakes his head. "They're specialists in exercise physiology, and they train pro athletes. This is what they do, and they've got it down to a science. In the ads, you can hear from pro basketball players and Olympians who swear by their methods. Why would those people make it up?"

"For money. Duh! Look, all of this stuff is just about genetics and some effort," Isaiah pleads. "Technically, I jump higher than you right now, and that's because I inherited my mom's legs. She was a champion high jumper. I owe my bounce to her and to coming down here and putting in the work. I'm down for working out and playing every day. But I'm not falling for that snake-oil stuff and wasting ten bucks a month to have someone show me exercises I already know about or tell me to eat more protein."

Frustrated, Gabe goes up for a dunk. The ball gets over the rim but caroms off the backboard. "I guess we'll just wait and see. I know genetics matter, but I'm going to do whatever it takes to dunk and make varsity next year."

Who is right? Is Gabe wasting his money? Is Isaiah correct that most of a person's athleticism comes from the genes inherited from their parents? When science and sales are mixed, how do you know what to believe?

That's what this book is about—scientific literacy, which means knowing how to think about science topics that you read or hear about. Our world has 24–7 news, social media, and too many websites to count. The amount of information we have to sort through is overwhelming, and all the information is not reliable. In the internet age, sources of information are often obscure or not trustworthy. It is good to process information with a healthy degree of skepticism.

We will make our way back to the topic of genetics versus environment by the end of the book. Along the way, the series of reading selections and the writing exercises that go with them will help you flex your mental muscles and sharpen your science literacy skills. The ability to read about science, understand the information, and tell truth from fallacy or misrepresentation is really important. Science literacy helps you as an individual and as a consumer, and it shapes the ways you affect the community in which you live.

Diversity of Phenotype

The **phenotype** of an organism is the outward expression of a particular genetic trait, such as eye shape, finger length, or hair texture. Phenotypes can even be chemical pathways, internal cell structures, or the presence or absence of chemicals. Within groups of related organisms—or even within the same species—there is a lot of diversity for any phenotype.



The potential height to which a person can grow is a trait that varies widely among humans. Each of these men is of a different phenotype. All humans are of the same species, *Homo sapiens*.

Vocabulary

phenotype, n. observable traits of an individual, based on interactions of the individual's genes and its environment

Different Phenotypes Within the Same Species





One red kangaroo is noticeably more muscular than another member of the same species (*Macropus rufus*). These are two phenotypes, or outward expressions, of the genes of each individual.



These two nudibranchs are of the same species (*Chromodoris geometrica*) but phenotypically different.





These two gorillas are members of the same species. Their phenotype for hair color differs.

Different Phenotypes Among Different Species





Polar bears and grizzly bears are different species. How might the different phenotypes for fur color aid in their survival?

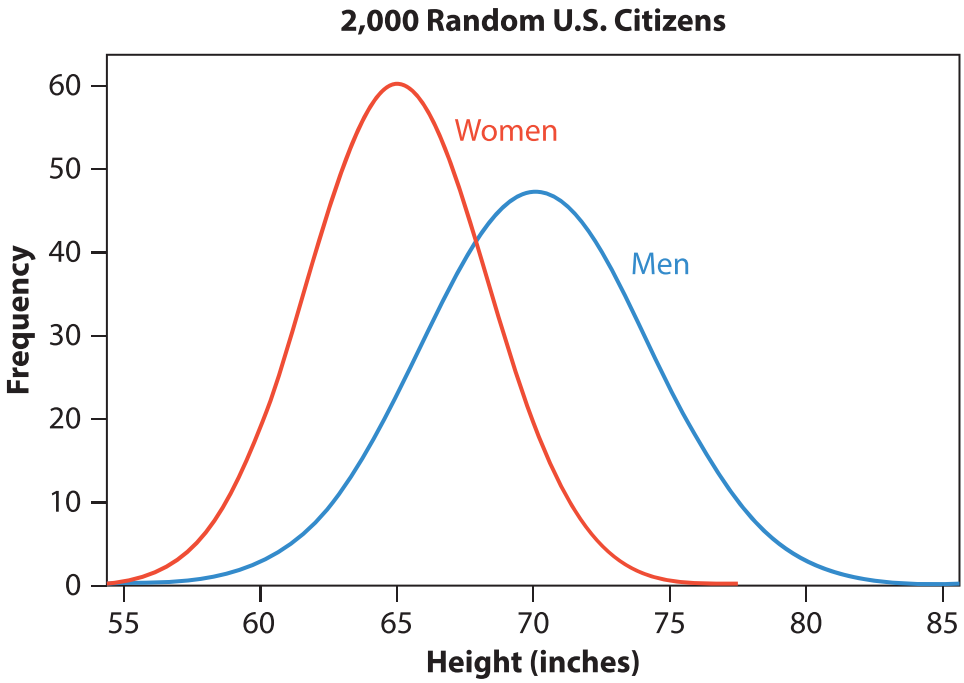




The blue-and-yellow macaw's beak is curved, while the hornbill has a large horn that helps the bird build nests, find prey, fight, and preen. Two species, two phenotypes.



These two sea stars are of different species. They are phenotypically different.



Phenotypes can be measured. In this population, the height of adult males ranged from about 4.5 feet to over 7 feet. The bell-like graph is called a bell curve.

Connection



An unusually tall person, such as Manute Bol, who stood 7'6", can widen a bell curve of human height in a specific population. In the National Basketball Association, the average player is about a foot shorter than Bol, which in turn is about eight inches taller than the average adult male.

Wellness Wonders Podcast



Episode: Muscle Mania

(Begin transcript)

(Intro theme music)

Ben: Hey, listeners! I'm Ben, and I want to thank you, as always, for listening to the Wellness Wonders Podcast. Today we have a great episode based on a lot of questions I've received lately about muscle composition and how it affects our strength and endurance. So to help me address this topic, we have a guest in the studio today, former ultramarathoner and friend of mine, Raquel Zilker. Raquel, thanks for joining us on the pod!

Raquel: Happy to be here, Ben!

Ben: So, Raquel, I've known you for years. But the listeners might not know who you are. Please tell us a little about yourself.

Raquel: Sure thing. I've been a runner ever since I can remember. I always participated in track and field, and I joined as many races as I could throughout college and beyond. I'd say in the last decade I've run five marathons, two ultramarathons, and three triathalons.

Ben: So you're closely acquainted with endurance! Now, the listeners want to know about muscle: what it's made of and how it supports the body in different activities.

Raquel: First of all, humans have many differing phenotypes when it comes to muscle potential. But let's take a step back and compare human muscle with, say, tuna. Humans and other animal species have different types of skeletal muscle fibers. These different fibers allow for a variety of movements and speeds. In fact, tuna—the fish—are great examples of this . . .

Ben: Sorry to interrupt, but I'm going to post a picture of a cross section of a tuna in a this episode's podcast show notes, listeners, so you can see exactly what Raquel's talking about. Okay, Raquel, go ahead.



Muscle cross section of tuna

Raquel: The abundant pink muscle is fast-twitch muscle. It has less access to blood and therefore less access to oxygen. But its fibers can twitch very quickly, which generates more power for high-speed bursts that help a tuna escape a predator or catch prey. The less-abundant, darker muscle on the sides is made of slow-twitch fibers. There are greater blood flow and oxygen-transporting proteins in the slow-twitch muscle, so it can work longer before fatigue. This is the muscle that helps a tuna swim long distances.

Human skeletal muscle has a mix of fast- and slow-twitch fibers like these. Someone with lots of slow-twitch, or Type I, muscle fibers might be naturally good at endurance events such as running long distances or swimming across lakes, though not necessarily at maximum speed. This is the category that I fall into. On the other hand, someone with lots of fast-twitch muscle fibers might jump higher or be able to lift more weight, but they are more likely to get tired sooner than a person who is endowed with slow-twitch muscle.

Ben: So, Raquel, you're saying that slow-twitch, Type I muscle fibers are most useful for doing lots of work over a long period of time but not at maximum speed.

Raquel: Correct. Marathon runners' muscles are likely to have a high proportion of slow-twitch fibers. Someone who competes in sprinting, jumping, or weight-lifting events is likely to have a high proportion of fast-twitch muscle fibers.

Ben: That's a great way to help explain it.

Thank you so much, Raquel, for coming on the show and talking to us about the different types of fibers within our muscles and the kinds of activities they support.

Raquel: Thanks for having me, Ben!

(Closing theme music)

(End transcript)

Buy Now and Bulk Up!

Spot the BS

Heads up! There are some questionable claims within these ads. What words in these ads trigger your **b**ad **s**cience detector?

Synthol

Summer's approaching. Almost time to get out of that baggy sweatshirt and show off your arms—ready or not! If you don't have time to get to the gym and you're put off by the idea of guzzling protein shakes, Synthol is for you! Synthol is a safe product that will magically make your arms get that "swole" look but without the work on the weights or in the kitchen.





Get huge with Mr. C's Creatine Shake! The best time to enjoy our shake is after your workout, provided you have already stacked with creatine to saturate your muscles with this important amino acid. Mr. C's Creatine Shake mix comes in three flavors: banana, chocolate, and vanilla. Within a few weeks, you'll notice you can power through extra reps, which will lead to greater gains at the gym.

You've probably heard about human growth hormone (HGH) and what it can to do help you build muscle and even avoid aging. It can be tough to get HGH without a prescription. Sue's PseudoHGH is a synthetic version of HGH that you can take in a small pill. It's safe and effective and can be purchased at most health supplement stores. If you don't like it, you'll get your money back—guaranteed!



Fact Check

The $37 billion health supplement market in the United States is not well regulated. It's very easy for a company to market something as healthy, safe, "natural," and beneficial for one purpose or another and not get into any trouble unless a user pays for chemical analysis of the product and tries to sue the manufacturer for fraud. Let's take another look at the ads, one by one.

What is left unsaid in this ad is how one takes Synthol and what it does. It is a blend of oil, alcohol, and painkillers that is injected into a specific body part—usually the upper arms—that someone wants to make bigger. It basically inflates the body part without causing any growth of muscle fibers. The compound can saturate muscles and cut off muscle cells from the blood, resulting in masses of scar tissue that needs to be surgically removed. It is basically a kind of plastic surgery that nonprofessionals are practicing on themselves, sometimes with disastrous results.

Creatine is made by several organs of the human body, from three amino acids. It helps provide the body with ATP, which cells need to conduct cellular respiration. It can be acquired through eating seafood and meat, or it can be taken as a supplement, usually a powder called creatine monohydrate. Studies have shown that providing the body with extra creatine led to more productive workouts aimed at building muscle. The ad mentions "stacking," which basically means preloading the body with the substance so there is a steady supply of it before and during a workout.

Human growth hormone is associated with muscle development, but aside from getting it from your own pituitary glands, HGH must be injected, and it should be provided by a medical professional. The term "pseudo," which means "fake," can be a tip-off that a product perhaps isn't what it says it is, and this pill could easily be filled with some baking soda and sugar and that's all.



