<u>You Can't Always Get What You Want: A Lesson in Human Evolution</u>

JULIE BOEHM: Hi. My name is Julie Boehm. I'm a biology teacher at Wellesley High School in Wellesley, Massachusetts, in the United States. Today, I'm going to talk to you about the topic of evolution-- specifically, human evolution.

Most of time when I ask my students what they think evolution means, especially human evolution, an image like this pops into their heads. You may think the same thing. Today we're going to change that misconception and move to an understanding that looks more like this, which is a graphical way of showing the relatedness of various species based on their genetic codes.

You read this chart by looking back about seven million years ago at the start of the tree. And as time progresses, you see branching of the tree leading to different species, such as humans and chimps. You can also see a branching on human section, but humans are all one species. This graphic just shows groups of humans as they relate to locations-- such as Africa, Asia, and Europe.

Using this tree, you can see that chimps and humans are related, though more as distant cousins rather than a direct lineage. And this, where you can see that humans are a diverse group of people from the same species. Additionally, we're going to look into many traits that human populations have evolved in more recent history to aid in survival, and learn how traits are selected for or against.

Before we dive into our first activity of the lesson, I want to share an interesting story of human evolution with you. Chances are you enjoyed something with dairy for breakfast this morning, maybe milk in your cereal or coffee. I just ordered a coffee with lots of milk for my breakfast this morning. You might know someone who's lactose intolerant, meaning they can digest the sugar-- lactose-- found in milk or milk products.

And when they eat those things, they get very sick. Did you know though that lactose tolerance-- meaning the ability to digest lactose-- is a recently evolved trait for humans? It was not always the norm.

Humans have always been able to digest lactose when we are babies because we rely on our mother's milk to feed us. But after that, the gene required for this breakdown is turned of. About 10,000 years ago-- a relatively short time when we think about evolution as a whole-- a mutation occurred that allowed a small population in Africa to keep that gene turned on, and they were able to continue digesting lactose after infancy.

This trait was a huge benefit for their population, because these people now had another nutrition source for their diets. The mutated form of the gene became more abundant over time, with those more fit individuals being able to survive and reproduce better than those without it. This mutation also independently occurred in other populations around the world.

Why was digesting lactose suddenly so important for this population? There must have been a change in their living conditions, or environment as we think of it in evolutionary terms, that made it so important for these people to digest lactose. Now it's time to establish this connection for yourselves. We're going to take a break and go into our first activity where you can look into the connection on your own.

You'll be given some maps of the world to analyze. One world map shows the frequency of lactose tolerance, and the other relates to the supply of food in those areas. It will now be your job to compare these maps. Think about how these traits relate to human evolution, and to make some hypotheses about selective pressures in the area of the world in which you live. I'll see you in a few minutes.

Welcome back. You've just completed the map analysis activity, where hopefully you've established the connection between lactose tolerance and the domestication of cows. I hope that you were able to see that in areas of high cattle and cow domestication there is a high prevalence of lactose tolerance, and vice versa. Areas of no or low cattle domestication had areas with little or no lactose tolerance.

You can think of this relationship in terms of the presence of milk as a prevalent nutrition source. This is a huge environmental selective pressure on the population of these countries. And those people who have a trait that allows them to take advantage of the new food source are able to survive and reproduce at higher numbers than those who don't.

The effects of this change that occurred about 10,000 years ago can be seen today in current human populations, with approximately 90% of people of East Asian descent being lactose intolerant, compared to only 5% of people of Northern European descent being lactose intolerant.

We're now here at the Broad Institute in Cambridge, Massachusetts. I was lucky enough to work with some amazing evolutionary biologists to help develop my lesson.

ELINOR KARLSSON: Hi, my name is Elinor Karlsson. I am one of the evolutionary biologists. I work here at the Broad Institute. And the Broad Institute is a research institution, one of many around the world, that's trying to use what we're learning from the Human Genome to understand disease and hopefully cure it.

JULIE BOEHM: Evolution can be a tough concept to understand, mostly because human evolution cannot be seen during one's lifetime. You can think of the term "evolution" as change, changes in allele frequencies, over time. Remember that alleles are different versions of a gene.

