Barbara McClintock was a cytogeneticist, meaning she studied DNA structure and how it works in cells. She is best known for her studies of chromosomes in maize, where she worked on the process of genetic recombination, the role of telomeres and centromeres, and the phenomenon of transposition - regions of DNA that can move from one location in the genome to another. This was some of the earliest data that genes are responsible for regulating physical characteristics by turning on or off in cells.



- Explain what you know about recombination/crossing-over, telomeres, and centromeres.
- Have you encountered information before that pieces of DNA can move locations in the genome of cells? Explain.

McClintock was born in 1902 in Connecticut, to her parents who were both physicians. She was independent and said about herself that she had a “capacity to be alone”. McClintock loved science through school and wanted to go to college, but her mother was concerned that further education would make her unmarriageable, which was a common concern in 1919. However, McClintock began studies at Cornell, taking up studies of jazz music and botany. One of her professors was impressed with her interest and offered her a spot in a graduate course in genetics. McClintock went on to earn her MS and PhD in Botany at Cornell, even though women weren’t officially allowed to earn degrees at the time.

- Have you ever experienced something you wanted to pursue, but weren’t allowed or encouraged, to do so? How did that affect you? Explain.

McClintock went on to study ways to visual chromosomes, including still-used staining techniques that she developed. In 1930, she was the first to describe the cross-shaped interaction of homologous chromosomes in meiosis, and she later showed this is the basis of recombination of genetic traits. She was awarded several fellowships across the United States and in Europe and moved among several research institutions. In 1940 she became dissatisfied with her position in Missouri because she was excluded from faculty meetings, and in 1941 she moved to Cold Spring Harbor Laboratory in New York. She was highly productive and began studies on the mosaic color pattern in maize seeds (corn kernels). This led to her work on transposons, mobile pieces of DNA, that she termed Dissociation (Ds) and Activator (Ac) in maize. McClintock’s work was foundational in so many areas, including general DNA structure, recombination, Neurospora (bread mold) genetics, maize genetics, and mobile DNA (which we now know occurs in most organisms).

- Think back to a time when you felt excluded or that you weren’t listened to – do you think that impacted the field you chose to study in college? Why or why not?

She has been awarded multiple honors and has left a legacy in genetics. She was awarded the Nobel Prize for Physiology or Medicine in 1983. McClintock died in 1992 at the age of 90 years old.

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Mary Frances Lyon is a geneticist who discovered that women, and all female mammals, are cellular mosaics. The so-called “sex chromosomes" were discovered at the end of the 1950s by noting their distinct size differences and that they assorted differently in males and females. The dilemma was that if females typically had two X-chromosomes and males most usually had only one X-chromosomes, did females use both Xs? Mary proposed that one X-chromosome undergoes X-inactivation, so that the number of active X chromosomes is equal in all cells, and that this happens very early in development.

- Describe the Lyon Hypothesis and how this explains calico cat coloring.

Mary Lyon was born in 1925 in England to parents who worked as a school teacher and a government civil servant. She became interested in science in grade school, and read up on her favorite topics during the Second World War, when she went to college at Cambridge. She was one of only 500 women allowed into Cambridge with 5,000 men already there. Because she was female, her undergraduate degree from Cambridge was informal, however she earned her PhD from Cambridge as well and published her early research. She studied mutations in mice, when she noted that some females were “mottled” which was a variegated fur color.

- How do you think the fact that Mary was one of few female students at Cambridge in the 1950s affected her interest to pursue studies in science?

Mary was later elected to fellowships, awarded for her work, and published several scientific journal articles. She won an award in 1994 for Human Genetics, in 1997 for work in Medicine, 2003, 2004, 2006 awards, and several genetics societies now give awards named after her in her honor. She died in 2014 at 89 years old.



Janaki Ammal has been called “the first Indian woman botanist”, for her work on plant cytology and patterns of gene expression in plants. Her work on breeding hybrids, in particular her work on sugarcane, developed varieties that had high sugar content but were also hearty and could be grown in India, not imported from other countries.

- Define ‘cytology’. What is the current importance of this field of genetics?