Growth in the Family Tree





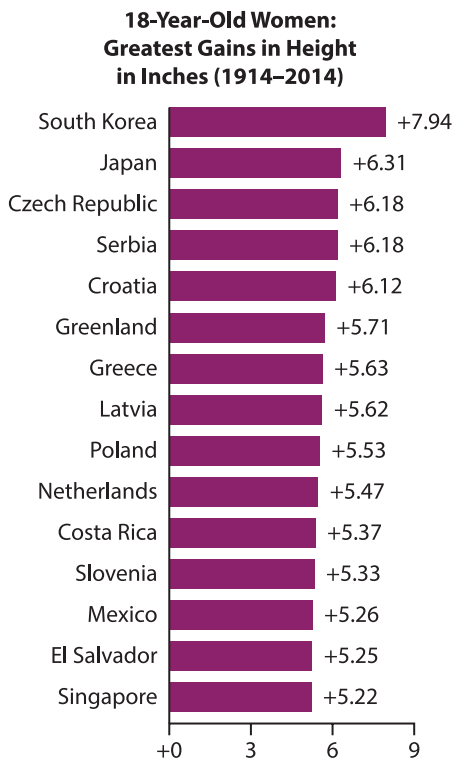
My mom was born in the United States to two people who immigrated here from South Korea in the late 1960s. My dad's family is traced back to Ireland, Germany, and other parts of Europe. My mom is 5'3", and my dad is 6'4". My doctor predicted that I would be exactly six feet tall, and sure enough, that's exactly where I am right now as a high-school junior.

What's funny about my family is there's a big disparity in height between my Korean grandparents (and great-aunts and great-uncles) and the generations that came after them. My mom's Korean American cousins are taller than their parents. Some of the guys are around six feet tall, while their moms and dads are between 5' and 5'7". And when we flew to Seoul for a family reunion last year, I could see that the same trend was true over there: the younger generations were all taller than the grandparents. So, it seemed to be a trend on both sides of the Pacific and not something specific to those of us who ended up living in the United States. Was it better food? More food? Something else?

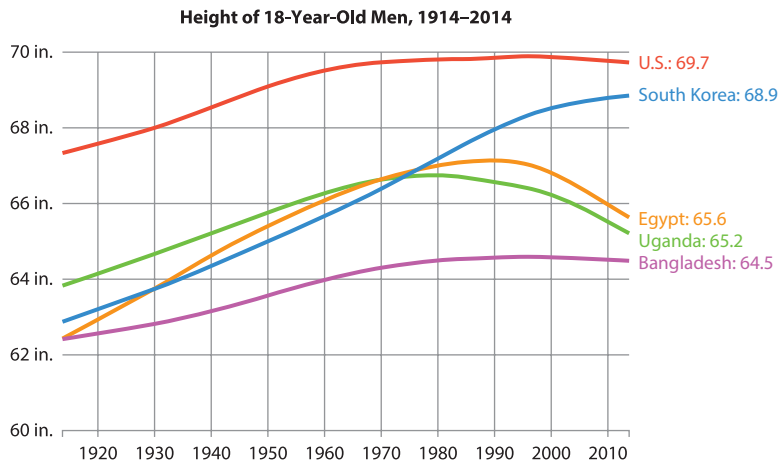
My point is you have to be careful about phenotypes. Yes, they are genetically determined, but they also vary depending on how the environment interacts with your genetics.

My grandparents' generation and those of their own parents and grandparents were all affected by years of war and occupation. Japan occupied Korea from 1910 to 1945, and then Korea split in half and had the Korean War (1950–1953). During and after these conflicts, food shortages and poverty were common, and many children grew up undernourished. So, for half a century, Korean children were not reaching the heights that they might have in terms of their genetics because their bodies weren't getting enough of the building blocks for growth. After the wars, nutrition improved, and South Korea's economy eventually took off. Korean Americans of my parents' and my generations also lucked out by growing up in a place where warfare and malnutrition have been less common.

It makes me wonder how much taller so many human beings would have been throughout history if they'd just had the nutrients their bodies needed to build tissues such as bone and muscle. Their genetic makeup was the same, but the environmental factors might have been quite different.



This bar graph shows South Korean women have had the greatest increase in height over the last century. An 18-year-old South Korean woman today is eight inches taller, on average, than she would've been a century earlier.



This graph shows the change in men's height in South Korea over the same period. It was about six inches.

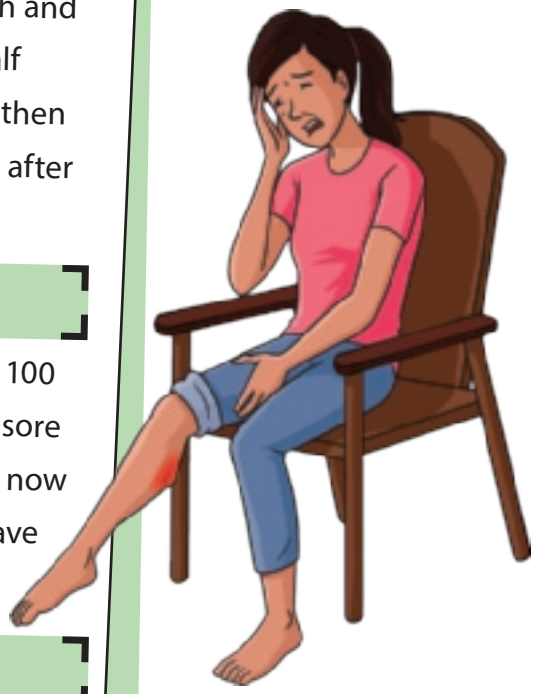
Doing It Right vs. Overdoing It

November 10

Basketball tryouts are just a few weeks away. Thanksgiving is four days before, so I'm not worried about having enough fuel in my system to get through the three-day grind of scrimmaging, running, and full-speed drills, but I am worried about not being in shape. I know my calf muscles need to be strong but also have endurance. To get both my fast-twitch and slow-twitch fibers in top shape, I'm going to do a ton of calf raises. I'll start today with just 20, then 100 tomorrow, and then increase by 50% every day after that until it's the weekend after Thanksgiving.

November 12

Well, 20 calf raises were no problem, but going from 20 to 100 may have been dumb, because my calves are so tight and sore today that I can barely walk. I hobbled around school, and now I'm going to miss pickup hoops tonight. I guess I should have built up more slowly.



November 14

Argh. My calves are still so sore. It's obvious that I strained them, which is really just another way of saying I tore the muscle fibers to the point that too many of them are being repaired for me to use them for much more than gently walking around. If I'd just built up my calf raises by 10 per night, I would have been strengthening them without putting myself on the disabled list. Impatient!

November 11

Samantha told me she started a calf-raise regimen last night to get ready for tryouts, so I'm going to do the same thing but take a slower approach by starting with 10 tonight, 20 tomorrow, and so on, until I'm up to 100. And then once I'm at 100 I'll increase by 50 reps per night and see how that goes. My thinking is to start with a slow build so my muscle fibers aren't too strained, and then once they're strong and they've grown quite a bit, I can up the reps to improve endurance.

November 16

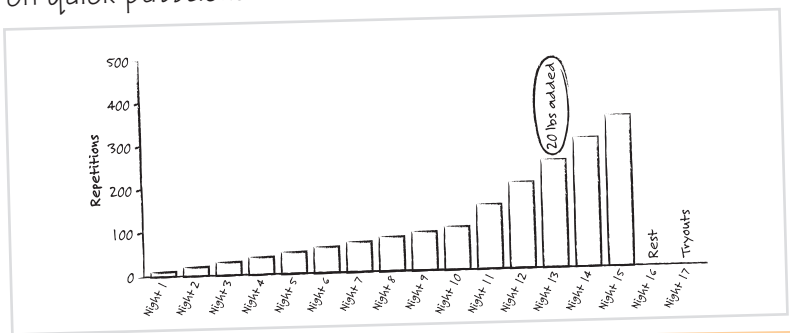
Samantha tore up her calves pretty good by overdoing it early on. So far my approach has been fine. Tonight I did 60, and five days from now I will hope to go from 100 to 150 and keep increasing by 50 per night right up until the weekend before tryouts. My calves are a bit sore, but I do some stretching between classes at school, and I haven't had any trouble playing ball in the afternoons. I'm also making sure to get protein at every meal so my muscle fibers are repaired.

November 23

Yesterday I was about to 250 calf raises when I realized it might make sense to add some weight by wearing a backpack loaded with all of my school books, in addition to doing a few hundred reps. I figure the extra weight means more resistance, so I'll be working on endurance by doing tons of reps but also challenging my calf muscles to move more weight up and down. I'm sore today but not too bad. Samantha got back on track with her program, but she's way behind. Hopefully we both make the team.

November 30

Both Samantha and I made varsity! We took different paths, but it seems like our pre-tryout workout regimens got us where we needed to be. We're both jumping higher, especially on quick putbacks after offensive rebounds, and we did well in the sprints, too.



Dig into Data

What pattern can you identify in the graph?

Essential Amino Acids and Protein Needs

There are twenty common amino acids that our bodies need, primarily to form important proteins. Nine of these amino acids are called essential amino acids (EAAs). They are essential because they aren't made in the body. They must be consumed through your diet.

The table shows the recommended daily amount of each EAA, in milligrams of EAA per kilogram of an adult's body weight. For example, every day, an adult should consume 10 milligrams of isoleucine for each kilogram of their body weight. Several foods that are rich in EAAs are featured in the table, to show the relative amounts of each EAA found in a 170-gram (six-ounce) serving of each. How much of each EAA a person needs is a function of their size as well as whether they are trying to gain mass. In turn, the amount of protein-rich food a person needs is a function of their size.

Amino Acid	Required Daily Amount, mg/kg body weight	Amount (mg) found in 170 g of Atlantic salmon	Amount (mg) found in 170 g of chicken egg	Amount (mg) found in 170 g of soybeans
histidine	8–12	1,107	3,740	591
isoleucine	10	1,731	9,180	2,890
leucine	14	3,053	14,620	4,695
lysine	12	3,451	11,900	3,890
methionine	13	1,112	9,690	1,076
phenylalanine	14	1,467	15,810	3,060
threonine	7	1,647	7,990	2,264
tryptophan	3.5	422	2,890	412
valine	10	1,936	11,220	2,890



Soybeans are a meatless source of EAAs.

Type of adult			
Body weight	66 kg	100 kg	63 kg
Recommended daily protein intake	0.86 g/kg body weight × 66 kg = **56.8 g/day**	3.0 g/kg body weight × 100 kg = **300 g/day**	0.75 g/kg body weight × 63 kg = 47.25 g/day + 10 g/day during pregnancy/lactation = **57.25 g/day**

The average fully grown adult who is not looking to add muscle mass needs under 60 grams of protein per day, just to maintain their size and overall health. A heavy bodybuilder who is looking to get even bigger needs 300 grams of protein per day. A person who is pregnant or nursing just needs an additional 10 grams of protein per day, regardless of their own body weight. Bodybuilders tend to eat a lot of lean beef and chicken eggs to get those 300 grams of protein. They can also consume protein powders, which deliver a lot of EAAs without adding a lot of nutrients that the bodybuilder does not necessarily want or need, such as fat or carbohydrates.