Now, when I say "time," you may think hours, days, weeks, years. But in the context of evolution, we mean tens of thousands of years. Humans-- *Homo sapiens*-- have been on this Earth for the last 120,000 years or so. You may or may not know that humans originated in Africa. We can look at this map to see how humans over a long period of time have migrated out of Africa and slowly populated the rest of the Earth.

Over that time, our species has undergone some amazing changes due to the environmental pressures placed on populations in these locations all around the globe. When we look at this graphic, we can see that there have been quite a few evolution events in recent human history, seeing our lactose tolerance example from the last activity pop up approximately 5,000 years ago, meaning that humans are still in the process of evolving.

This graphic is similar to the one in the first segment, but now we've focused in on the human branches. The time above shows years before present, and the red areas show the emergence of gene mutations that lead to various traits-- one of which we've already discussed, such as lactose intolerance. You can see how the various traits relate to the location of each population.

For instance, you can see that the lactose tolerance gene is expressed in the populations of Africa and Europe, but it is not seen in the Asian populations. We will return to this later. When you look at the diversity of humans in this world, you can notice that we have many subtle changes in the way we look-- skin color, hair color, eye color.

For instance, as we'll talk about later, darker skin colors protect populations in regions with intense UV sunlight from skin damage and cancer. These physical traits are also adaptations to varying degrees to local environmental pressures, much like the lactose tolerance example we've been learning about. Natural selection drives this adaptation.

Remember that survival is based on the ability to survive and reproduce in an environment. If you can do that, then you can contribute to evolution on a greater scale. When you think about the concept of evolution, one important clarification is evolution is a process that happens within populations, a product of differential survival where some individuals are better able to survive and reproduce than others.

Those survivors also need to reproduce and pass on those advantageous genes in order to contribute to the evolution of the population. These are not situations in which individuals-- or populations for that matter-- decided to acquire a trait. Evolution is a random process. You can't simply get what you want.

Now you're going to do an activity to simulate how natural selection works on a population. You're going to see how some traits based on environment are able to survive and some are not. You're going to be using inanimate objects for this simulation, but try and pretend like they're real living organisms fighting to survive and ultimately reproduce. This activity should take the rest of your class time today, so I'll see you next class to summarize the results and debrief.

Welcome back. You've just completed a simulation of survival based on environmental conditions. Depending on the environment, some of these organisms were better able to survive and ultimately reproduce, thus changing future populations. For instance, if you completed the activity outside on the grass using the tri-color pasta, you probably noticed that the green pasta were able to survive much more than the orange or white ones. The green survival led to an increase in the green pasta population over time, as that population had more survivors, thus were able to pass on their traits to the next generation.

Again, we can imagine that these were real organisms trying to camouflage themselves so that they were not eaten by the predators, and that some have a selective advantage over others. Now it's time to figure out where these traits and their variability come from. People in different parts of the world exhibit different traits, some of which are adaptations to their local environments.

Thus far we've discussed examples of how physical traits confer advantage, such as lactose tolerance, skin color, and the survival of our pretend pasta species. Where do these physical traits, or phenotypes, actually come from? DNA. We can revisit the graphic we looked at earlier, showing the relatedness of organisms and related to the DNA changes or mutations.

If we look at this graphic again, we can see that the phylogenetic tree split 6.5 million years ago when humans diverged from the common ancestor we shared with chimps. When a new species is formed, it's actually caused by DNA mutations or changes. As DNA changes over time, the differences accumulate, and we can see these changes in phenotype or the traits exhibited by the organism. When these changes are significant enough, a new species can form.

Remember that Darwin showed that natural selection drives adaptation. And as we saw in our last activity, individuals with traits best suited to their environments are able to survive and reproduce more. Remember that natural selection acts on traits that are present in a population. Something that Darwin didn't know, or understand at the time he was alive, was that those traits are the result of genetic variations. DNA mutations occur randomly, giving rise to new variations of the original trait.

You probably remember from your unit on genetics that we call these versions of genes alleles. Alleles contribute to an organism's genotype, which then determines its phenotype or trait, some of which are dominant and some recessive. The traits that provide a selective advantage to people who have them will become more prevalent or common in that population over time.

We've just talked about how certain alleles become more prevalent in a population when they give selective advantage to the individuals that have them. This is very much the case when we look at humans living in places at high altitude, such as indigenous populations living in the Tibetan Plateau in Asia. When you travel to an area of high altitude, you are likely to suffer from hypoxia, a condition created by a diminished supply of oxygen to body tissues.