Edavaleth Kakkat (E.K.) Janaki Ammal was born in 1897 in Kerala, India to a family that would have 19 children total. Her father was a judge but also an avid gardener and bird watcher. As Ammal grew up, she watched her sisters leave through arranged marriages. She chose to not accept a marriage and instead went to Queen Mary’s College in Madras to earn a bachelor’s degree and honors in botany.

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- It was rare at this time in India for women to get any higher education, above 10th grade. Do you think it was difficult for Ammal to take a different path from the rest of her family? Explain.

After Ammal taught at a Women's Christian College for three years, she had the opportunity to study abroad at the University of Michigan. Before she could get to Michigan, she was detained in Ellis Island until her immigration status cleared and it's possible she was only let through because she was mistaken for an Indian princess. In Michigan, Ammal earned a Masters of Science in 1925 and a Doctorate in Botany in 1931. Her well-developed background in hybrid breeding of plants and their chromosome make-up, allowed her to eventually move to England and co-authored botanical atlas 'Chromosomes Atlas of Cultivated Plants' in 1945, which is still an important text today.

In 1946, Ammal became the first paid female staff member as a cytologist at the Royal Horticultural Society in England. She worked using colchicine, a chemical that could induce doubling the chromosome number in young seedling plants. She returned to India in 1950, at the request of the Indian Prime Minister, to help the country establish protocols to boost food crop production. During this time, 25 million acres of forestland were cleared for food cultivation, and this disturbed Ammal greatly, because the deforestation also destroyed a number of India's native plants. Thus, in the later years of her career, she was an environmental advocate for the importance of Indian people studying and cataloging India's native species.

- Have you found something you are passionate about in science? Give a brief description.



Ammal died in 1984 at the age of 87. She has a number of plants named after her, including the Magnolia Kobus Janaki Ammal and the E.K. Janaki Ammal rose.



Carlos D Bustamante works on the genetics of human populations at Stanford University. He has commented that race isn't a meaningful way to characterize people and that genetically there are no distinct races, there is instead a broad continuum of genetic variation across the planet.

- Does this surprise you to learn that our DNA differences don't separate humans into different races genetically? Explain.

Bustamante was born in Caracas Venezuela in 1974 and immigrated to the United States when he was seven. He was interested in how history and science intersected, and began volunteering at a lab at the University of Miami. He graduated from Harvard with a bachelor's in biology, a Master's in statistics, and later a doctorate in Biology.

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Bustamante went to Oxford to study Mathematical Genetics, and then received a faculty job at Cornell. In 2010, he was awarded a MacArthur Fellowship (sometimes called the 'Genius Grant'), to study DNA sequences in humans that might show how evolution works. At this time, the Human Genome Project had been published, but it was still unclear how genomes of individual people could be used in human medicine, and there was lots of work to do. He has stated that currently DNA databases are "too white" and we need more data from non-white people.

- What might we gain in terms of research data if we had more DNA from non-white people in DNA databases?

In 2013, Bustamante found a region of DNA that can trace all *Homo sapiens* back to Y-chromosomal Adam and Mitochondrial Eve.

- Do a quick google search, and describe what is meant by the Y-chromosomal Adam and Mitochondrial Eve.

In 2018, Bustamante was the researcher who carried out DNA testing on Senator Elizabeth Warren to note that her ancestry is mostly European, but she does have Native American ancestors six to ten generations ago. He currently works on connecting markers in the Human Genome DNA to help treat diseases in different human population groups.



Mary M Daly is the first Black American woman in the United States to earn a PhD in Chemistry and was an American biochemist. Her work was foundational in histone structure and protein synthesis, then later on the connection between cholesterol and hypertension.

Daly was born in Queens, New York in 1921, and she developed a love for science from a young age. She attended a laboratory high school for girls that encouraged her to work in chemistry. She graduated from Queens College in 1942 with a bachelor's degree in Chemistry, one of the top 2.5% of her class. She completed her Master's degree in Chemistry in 1943 where she met Mary Caldwell, who had a PhD in human nutrition. She helped Daly study body chemicals that aid digestion, and Daly's doctoral thesis was on pancreatic amylase toward her PhD in 1947. She worked at Howard University and then joined a group at Rockefeller Institute of Medicine to study how proteins were constructed in the human body.