Big-Screen Genes

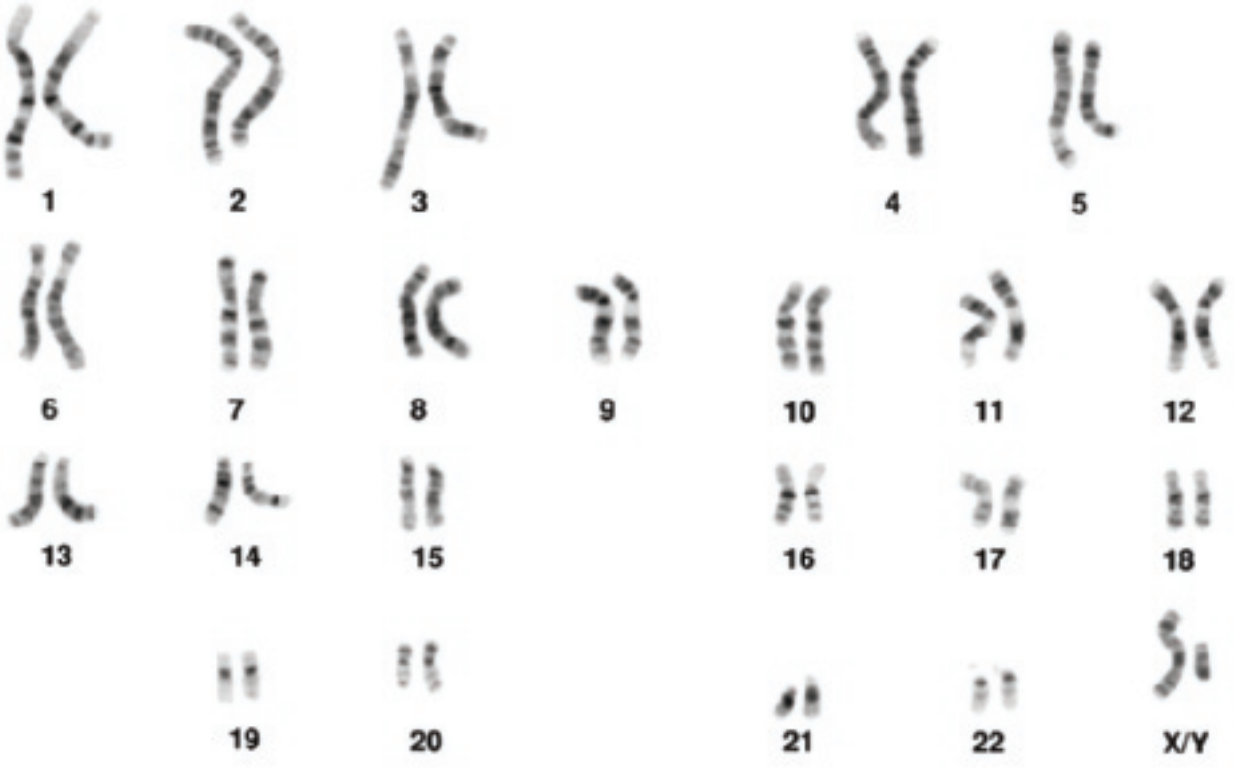


Many filmmakers are enthralled with the areas of genes and genetic engineering. Take *Jurassic Park*, for example. In this fun film, scientists use the preserved DNA of dinosaurs to recreate new dinosaurs to be displayed at a theme park. They are manipulating the dinosaurs' genes to make something seemingly more desirable.

We see a similar concept in the 1997 movie *Gattaca* where people have control over genetics and can know the exact genes a person carries and what types of health issues they will develop in the future. In fact, the word *GATTACA* is made up of letters of the bases found in DNA.

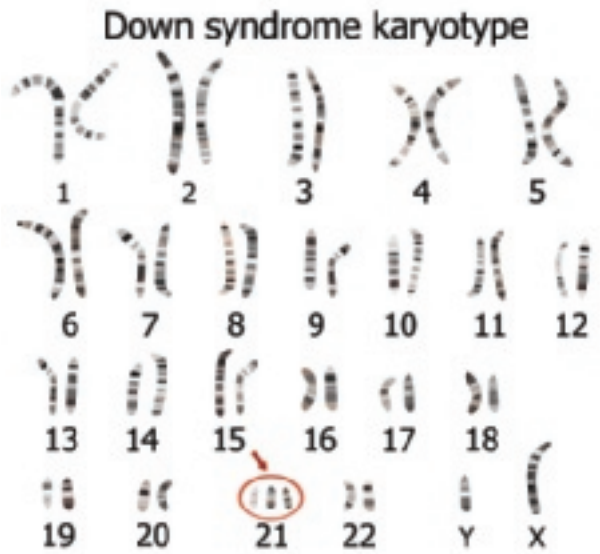
And then there's the comic-book-based movie series *X-Men*, which approaches the topic of genes a little differently. In this storyline, characters like Professor X, Magneto, Wolverine, Storm, and others are born with genetic mutations that give them unique superpowers. Some are able to control elements like the weather. Others can read minds. Some can fly and have incredible strength. Others can manipulate metal. These characters, called "mutants," use their superhuman throughout their adventures. Professor X is the leader of the crew and spends his time studying the genetic mutations and their causes.

If only Professor X in *X-Men* had access to karyotyping technology, he might be able to solve the question of what kind of genetic mutation lets Cyclops shoot laser beams out of his eyes!



The *X-Men* story discussed on the previous page is fantasy fiction about characters with superpowers stemming from mutated genes. Gene mutations do occur in real life. By definition, a gene mutation is some kind of change in a gene. This means that the gene itself is not formed in the usual manner.

If Professor X really wants to get to the bottom of genetic mutations, he should review the characters' karyotypes. Karyotypes are visual displays of a person's chromosomes that are sorted and paired up. Scientists use karyotypes to count and analyze chromosomes. A karyotype can confirm a diagnosis of a chromosomal disorder, or it can be used to diagnose a disorder before symptoms have shown up.



The karyotype at the top shows typical chromosomes in an average male. You can see that the chromosomes occur in pairs. However, the karyotype at the bottom shows an extra chromosome on the 21st pair. This arrangement results in a condition known as Down syndrome.

Coins and Chromosomes

When you flip a coin—say, a quarter—there are two possible outcomes, heads or tails.

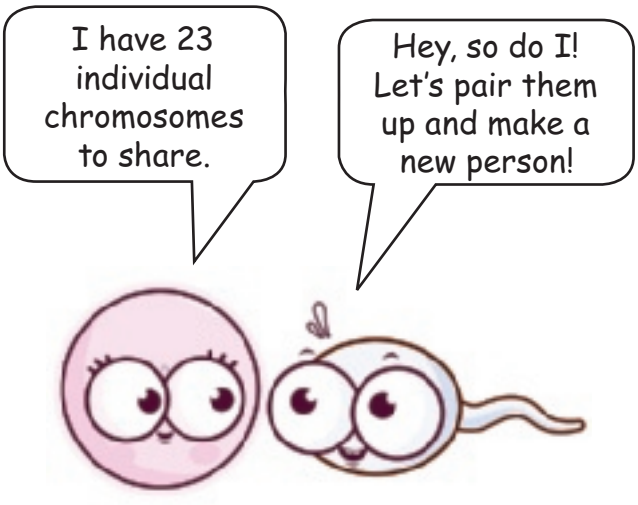


How many possible outcomes are there if you flip both a quarter and a penny at the same time?

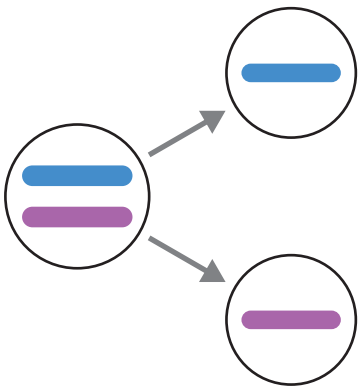
1. 
2. 
3. 
4. 

How many possible combinations could turn up if you flipped 23 different types of coins at once? How about tossing 64 different coins at the same time? Your genetic makeup is the product of something as complicated as such a coin toss.

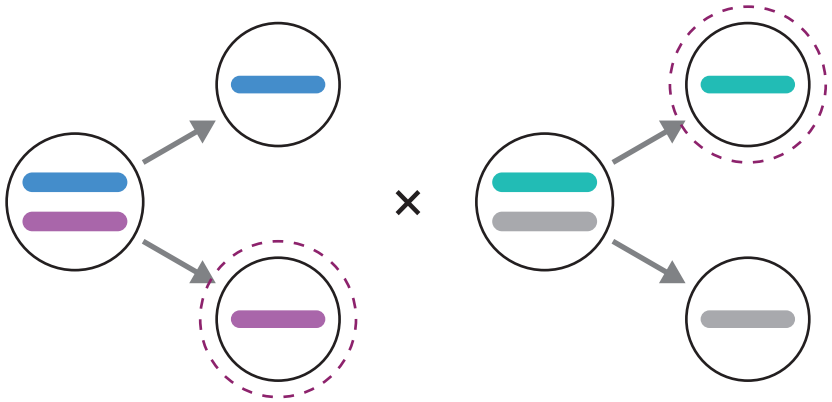
Every human develops from two sex cells called **gametes**. One gamete comes from each parent. Each parent's gamete carries half of the chromosomes that will make up the new human's unique karyotype—their set of 23 chromosome pairs.



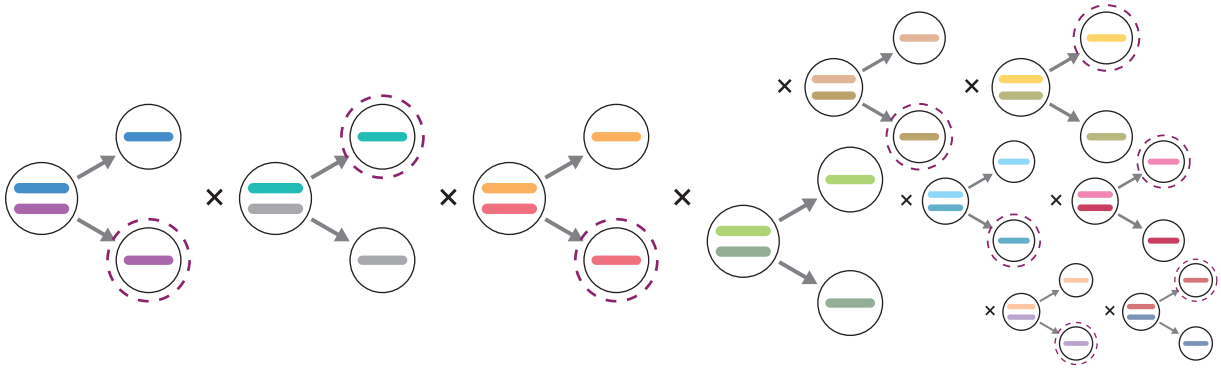
When a body produces gametes, that person's pairs of chromosomes are split up. A gamete gets one chromosome or the other from each of the person's 23 chromosome pairs. This is like flipping a coin once per chromosome. There are two possibilities per chromosome. Whichever one of a pair ends up in the gamete represents the outcome of flipping a single genetic coin.



When you factor in a second pair of chromosomes, the number of possible outcomes doubles from two to four. From the two chromosome pairs, there are four possible combinations—like flipping the quarter and the penny.



Each additional chromosome pair represents another doubling of the possibilities.



Multiply it all out, and it's 2^{23}, which equals 8,388,608. That means there are over 8 million possible combinations of chromosomes in a gamete from just one parent.

The number of possible chromosome combinations from one parent ends up being multiplied by the same number for the other parent.

$2^{23} \times 2^{23} = 70$ trillion combinations

This means each human **zygote** carries one of about 70 trillion possible chromosome combinations that could have come from their parents. In other words, based on the chromosomal coin toss, there could've been 70 trillion different versions of you! (Curious about what a different version might have been like? If you have a sibling from the same two parents, you can see how a different toss of the same chromosomal coins turned out.)

Vocabulary

gamete, n. a male or female germ cell that can fuse with a cell of the opposite sex in sexual reproduction to produce a zygote

zygote, n. a cell resulting from the fusing of two gametes; a fertilized egg

The Brothers of Bogotá

Twins are siblings born at the same time. Fraternal twins develop from four separate gametes that combine into two separate zygotes. Identical twins form when a single zygote splits into two genetically identical copies.



Identical twins

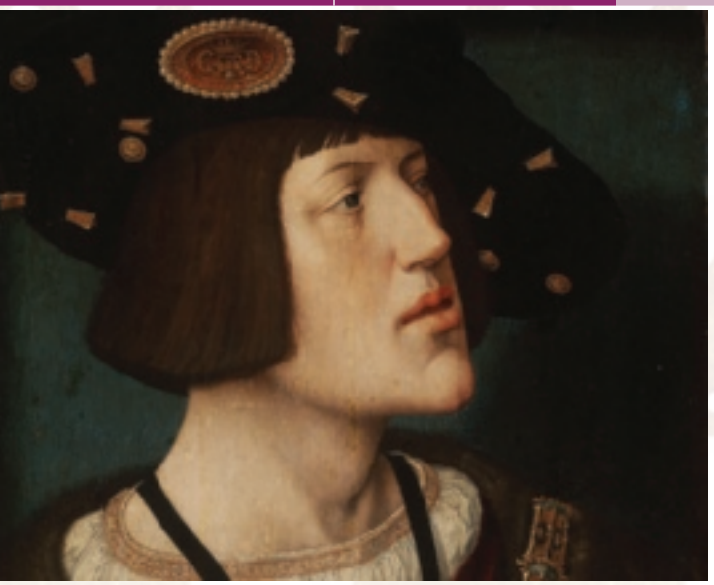


Fraternal twins

In 2015, a writer named Susan Dominus wrote a fascinating story about twins in *The New York Times*. In late December 1988, in Colombia, two sets of twin boys were born at the same hospital. Twenty-five years later, one of the boys, now an office worker named Jorge, was shown a photo that a coworker had taken at a local butcher shop in Bogotá. In the photo, it seemed, was Jorge. Same face, same hair. But Jorge was working behind the counter of the butcher shop. Jorge didn't work at a butcher shop, though. The coworker explained that she had assumed it was Jorge and had been surprised to see him working a second job, but the man she thought was Jorge said his name was William. Jorge eventually found a Facebook page belonging to William, his body double, and he looked at other photos, confirming that this person seemed to look exactly like him. He came upon photos of William with another young man. William's friend looked identical to Jorge's fraternal twin brother, Carlos. It was Carlos, but his name was Wilber.

Over the next few months, it was confirmed that each pair of fraternal twins turned out to not be brothers at all. But each man was an identical twin. Jorge was in fact William's identical twin brother, and Wilber was Carlos's identical twin brother. William and Carlos had been swapped in the hospital and were raised by people who were not their biological parents. The four of them met and began a bewildering and emotional experience. The biological twins quickly learned how alike they were despite being raised apart and in different circumstances. Each of them now had two brothers—one identical twin they hadn't known until then and one brother they'd known forever as a fraternal twin but who was not actually related by blood.

The story of the two sets of identical twins who'd been separated at birth prompted scientists who had already been studying such cases to visit the men and research how their different paths through life affected them while their genetics had made them, despite the separation, very similar. Not only did Jorge and William look alike, but they had many of the same mannerisms and likes and dislikes. The same held true for Carlos and Wilber. Since meeting in 2014, the four brothers from Bogotá, as they came to be known in the media, have all grown closer and now regard themselves as a quartet that will never be separated.







The Hazard of Royal Bloodlines

Notice anything unusual about these faces? Maybe their chins and lower jaws seem rather pronounced? In the medical field, this condition is called mandibular prognathism. The lower jaw protrudes because of excessive growth of the jawbone. In everyday language, it is known as Habsburg jaw, named after the royal family of which these men were prominent members.

The Habsburg family was from Austria, but they ruled over Germany, Spain, and other parts of Europe for many centuries. Charles V, captured in the first painting, was emperor of the Holy Roman Empire from 1519 to 1556. His great-great-grandson, Philip IV, is shown in the second painting. Philip, who had the same distinctively heavy jaw, ruled Spain from 1621 until his death in 1665. Alfonso XII, King of Spain from 1886 to 1931, also inherited the Habsburg jaw. He is seen in the photograph to the right. What caused this trait to take root in the Habsburg family tree?

For centuries, across different cultures and continents, being a royal figure often meant having limited options in terms of whom you could marry. Often there were expectations or rules requiring a prince or princess to marry

another prince or princess—and sometimes that meant cousins marrying cousins or even siblings marrying siblings. Those families were doing what they thought would help preserve or purify royal bloodlines. Unfortunately, marrying within a narrow gene pool and—more to the point—reproducing can result in problems among the offspring.

By studying the extensive but narrow family tree of the Habsburgs over centuries, they estimated that about 9% of a given royal's genes were identical, meaning they came from the same ancestor. The average Habsburg was the offspring of people who were more closely related than first cousins.

What exactly causes health problems and deformities to be more common among people produced by closely related parents? In the case of the Habsburg jaw, geneticists think the condition is caused by a recessive gene—one that is expressed only if both parents have the gene and pass it along to the offspring. When royals married each other and produced the next generation, they were inadvertently making their offspring more likely to have health problems and, quite often, features that were considered deformities.



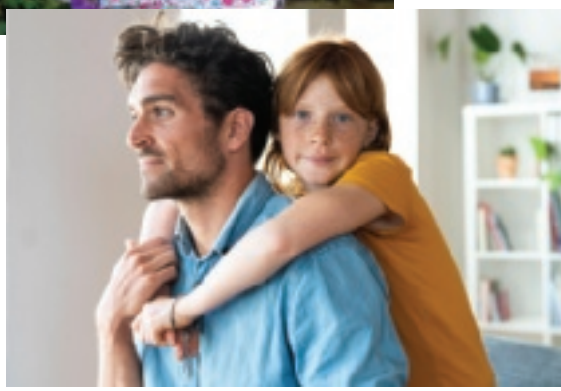
Of Charles II, a British diplomat reported home that "He has a ravenous stomach, and swallows all he eats whole, for his nether jaw stands so much out, that his two rows of teeth cannot meet."

Inheritance Misconceptions

Scenario Nadia is one of three children. She has striking blue eyes. Her younger twin brothers, Andrew and Stephen, have brown eyes. Their parents, Kristos and Ann, have brown eyes. Stephen and Andrew tease Nadia. "You're the only one with blue eyes. Mom and Dad have brown eyes. They must have found you in the garden!"

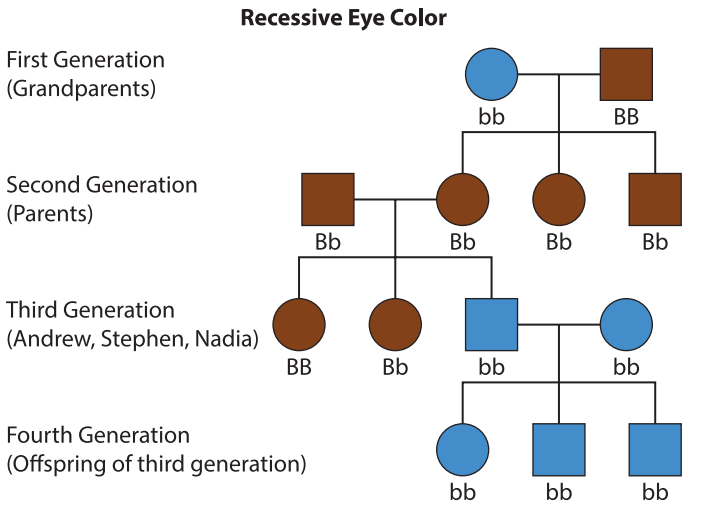


Misconception Blue-eyed children must have blue-eyed parents.



Reality Brown eyes are "dominant" over blue, but brown-eyed parents can have blue-eyed children if they are carriers of the blue eye gene. In Nadia's case, her parents must be heterozygous for brown eyes. She inherited two recessive alleles, so her eyes are blue. Her brothers did not, so their eyes are brown. If Nadia has children with a blue-eyed man, her children will be blue-eyed.

Explanation



Phenotype shown as brown or blue while dominant brown gene = B and recessive blue gene = b. Individuals with bb have blue eyes, while individuals with BB or Bb have brown eyes.

Scenario Michael wonders if he'll end up going bald like his dad. His mom says he has nothing to worry about, because baldness comes from the maternal grandfather, and her dad had lots of hair.

Misconception Male pattern baldness is passed from a bald maternal grandfather to the grandson. The grandson of a grandfather who is bald will be bald. If the grandfather has hair, the grandson will as well.

Reality About 80% of male pattern baldness is based on genetics, but it's not as simple as looking at Grandpa.

Explanation A male's X chromosome, in the 23rd pair, comes from his mother. The gene most responsible for baldness is on the X chromosome, but that X chromosome could have come from the mother's mother or father, meaning there's only a 50% chance that a bald grandfather's X chromosome is in the grandson's genome. Meanwhile, genes on nine other chromosomes also appear to affect head hair and baldness, and all of these genes appear to interact in complex ways.