- During these studies on protein synthesis from 1948 to 1955, the structure and function of DNA had not been worked out. What might have been some questions researchers had at this time about how proteins are made?

Daly was working at Columbia and then at the Albert Einstein College of Medicine from 1955 to 1975. She enjoyed combining research with teaching medical students and she began exploring heart function and factors in heart disease at the same time she was working to increase the number of minority students in medical schools.

- Daly attended a conference in 1975 which prompted the AAAS to release a report that recommended recruiting and retaining minority women scientists. Yet we still are working

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to recruit and retain minority scientists, especially minority women and non-binary people. What might be some factors that contribute to fewer minority folks in STEM fields?

She received a number of awards and career designations during her years of work, including recognition as one of the top 50 women in STEM. Daly died in 2003 at age 82.

Rajeev Kumar Varshney is an agricultural geneticist, specializing in genomics, DNA techniques in plant breeding, and capacity building in developing countries. In particular, he works on the genome of barley and other cereal grains to be able to grow these more productively across climates and with increased yields. His work has direct implications for food security, world hunger and malnutrition. Being able to improve global agriculture is a "wicked problem" with many areas of active research.



- What is a 'wicked problem'? – do a quick google search if you are unfamiliar with this term and describe this in your own words. Also give some examples of other wicked problems in the U.S. or globally. Which of these might be tackled in part through genetics research? Explain how so.

Varshney was born in 1973 in Bahjoi, Uttar Pradesh, India into a middle-class family. Growing up, he wanted to become a space scientist, fueled by reading comics. However, living in India he said everyone is touched by agricultural concerns, thus he turned his interests to genes and plant breeding. He received his college Bachelor's degree in Botany, and then Master's and PhD degrees in Botany with a specialty in plant genetics, all in India. He then moved to Germany after his doctorate to further study agricultural science and molecular breeding techniques. During this time, he attended a conference in Italy where the speaker challenged the next generation to "embrace new tools and technologies to tackle food security issues in the developing world". This motivated Varshney to think about translating his research to development of better crop varieties with improved yield and nutrition.

- What do you think of a decision to pursue work that is needed by society versus work that is of interest to someone personally? Is one choice better than the other? Explain.

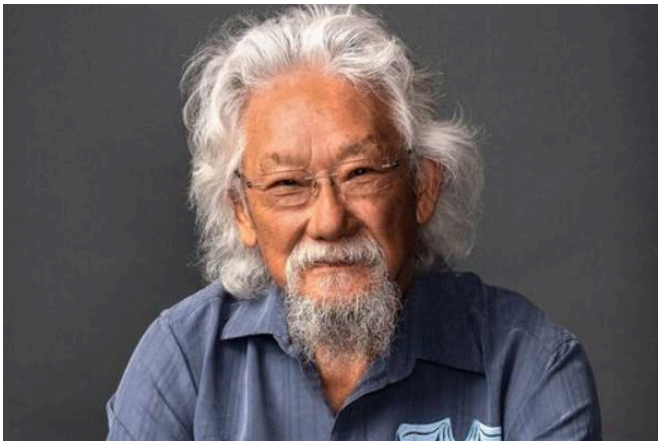
Varshney applies genomic resources to breed crops with high stress tolerance, high nutrition, and easy seed delivery systems. He has done this, in part, through development of DNA markers that identify useful genetic variation in tropical crops, which he then applies to grain and cereal crops. Varshney developed groundnut strains with high omega-9 fatty acids, chickpeas with drought tolerance for Ethiopia, and legumes with drought- and pest-tolerance for sub-Saharan Africa. He wants to see these seeds in the hands of small, independent farmers.

- What are the benefits to helping small, independent farmers grow these crops? Are there any downsides? Explain.

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Varshney (aged 47 in 2021), is an elected fellow of about 10 science and agriculture academies/societies in India, Germany, USA, and more and the recipient of multiple prestigious awards including the SSB Prize, the most prestigious agricultural science award in India. He credits his research mentors for his success, in particular the way they instilled in him the importance of hard work, commitment, and perseverance. Varshney has initiated and led international programs to create and deliver sturdy and abundant crop varieties to farmers in some of the economically poorest areas of the world. He works with a team of his own in conjunction with the Bill & Melinda Gates Foundation to spread the developed crops to multiple locations. Varshney says “Science research cannot be restricted to any one nation, we conduct our research with partners in the national system from India, sub-Saharan Africa and other parts of the world as well, with the potential to help the global scientific community as well as smallholder farmers across the globe”.