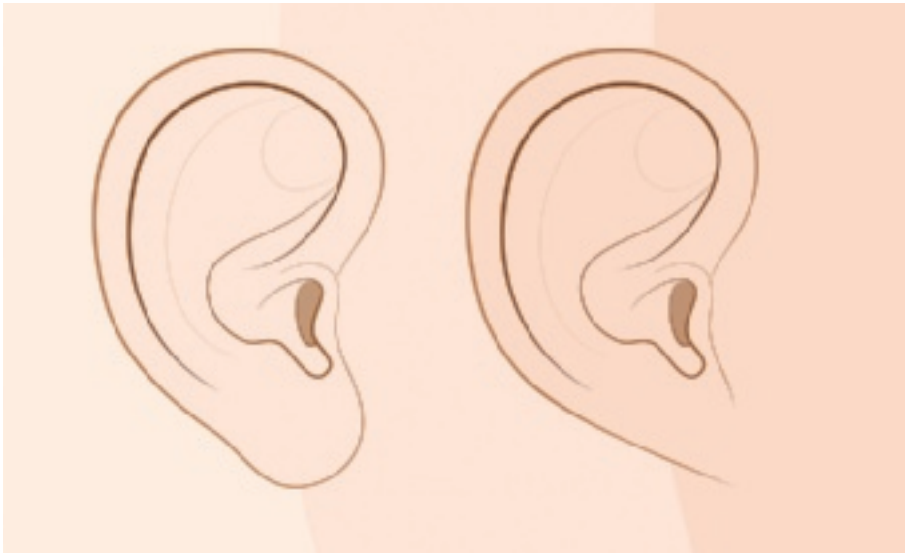
Scenario Michelle's father tells her that she's descended from a king from 1,000 years ago and that she has some of that royal DNA in her cells.

Misconception A person is genetically connected to all of their ancestors, via DNA.

Reality Many ancestors' DNA is excluded from the genomes of their descendants, especially those who live many generations later. With each generation, it is more likely that an ancestor's DNA is not in the genome of a descendant.

Explanation On average, a person gets about a quarter of their DNA from each of their grandparents. In some cases, a person inherits less than that. Some descendants of that person could also inherit lower-than-average percentages of the original grandparent's DNA, until none is left.





Scenario Pete looks through an old biology textbook in his parents' library. It says that earlobes are either attached or hanging and that this trait is probably controlled by one gene for earlobe shape.

Misconception There's a gene for every trait.

Reality Many traits are controlled by many different genes, and their interactions are unclear. Traits often are based on ranges, not either/or possibilities.

Explanation Researchers looked at the earlobes of 74,000 people and then their DNA. They found 49 different genes that appear to affect how earlobes are attached to a head, but none of them are "for" earlobe attachment or detachment.



Finding Mates

In Water . . .



Sharks reproduce by getting together in pairs. The male might gently bite the female's fins as they mate. A relatively small litter of sharks will be born months later.



Many bony fishes mate in mass spawning events. Sperm and eggs mingle in the water. Larvae are mostly on their own once they hatch.



Some bony fishes pair up, mate, and take care of their eggs. Sometimes, males without mates turn into females.



To prove his worth, the male crab does a dance for a female. Once she accepts him, she molts—sheds her old shell as a new one hardens—while the male stands guard over her.

Word to Know

A *pheromone* is a type of hormone that sends a signal from one organism to another.

Connection

What similarities do you notice about the way land and water animals mate?

On Land . . .



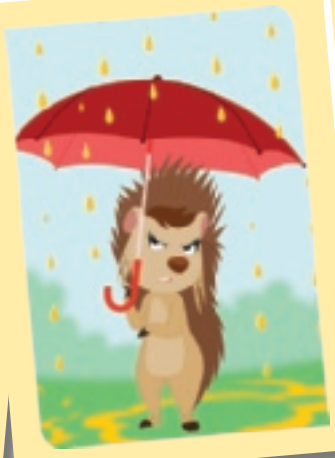
Males of sheep, antelope, deer, and other mammals use their horns to battle for the right to mate with a female.



Many insects use pheromones to attract mates. These hormones move through the air and can be traced back to the individual that emitted it.



The male club-winged manakin uses high-speed flapping of its wing feathers to make a drumlike sound that attracts females.



Female porcupines receive showers of urine from male suitors. The urine has pheromones that will attract the female . . . if it works.

History of Selective Breeding



Humans in Asia begin to domesticate wolves that follow tribes of people as they hunt and gather.

30,000 BCE

Wild bananas are cultivated in what is now New Guinea.

5000 BCE



Potatoes are cultivated in South America.

2500 BCE

30,000 BCE

7,800 BCE

Humans begin to breed types of wheat and corn to increase the size of the grains.

4000 BCE

The Chinese begin to selectively breed peaches, which began as small, sour, waxy-skinned fruit with very large pits.

Vocabulary

selective breeding, n. the human practice of choosing and pairing parent organisms for the purpose of promoting desired traits in offspring



Chinese and European pigs, which were already selectively bred, are mixed to produce a type of pig that grows large (European trait) and produces lots of offspring (Chinese).

1700

The most dominant form of banana is wiped out by a fungus. Selective breeding had made it seedless and therefore more difficult to regrow from seed.

1950s

The first truly genetically modified crop is approved for sale by the Food and Drug Administration.

1994

1800

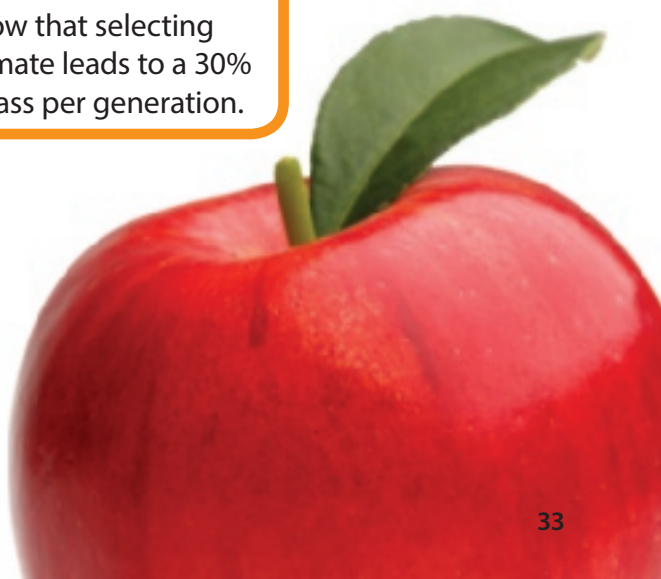
Koi fish are selectively bred for their colorful markings.



1979

Experiments with farmed Atlantic salmon show that selecting larger fish to mate leads to a 30% increase in mass per generation.

Future



Flowering Plant Reproduction



The bee orchid is a flowering plant whose flower resembles a type of bumblebee. This attracts bees to the flower, resulting in pollination of the flower as the real bee moves around on the reproductive parts of the flower.



Some flowering plants have evolved to produce deeply held nectar that can be reached only by certain moths. The moths get a kind of food that seems meant only for them, and they pollinate the flowers.



Monkey flowers' shapes suit the beaks of hummingbirds—and vice versa. Like with bees and moths, the hummingbird helps pollinate the flowers while getting nectar.



Male pine cones release their pollen all at once. The cloud of pollen can drift on the wind to other trees' flowers, including those that are far away.



Squirrels help oak trees reproduce and extend their range by gathering oak fruits, called acorns, and burying them in the ground. The squirrels store the acorns to dig up and eat later on, but they forget about some of them. These forgotten acorns sprout, and the enclosed seeds grow into trees.



Once pollinated, yellow dandelion flowers turn into fuzzy heads bearing feathery fruits. The wind catches the fruits and carries them near and far, helping to spread the seeds.



Some pine trees are dependent on fire to help their cones open. Not only does fire clear space and remove competitors for sunlight and water, but the intense heat causes the cones to open and release their seeds.



Witch hazel fruits burst open and shoot seeds up to 30 feet. This is known as ballistic seed dispersal.

Pollinating Meyer Lemon Trees

September 4, 2021



A while back, I bought three young Meyer lemon trees. I thought I'd give them as holiday gifts, but then Covid hit, and holiday gatherings were canceled. Long story short: I have three Meyer lemon trees, and at this point I'm pretty sure they're mine for life. When life hands you lemons, make lemonade, right? Well, that's my plan this year!

I know that citrus trees can self-pollinate, meaning each can make fruit even if it doesn't get pollen from another tree. However, with a rather hands-off approach so far, I've noticed that a lot of the flowers simply fall off the trees and do not become lemons. Maybe I'm wrong, but the only tree that seems to produce some fruit is the one that happens to be underneath the forced-air vent that blows cool air in summer and warm air in winter. My hypothesis is the "wind" produced by that vent helps pollinate that particular tree, while the trees that are not getting wind don't have anything to pollinate them. I'm looping in my children, Max and Thea, so they can report on our investigation in their high school science classes. They will write the next blog posts on this subject.

September 17, 2021

Hi, readers of my mom's blog. This is Max, and I'll be guest posting about the experiment we are conducting with the lemon trees that we ended up with due to the pandemic. We think one of the trees is getting an assist from the air that flows out of the vent in the ceiling. We're leaving that tree in that same spot and calling it Tree A. The other trees are nearby, and they all get the same amount of sun and water, so we're going to call them Trees B and C. We're going to leave Tree C alone and not give it any help with self-pollination.

Tree B is going to get our help. We are going to use fine paint brushes (or something similar) to transfer pollen to the parts of the blossoms where pollen travels inside and fertilizes the eggs. We need to do a bit of research and buy some supplies first.

By the end of the fall session of our experiment, we will count how many fruit have been produced as well as the total mass of fruit per tree and fill in the data table here.

	Tree A (wind pollinated)	**Tree B (help from us)**	**Tree C (no help)**
# of fruit			
Total mass of fruit (kg)			

Wish us luck! And if anyone has any tips on the type of brush we should use to pollinate Tree B, put a comment below!

Maria, September 18

Cool experiment, fam! I had a great Meyer lemon tree for years, and I found the easiest tool to pollinate the flowers was a cotton swab. Just lightly brush the end against the anthers of the flowers until its coated with yellow dust (pollen). Then dab that dust onto the sticky thing right in the middle of the blossom. Good luck!

Ferg, September 19

Any small paint brush will do. No need to buy anything specific.

October 10, 2021



Hi, folks. This is Thea. Max told me it's my turn to write the blog about our Meyer lemon pollination experiment. We've been reading up on flower parts, so I guess I'll talk about how we're pollinating the flowers of Tree B, which we've started to call "Treebee" like it's a pet.

Each blossom has male and female parts. Male parts are called stamens. Each stamen has a filament, which is like a stem, that holds up the anther, where the pollen is made. Pollen contains sperm. Set in the middle of a bunch of stamens is the pistil, which is the female part. The egg-making ovules are at the base of the pistil. Above is the style, and atop the style is the stigma. It's cool that all of these female parts have *st* in them because it reminds me of the word *sticky*, and that's what the stigma is. Pollen gets stuck to the sticky surface of the stigma, and then sperm travels from the pollen down into the style and onto the ovules, where sperm can fertilize eggs. The fruit is basically a swelled-up form of the ovary. In this case, each ovary becomes a wedge of the lemon, and fertilized eggs become seeds.

We've decided to use some fine paint brushes that our mom used to use for painting birds. These brushes are the right size for brushing pollen off the anthers and gently brushing it onto the sticky stigma.

February 4, 2022

Max here. It's been a while! Turns out Meyer lemons can take months to form and ripen, so we've been patiently watching our three trees and trying to keep the cats from climbing them and whacking at the lemons. All three trees produced fruit. Our data are shown below.

	Tree A (wind pollinated)	**Tree B (help from us)**	**Tree C (no help)**
# of fruit	0	18	0
Total mass of fruit (kg)	0	4.5	0

Wow. We were really wrong in our hypotheses about these trees. We assumed they were wind pollinated, but this data shows that the wind didn't cause any of the trees to be pollinated. We went back and read about citrus trees and found they are pollinated by insects! Now the data makes sense. When we used paint brushes to transfer pollen, we were mimicking the insect process. The data showed we had guessed wrong, but it also pointed us in the right direction about our trees.

Spot the BS

A science student reads this lemon tree study and claims that he can put Trees B and C together to try cross-pollinating them while continuing to let Tree A be taken care of by the breeze.

Where is the **b**ad **s**ensemaking in this student's claim?

Dig into Data

What pattern can you find in the data when comparing the three trees, the number of fruit, and the fruits' mass?



Trouble in the Banana Plantations

Worry is spreading among the banana farmers here in Santo Tomás de Castilla. One of the main exports from Guatemala is the banana. Ninety-nine percent of the bananas that are exported and shipped around the world are the Cavendish variety, which stays green (unripe) for a long time, has a fairly dense skin, and can be shipped pretty much anywhere on the planet and turn ripe in someone's kitchen. The Cavendish bananas are basically seedless, like other bananas that have been selectively bred over time. But that's also the problem with the Cavendish. Just about every Cavendish banana plant is a clone of every other Cavendish banana plant on Earth. That lack of genetic diversity means the plant could be wiped out by a disease that harms it.



This is exactly what happened to the predecessor of the Cavendish, the Gros Michel. The Gros Michel dominated the banana trade for decades until it was wiped out by a soil fungus that causes Panama disease, known as banana wilt. I found a photo from the early 1900s that shows Gros Michel banana trees succumbing to banana wilt. The Gros Michel banana tree was basically gone by the 1950s, and the Cavendish replaced it.

Vocabulary

genetic diversity, n. the range of different inherited traits that contribute to variations within a species

In neighboring Honduras, the Honduras Foundation for Agricultural Research (FHIA) has been developing disease-resistant varieties of bananas. It's likely that the world will need to embrace these and other types of non-Cavendish bananas if there is a pandemic that wipes out the Cavendish. Editing the genes of the Cavendish so it is resistant to wilt and other threats could be another approach. Getting away from monoculture in the banana trade may help the farmers here. That way, if bananas are hammered by a pandemic, they will have other crops to fall back on, such as coffee and sugarcane.



Reproduction: A Comparison

Living things make more of their own type by either sexual reproduction or asexual reproduction. There are benefits and costs to both types of reproduction. In this table, the **benefits are shown in blue**, and the **costs are shown in orange**.

Asexual Reproduction

Asexual reproduction has low metabolic costs. The energy costs to an asexually reproducing organism when making copies of itself are relatively low. There is no parental care involved, either.



Individuals and traits that are well adapted to the environment can be cloned indefinitely.

If the environment changes, the low diversity in the population can spell doom.

Sexual Reproduction

Sexual reproduction is energy- and resource-demanding. The act of reproducing via sexual means can require tremendous amounts of time, energy, and other resources.



An individual that is perfectly adapted to its environment ends up giving only half its genes to its offspring.

Greater genetic diversity in the population makes it more likely that some individuals will be well adapted to a changed environment—or completely different environments that could be discovered.

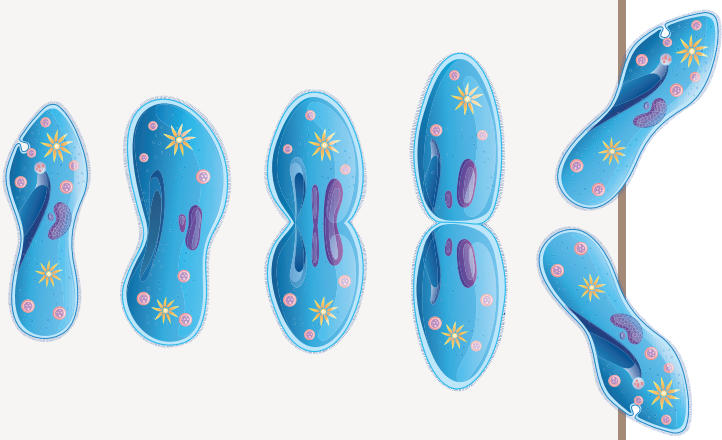


Strawberry plants can reproduce asexually (extending runners out across the soil) and sexually (flowers). This allows the species to get the benefits of both types of reproduction.

Asexual reproduction is simple and fast. At the level of cells and above, asexual reproduction takes less time and is a simpler process. This allows things such as bacteria to reproduce very quickly.

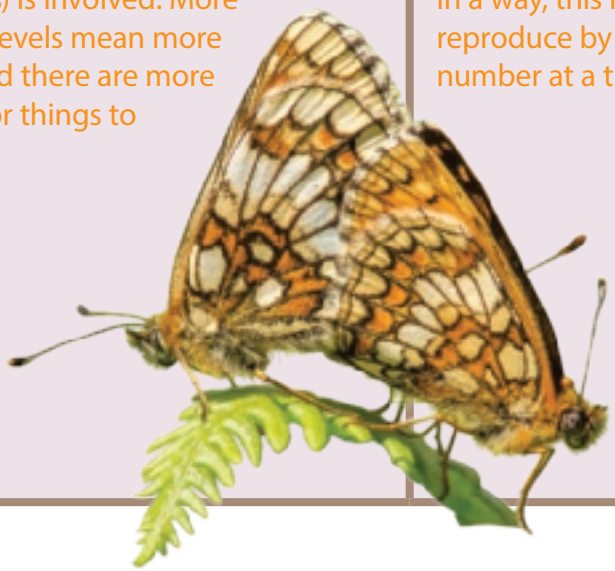


Asexual reproduction is a one-organism job. All it takes for an asexually reproducing organism to make offspring is itself.



Sexual reproduction is complicated and slow. At the level of cells, a whole other process (meiosis) is involved. More steps at higher levels mean more time is spent and there are more opportunities for things to go wrong.

For sexual reproduction, it takes two. Two individuals need to combine their gametes. In a way, this means the population can reproduce by only roughly half its total number at a time.



When Is an Offspring Just Part of the Parent?

Natalie, a forester who studies redwood trees, takes her brother Liam, a student of philosophy, on a tour of a forest along the central coast of California.

Natalie: This grove of trees is interesting because some of them are genetically identical to the larger ones. See the burnt stump in the middle of this ring of more slender trees? The ones around it are its offspring. It turns out redwoods can reproduce asexually as well as sexually. We call the ring of clone trees a fairy circle.

Liam: Kind of like strawberries and mint?

Natalie: Yeah, though in the redwood's case, it's usually the result of some kind of stressor, like a forest fire or the parent tree being cut down.

Liam: You mean a 200-foot redwood can be cut down and then offspring shoot up from the roots even though the parent is dead?



Natalie: Yup. Chemical signals are sent to budding tissue that then grows new trees. The parent is called a genet, and the offspring are ramets.

Liam: So, genets generate ramets, which are arranged in a ring?

Natalie: That's it.

Liam: Are the ramets really offspring? I mean, I know they literally spring off the roots of the parent, but it seems like they are extensions of the parent.

Natalie: I guess it depends on how you look at it. Any clone is a copy of the original, but it gets to have its own life, and in some cases it can end up sexually reproducing, so clones don't necessarily turn into or produce other clones.

Liam: Do genets always die when the ramets grow around them?

Natalie: No, the stressor doesn't need to be fatal. Sometimes a tree is burned or damaged in some other way, and then it produces ramets, but it recovers and ends up surrounded by its offspring.

Liam: If some of the ramets in a ring get stressed or die and make their own ramets, it seems like it's the same organism kind of . . . refusing to die? You're the forester. Do you think of a fallen or burned-out genet as dead and gone? Or is it still here through its ramets . . . potentially forever?

Natalie: Personally, I think of the fallen tree as gone. It was there for a long time, majestic and massive, and now it's not there anymore. To me, that means that tree is gone. Is that the same as death? I guess I wouldn't say that, especially with the ramets being living remnants of the parent tree.

Liam: Maybe our perspective is skewed because we're up here, above the soil and roots.