David Suzuki is a geneticist, environmental activist, Canadian researcher, and science broadcaster. He is best known as host and narrator of a well known and loved CBC Television science show called ‘The Nature of Things’ and as an outspoken environmental activist. He has also been vocal about the government’s mistreatment of First Nation people in Canada, and an advocate for Black Indigenous and People of Color in the US and Canada.



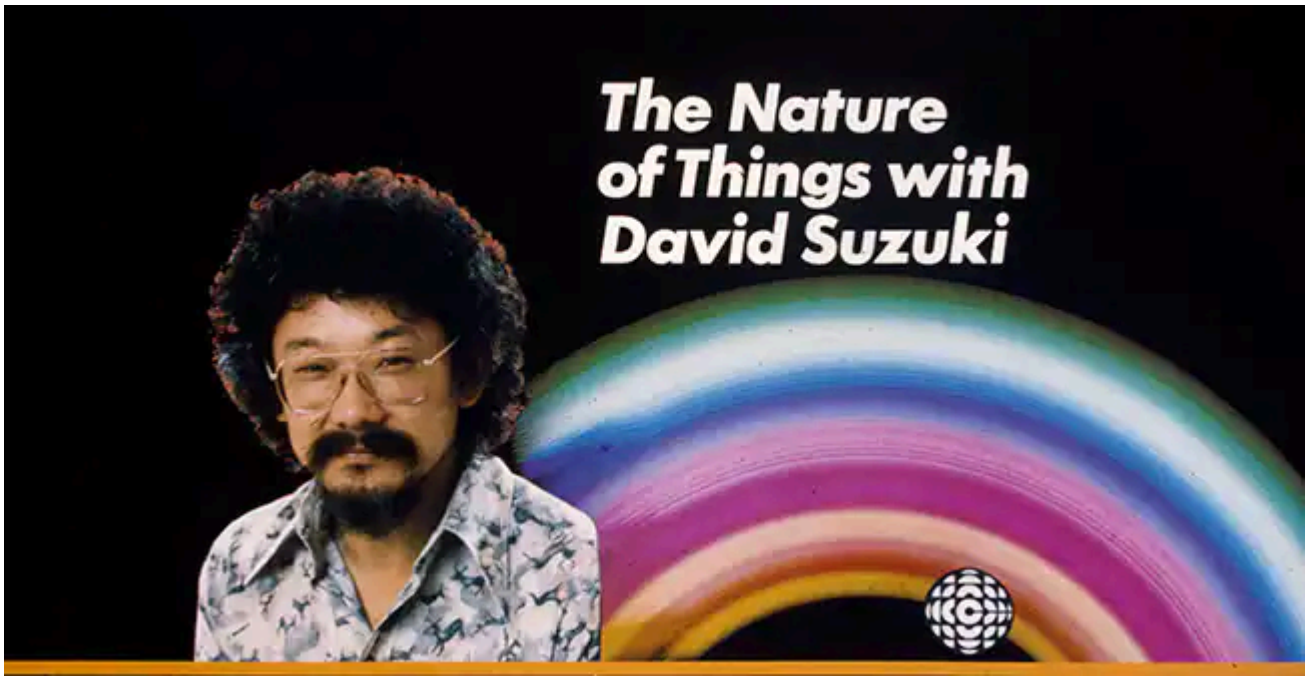
Suzuki was born in 1936 in Vancouver, BC, and is a third-generation Japanese Canadian. He has three siblings, and he and his family suffered in a BC internment camp during World War II from the early 1940s to 1945. After WWII, like many Japanese-Canadians, Suzuki and his family were moved east, to Ontario province. Suzuki credits his father for continually interesting him in nature and sensitizing him to nature’s importance. Suzuki graduated with a BA in Biology in 1958 from Amherst College, and earned his PhD in Zoology at University of Chicago in 1961. He began his research on *Drosophila melanogaster,* fruit flies, during his BA degree, and continued as a professor of genetics from 1963 to 2001. He is best known for studies of temperature-sensitive mutations in Drosophila that led to understanding neural synapses and neural-muscle function.