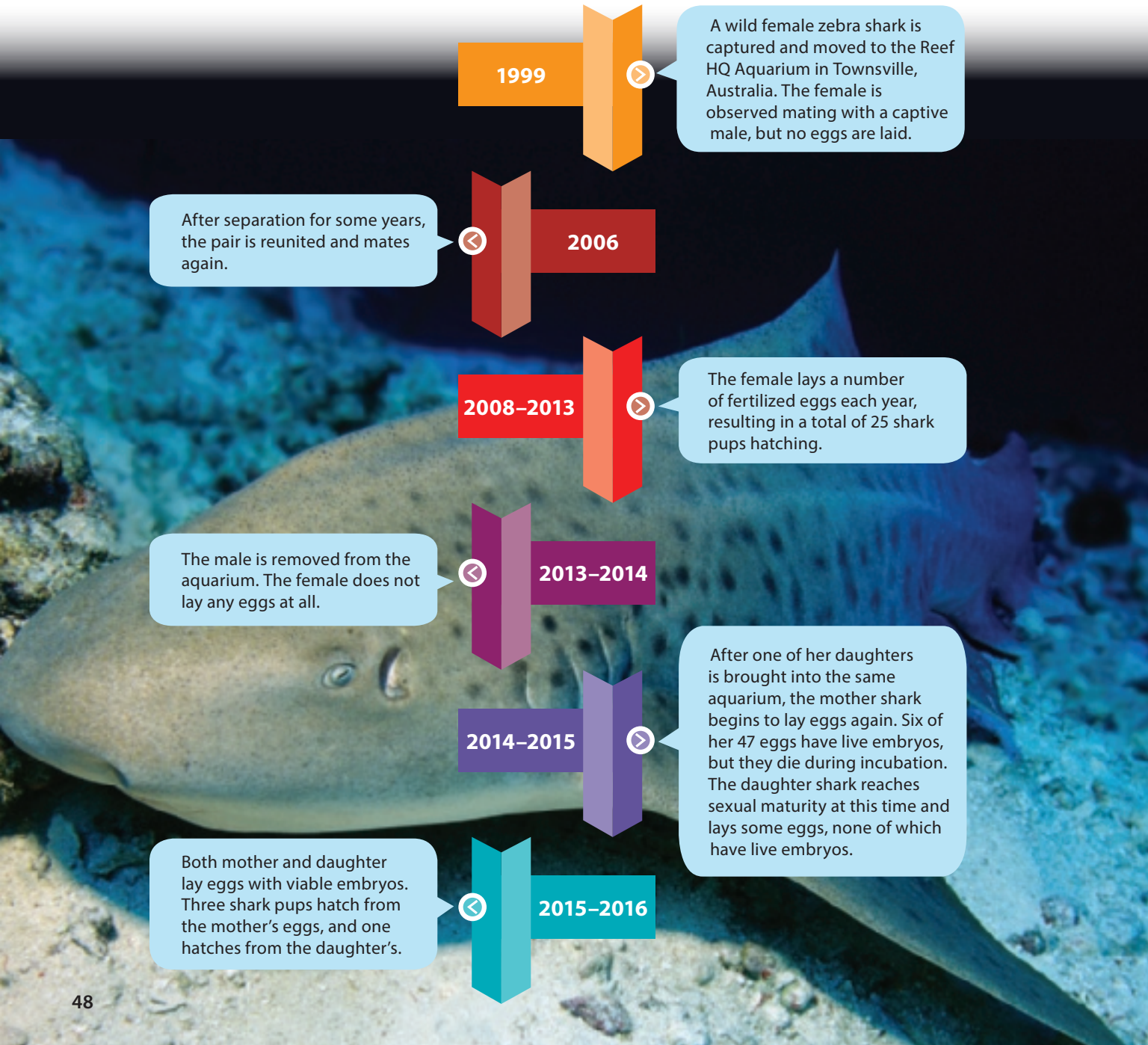
Natalie: That's an interesting idea. We tend to think of mushrooms that way, too. The part we see and harvest above the soil is just the fruiting body. The rest of it is out of sight and therefore, in a way, out of mind.

Liam: Maybe when I graduate, we could create a new branch of biology that's merged with philosophy?

Natalie: If that's your way of saying you need a job after graduation, I might be able to find you an internship.

A Shark Reproduction Whodunit

In an Australian aquarium, a mating pair of zebra sharks (*Stegastoma fasciatum*) produced 25 shark pups over the course of five breeding seasons. The male was then removed from the aquarium. What happened next puzzled aquarists and biologists around the world.



Sperm Storage or Parthenogenesis?

Some shark species had shown an ability to mate and then put off fertilization and gestation until later. This is known as sperm storage, in which the female's body is able to store and support sperm and then mix it with eggs to produce offspring months or years after mating. In this case, sperm storage could only explain what the elder female was doing, as she was the only female who had actually mated with a male in the past. But even with her, sperm storage seemed like a stretch because of how much time had passed between the last time she mated and the most-recent litters of pups she had produced.

In the case of her daughter, sperm storage seemed impossible because the daughter had never mated with a male. Instead, scientists hypothesized that both females had produced clones of themselves, in a process called parthenogenesis. Genetic sequencing of the mothers and their offspring confirmed this hypothesis.

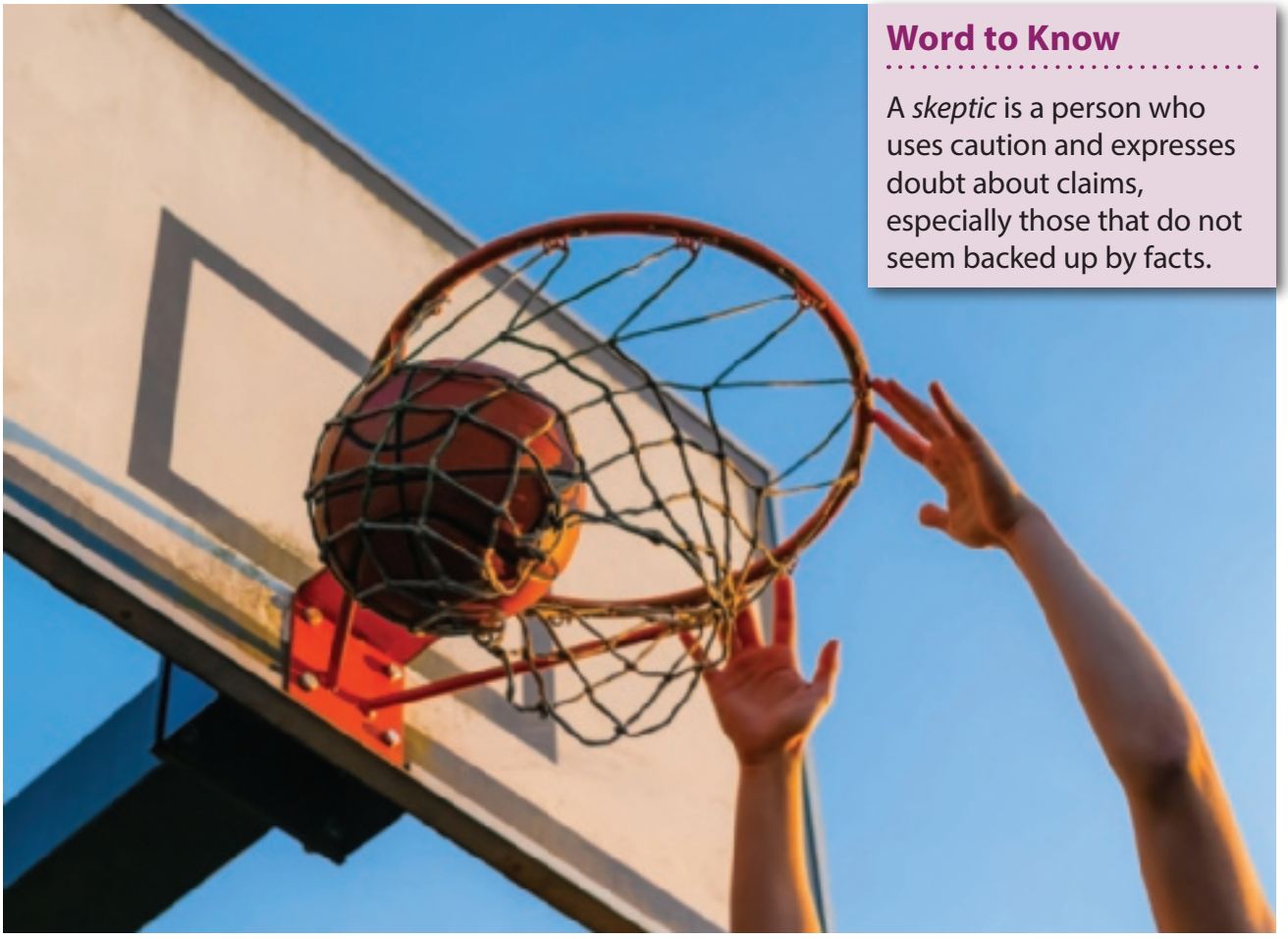
Shark biologists think that the zebra shark and perhaps a number of other cartilaginous fish species are able to switch from sexual reproduction (females mating with males) to asexual reproduction (parthenogenesis) when females are isolated from males. This would be an evolutionary adaptation because an individual with this ability would be able to pass on her genes all by herself, and this could even occur over generations, as shown by the mother and daughter sharks in the Townsville aquarium.

Word to Know

Parthenogenesis is the spontaneous development of an embryo from an unfertilized egg.

Nature and Nurture: Checking In with the Dunking Duo

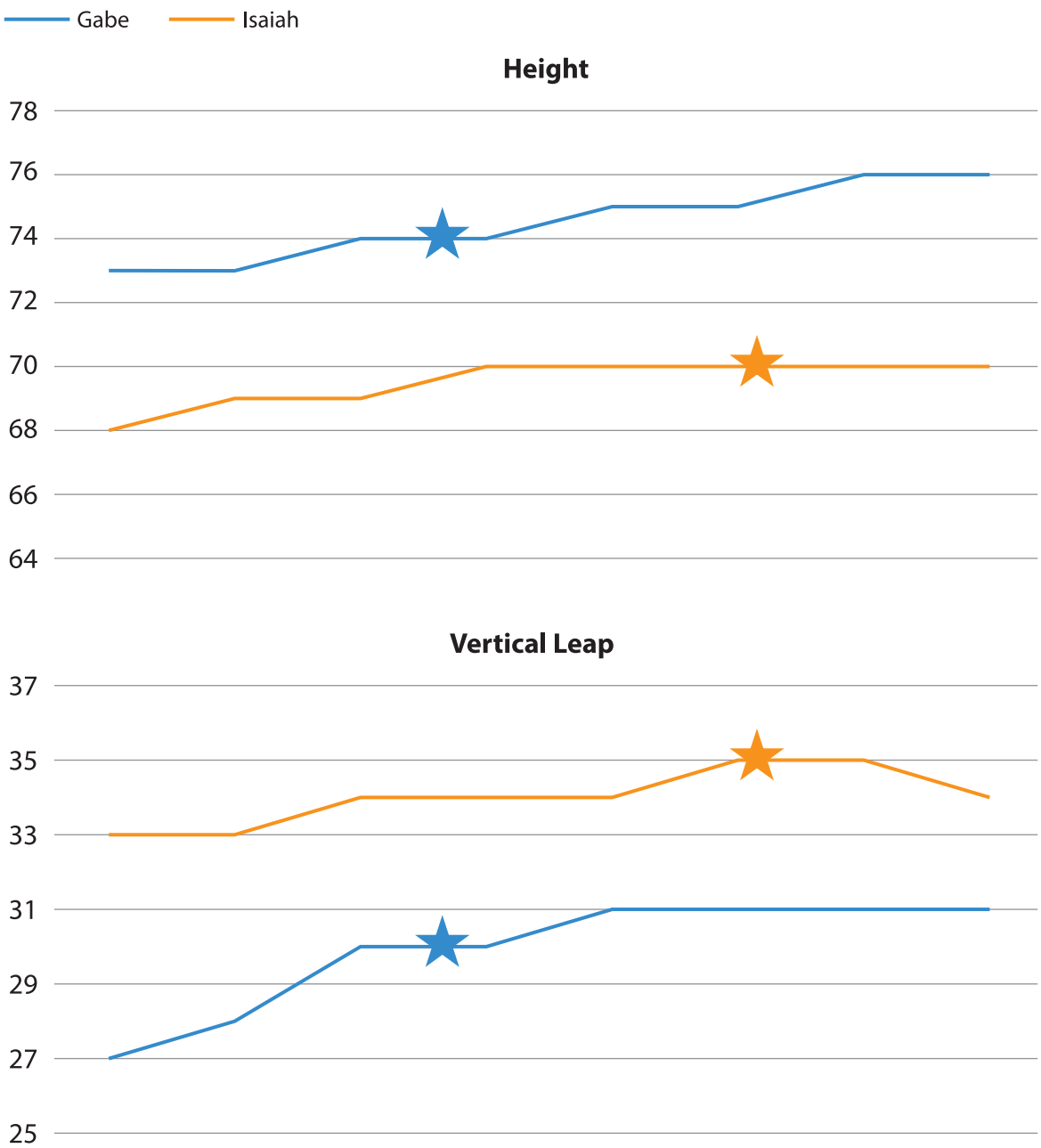
It's been two years since high-school basketball players Gabe and Isaiah debated the merits of special workouts designed to improve their vertical leaps. Isaiah was a skeptic. He thought Gabe was wasting $10 a month on an app that promoted specific exercises to improve leaping ability, because it was mostly genetic. Isaiah thought he had better genes for leaping than Gabe but that what might ultimately hold Isaiah back from being able to dunk was his shorter stature. Gabe was a believer in the app and has stuck with it for several years. Gabe has invested over $240 in the app, while Isaiah has saved his money for other things.



Word to Know

A *skeptic* is a person who uses caution and expresses doubt about claims, especially those that do not seem backed up by facts.

Where are Gabe and Isaiah today? Both boys have grown in height and in their vertical leaps. The graphs summarize their progress.



The first graph shows Gabe's and Isaiah's heights in inches over the last two years. The second graph shows their vertical leaps in inches in the same time period. The stars mark the points in time when they were first able to cleanly dunk the ball through the basket. Isaiah's vertical leap has increased less than Gabe's, but it is higher than Gabe's. Because Isaiah is shorter, it took longer for Isaiah to be able to dunk, and he does so more rarely than Gabe, especially in games.

As high-school seniors, both Gabe and Isaiah are on the varsity basketball team. Gabe is 6'4", and he has increased his vertical leap from 27 to 31 inches. He has been able to dunk the ball for over a year. Isaiah reached 5'10" just as he predicted. Isaiah still teases Gabe about the money he spent on the VertiCalisthenics app.

"$240 *gone*, and all you've got to show for it is a measly four-inch increase in your vertical," Isaiah says. "I told you: all you needed to do was keep getting taller and playing ball. "

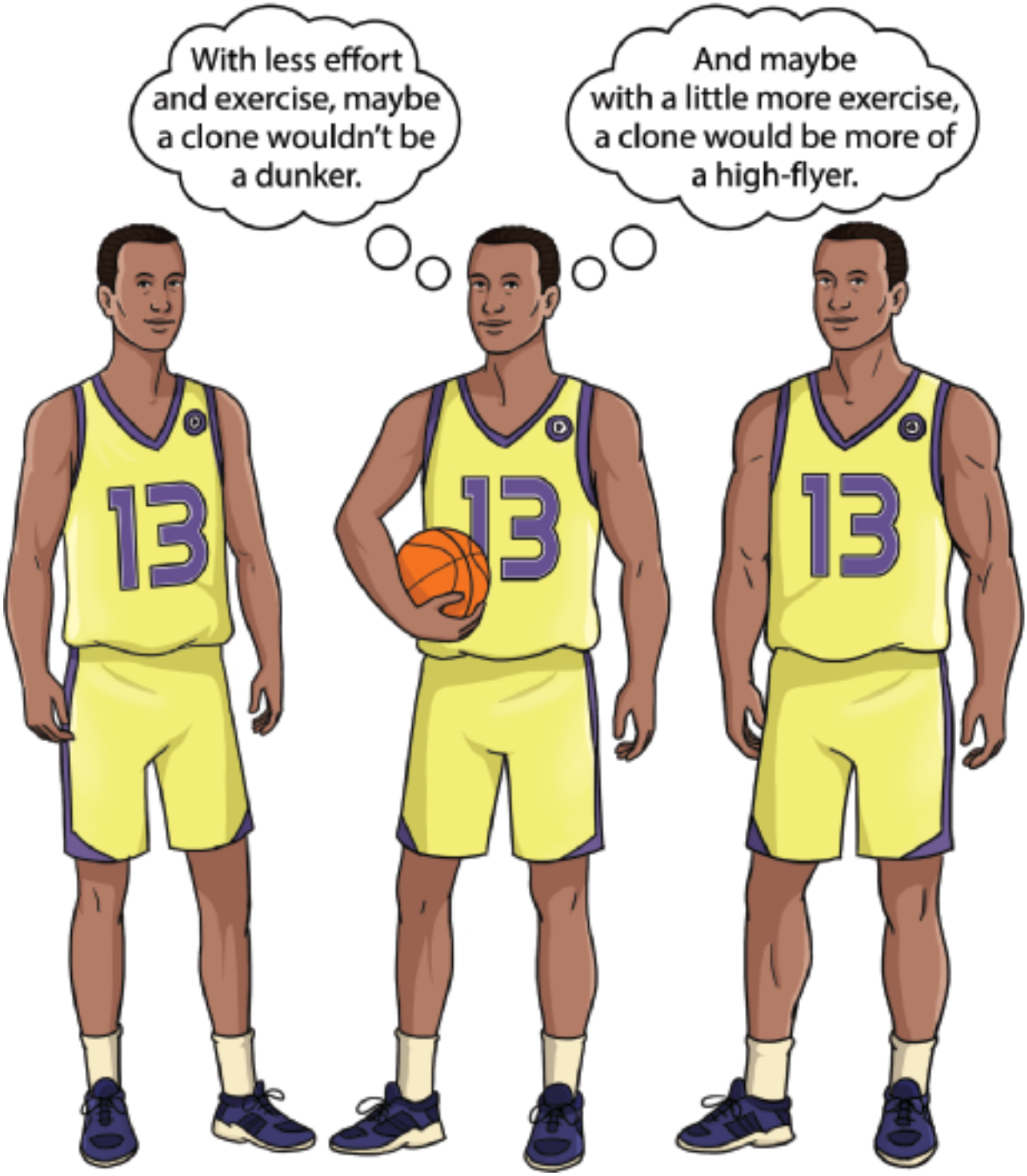
"Well, I still added more to my vertical than you did," Gabe responds.

"So, let's do the math. You paid $240, I paid nothing, and you added just 2 more inches than I did. $120 per inch. Wow, what a deal!" Isaiah cackles.

Gabe and Isaiah are also partners in biology class. For their second-quarter project, they are doing a presentation on cloning. This makes them wonder if their own **clones** would be good basketball players, or more or less able to dunk the ball. Given Isaiah's own experience, he thinks genetics determines about 80% of a person's abilities and traits. In his mind, he can dunk the basketball because he inherited lots of fast-twitch muscle fibers from his mom. If Isaiah could clone himself, his clone would have the same DNA and therefore the same ability. With less effort and exercise, maybe a clone wouldn't be a dunker. And maybe with a little more exercise, a clone would be more of a high-flyer than Isaiah.

Gabe's perspective is different. Even though Isaiah downplays it, Gabe improved his vertical leap and is convinced that without those efforts he would not be able to dunk, at least not as easily as he can. He knew he had fewer fast-twitch muscles than his friend Isaiah. He thinks a person's athletic ability is closer to a 50:50 ratio of "nature" and "nurture." Genes mean a lot. For example, without Gabe's parents being relatively tall, he knows he would not have reached 6'4". He also knows that he inherited his parents' ratio of fast- and slow-twitch fibers. However, Gabe feels strongly that one can work on athleticism and strength and speed through exercise and diet. The fast-twitch muscle fibers he was born with were strengthened and enlarged by doing various weight-bearing exercises, especially for his legs.

Gabe has also read about **epigenetic** factors that can affect the expression of traits. Things can occur while an embryo is developing to turn genes on or off. This can occur later on, too, as the environment of the organism can chemically affect its genome. Gene therapies are now used in medicine. Will they one day be used to give a developing human embryo a higher chance of having lots of fast- or slow-twitch muscle fibers?



Vocabulary

clone n. a genetically identical copy of an organism

epigenetic, adj. above the gene; something that affects the expression of a gene

Glossary

asexual reproduction, n. reproduction that occurs without the union of a male and female gamete

chromosome replication, n. the process of a chromosome duplicating itself as part of the process of cell division

clone, n. a genetically identical copy of an organism

DNA bases, n. biological compounds that form pieces of the complex chemical makeup of DNA

environment, n. the surroundings or conditions in which an organism lives

epigenetic, adj. above the gene; something that affects the expression of a gene

essential amino acids, n. chemical components necessary for life function but that cannot be made by the body and thus must come from food

fast-twitch muscle, n. muscle tissue composed of fibers that provide quick bursts of power but for short durations

fraternal twins, n. a pair of offspring produced by two separate zygotes during the same pregnancy

gamete, n. a male or female germ cell that can fuse with a cell of the opposite sex in sexual reproduction to produce a zygote

gene pool, n. the collective of genes in an interbreeding population of a species

genes, n. segments of DNA that transfer hereditary information from parent organisms to offspring

genetically modified crop, n. food produced with modifications to organisms' DNA

genetic diversity, n. the range of different inherited traits that contribute to variations within a species

genetic mutation, n. a change in the sequence of chemical components within a section of an organism's DNA

genetics, n. the branch of biology concerned with the study of genes and heredity

heterozygous, adj. having inherited different forms of a particular gene from each parent

homozygous, adj. having inherited the same forms of a particular gene from each parent

identical twins, n. a pair of offspring produced by the division of a single zygote into two during the same pregnancy

inbreeding, n. the mating of individuals who are closely related with common ancestors

karyotype, n. an individual's complete set of chromosomes

parthenogenesis, n. spontaneous development of an embryo from an unfertilized egg

phenotype, n. observable traits of an individual, based on interactions of the individual's genes and its environment

pheromone, n. a type of hormone that sends a signal from one organism to another

pollination, n. the transfer of pollen in plants enabling fertilization

recessive allele/gene, n. a variant of a gene that is overridden by a different, dominant variant of the same gene

science literacy, n. the ability to read, hear, and comprehend information about scientific topics and demonstrate understanding in discussion and through writing

selective breeding, n. the human practice of choosing and pairing parent organisms for the purpose of promoting desired traits in offspring

sexual reproduction, n. reproduction that results from the union of a male and female gamete

skeletal muscle, n. organs in humans and other vertebrates that attach to bones and enable movement

skeptic, n. a person who uses caution and expresses doubt about claims, especially those that do not seemed backed up by facts

slow-twitch muscle, n. muscle tissue composed of fibers that provide fatigue-resistant duration

trait variation, n. differences in appearance and function among organisms of the same species stemming from different inherited information

zygote, n. a cell resulting from the fusing of two gametes; a fertilized egg

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