- Drosophila melanogaster is one of the best-known model organisms. In 2-3 sentences describe what a model organism is and their importance in genetics (do a google - search if needed) – make sure to explain in your own words.
- What are temperature-sensitive mutations? How do they affect phenotype? Look this up if needed and explain in your own words.

Suzuki began a children’s show called ‘Suzuki on Science in 1970, and later founded radio and TV programs. He has hosted several Public Broadcasting Service (PBS) science shows that have been viewed millions of times. In the 1980s Suzuki began doing more work in

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climate change education, and in 1990 co-founded the David Suzuki Foundation which works “to find ways for society to live in balance with the natural world that does sustain us”.



Suzuki has become an outspoken climate change activist, which has led to controversy regarding his views. He has advocated for jailing leaders and CEOs of companies that harm the environment. He states that there is enough research to conclude that climate change is real and that it is human-caused. In Suzuki’s view, a small number of very vocal climate change critics are causing the public and the media to be more doubtful about climate science that is justified. He has also spoken forcefully against GMOs, about concerns of nuclear power, oil, and coal companies, and on immigration and Canadian justice systems.

- Suzuki has had a life-long focus on educating children in science – genetics, climate change, and beyond – and making science and environmental issues relatable to the public. What do you think is the importance of science education for children and the general public?

Suzuki married his first wife in 1958 and they had three children. He divorced, and married again in 1973 to his second wife and they had two more children. Suzuki says he and his second wife have a pact that she does all the cooking and he does all the dishes – he considers doing dishes a Zen experience. He currently has several grandchildren. Suzuki is vocal about his love of nature and concern for our climate and world ecosystems. In total, he has published 52 books, including 19 children’s books, has been awarded numerous honors, and has at least 29 honorary degrees from around the world.

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Wendy K. Chung is an American doctor and geneticist. She was born in Nebraska and raised in Florida. Since her parents are both in science and medicine, she was interested in the field early on and double-majored in biochemistry and economics at Cornell University. She later earned her PhD and MD and was focused on pediatrics and molecular genetics.

She focuses her practice on the genetic basis of human disease, in particular she works on genetic birth defects and rare disorders in children. She and her team have discovered hundreds of genes involved in human genetic disorders. Chung helped develop a screening for spinal muscular atrophy (SMA) in newborns and is working on treatment.

- How are recessive genetic disorders inherited from parents?

Chung started the DISCOVER program at Columbia University. The name stands for Diagnosis Initiative: Seeking Care and Opportunities with Vision for Exploration and Research. This group analyzes all the genes in a person with a genetic disease, and looks for the gene or genes that are the problem. She will often work with parents and other families from around the world whose child has similar symptoms to try to track the disease. Finding the genes helps Chung and colleagues then develop a treatment. Through this program, she has discovered 41 diseases never known before. Examine a case study of a genetic mutation for retinitis pigmentosa (RP) here, if you wish.

- How many genes approximately does a person have in their genome?
- Why might working with the parents of a child and other families whose child has what looks like the same disorder be helpful to figure out the genetics of rare disorders?

The year Chung started medical school was the first year of the Human Genome Project. She thought “They’ve got a 20-year plan to complete the human genome. I’ve got a 20-year training plan; we’ll both finish at the same time.” And indeed, sequence of the human genome has been valuable in her research. For most of her patients, the journey doesn’t stop with the diagnosis, that’s only the beginning. Diseases that present in childhood are often more severe than those that present in adults, and likely to be genetic, but without treatments currently available. She says, “I’m your Sherpa….I don’t know all the answers, but together, we are going to go on this journey into uncharted territory.”

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Alejandro Sanchez Alvarado grew up in Caracas, Venezuela. He moved to the United States to study molecular biology and chemistry at Vanderbilt University in Nashville, TN, because he says, the only way to study biology in Venezuela was to go to medical school. When Sanchez Alvarado began at Vanderbilt, he spoke no English, and he thought Nashville would be the best place to learn English fast because no one there spoke Spanish. During his undergraduate classes, he became interested in the process of regeneration.

- Sanchez Alvarado helped develop planaria as a model organism for research. In particular, he and his group have produced tools and reagents for working with *Schmidtea mediterranea*. Do a quick google search to find out what planaria has taught researchers about the genetics of tissue regeneration.

Growing up, Sanchez Alvarado enjoyed art, nature, running, and reading. He was very inspired by a high school teacher named Maldonado, who began all classes by asking questions and having the students come up with tentative answers to stimulate more questions. After his undergraduate school, he went back to Venezuela to practice biology, but he couldn't earn enough money. So, he went to Cincinnati to be a lab technician and earn enough money to start graduate school.

He then went to the University of Cincinnati College of Medicine for earning his PhD in pharmacology and cell biophysics. While working on his PhD, Sanchez Alvarado first attended the Marine Biological Laboratory at Woods Hole, MA. This research space has taken in students and teachers since 1888, for the study of scientific discovery. Sanchez Alvarado said he has loved his time at MBL and has been back for research and study many times since his first visit in 1995.

- Humans are evolutionarily related to organisms that can perform regeneration of organs or entire body parts. One idea is that humans lost the ability to regenerate because it encouraged tumor formation. How might processes for regeneration and cancer be related?

Sanchez Alvarado has given talks on the fact that life on earth is a history of rule-breakers, and has advocated strongly for the importance of basic research in science – research to discover the unknown as opposed to development of something for a specific purpose. In this type of research, people are constantly trying to understand something that doesn't initially make sense to them. He says, "If you don't feel like a complete idiot most of the time, you're just not sciencing hard enough." As of January 2021, Sanchez Alvarado is the Executive Director and Chief Scientific Officer for the Stowers Institute, a nonprofit basic biomedical research organization in Virginia , where he heads several research groups studying regeneration and the genetics of tissue development and maintenance.

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Rene Begay is an Indigenous geneticist and public health researcher. She works right now as a Professional Research Assistant at the Centers for American Indian and Alaska Native Health at the University of Colorado School of Public Health, with her Masters degree in clinical science.

Begay was raised on the Navajo Nation by her mother, who worked as an Indian Health Service nurse. She went to high school off the reservation, in Flagstaff, AZ at Coconino High School, and discovered her love of a whole room dedicated to being a science lab. The hands-on nature of science and problem-solving appealed to her. Begay studied Biology in college and took a genetics course. Around this time, a research lab in Denver, CO approached her to see if she was interested in graduate genetics study. And she thought "I got a C in genetics! I don't know if I can do that." But Begay was very interested in genetics and heart development in particular, so she began grad school in Colorado and says it felt very foreign at first.

- What is the benefit to pursuing a career interest, even if it feels foreign at first? Additionally, what factors might have influenced the fact that Begay felt she wasn't good at genetics, but she was able to earn her master's degree and still works in that field?

In graduate school, she worked on tracing family genetics and correlations to heart disease. She thought, wow, this could really help Navajo people who are disproportionately affected by obesity, diabetes, and heart disease. Just as she was beginning to merge her interests in medicine and genetics with her Navajo background, she learned that the Navajo Nation has banned all genetic testing on tribal land, from 2002 onward. She still feels passionate about genetic research and advocates for genetic testing, but understands why the Navajo Nation is cautious. She says, "*Because, you know, if you're gonna decide,* Oh, I want my DNA back at a certain point*. So, you know, you really need to have—have thought about this. You know, what are you going to benefit from? And what are you comfortable giving up to these researchers or medical professionals when you provide your DNA to researchers?"*

- What are the pros and cons of providing your DNA to a genetic research study on the human genome and genetic diseases?

Begay graduated with her Master's Degree working on the hereditary causes of heart disease. She plans to complete her Public Health Training Certificate for American Indian Health and then pursue medical school or a combined MD/PhD program. Begay feels it's crucial to get more Native voices in genetic research. She wants to work on human genome research as it applies to personalized medicine and how it integrates with genetics. She also has deep roots in Native concepts of health and balance. Begay says her grandmother spoke of "living in harmony with the mind, body, and earth."

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