At high altitudes, there air is much thinner than at sea level. As a result, a person inhales fewer oxygen molecules with each breath. Symptoms of hypoxia-- sometimes known as mountain sickness-- include headaches, vomiting, sleeplessness, impaired thinking, and an inability to sustain long periods of physical activity. At elevations above 25,000 feet, hypoxia can kill.

We see in this graphic that the Tibetan populations, less than 3,000 years ago or so, developed a few mutations that allowed them to live much better at high altitude. One of those mutations is associated with being able to have a larger than average lung capacity, and another is associated with being able to bind to more oxygen in the bloodstream, even when the environment has very little oxygen in it, as is the case at high altitude.

It has been documented that Tibetan women with a high likelihood of possessing one or two alleles for the high blood oxygen content-- which is odd for normal women-- had more surviving children. The higher the oxygen capacity, the lower the infant mortality. The more offspring these women have, the more frequent the allele will become in that population over time.

We see that populations in unique environments are so well-suited to the selective pressures that exist there. So does this means that those individuals or populations can simply acquire the traits that they want or need? You're now going to engage in an activity where you're going to become part of a population either living at high altitude in a very harsh condition or at sea level. You're going to see if you can get the traits you want or need to survive, or see if other factors are at play. See you in 20 minutes.

Welcome back. Hopefully, you enjoyed the coin flipping game and simulation of survival. At this point, hopefully you've been able to synthesize your results and talk about your findings with your class. And I also hope you were able to realize that although certain traits may give you a survival advantage, you can't always get what you want or need.

DNA mutation is random, and the traits you have are passed on from your parents. You probably also remember the Punnett squares you did during your genetics unit. And remember that even if your parents have a trait, it does not always guarantee that you'll inherit it from them. The coin flips that you did were a simulation of the probability that comes into play every time two parents create offspring.

How do we know which mutations cause which traits and how these mutations have evolved over time? 10 years ago, the human genome was sequenced for the first time. You may have heard of the Human Genome Project, which gave scientists the complete map of the genetic material that makes up an average human. Each individual, and individual populations, have variations on this average human genome.

These DNA mutations make us genetically unique and are the source material for natural selection. Over the last decade, scientists like those here at the Broad, have continued to sequence the genome of many individuals, and also DNA fragments extracted from fossils of early humans. It turns out that the process of natural selection leaves unique patterns in the genome, and scientists can look for molecular signatures of selection that are present as proof that evolution was the culprit. This allows scientists to discover new genes under selective pressures that were previously unknown and not obvious based on phenotype.

Here are some examples of traits that have been recently found through this hypothesis generating approach to evolution. For example, malaria resistance evolved 35,000 years ago in Africa and Asia, where malaria is most common. About 20,000 years ago in East Asia, people evolved to have more sweat glands and thicker hair, but we don't know why-- maybe heat tolerance? In Tibet, people living at high altitudes evolved the ability to use oxygen more efficiently less than 3,000 years ago.

Finally, let's talk about the pigment trait that we see on the chart more than 10,000 years ago. Human skin color is another human trait that's undergone selective pressure since humans have migrated out of Africa. Remember that the original skin color phenotype was very dark skin in order to survive in the very strong sun of Africa.

As humans made their way out of Africa, mutations in two specific genes became more common. They caused the body to produce more pheomelanin and less eumelanin, causing a lighter skin color phenotype. Pheomelanin is better at producing its own vitamin D. So if you live in a sunshine poor environment relative to the equator, it makes sense to have lighter skin.

I hope you've enjoyed the last two classes of information and activities based on human evolution. Now it's time for you to wrap up this experience.

ELINOR KARLSSON: You've learned an awful lot about the history of human genetics at this point in time and how we understand evolution, and that evolution is a random process that acts on individuals within a population and changes the frequency of traits in that population.

JULIE BOEHM: Now we'd like to pose two open-ended questions to you to wrap up-- one being, where do you think human evolution is going in the future?

ELINOR KARLSSON: What sorts of selective pressures do you think are going to act on people in the future to change the prevalence and distribution of alleles within the population and across the world?

JULIE BOEHM: It's now time for you to take what you've learned in the BLOSSOMS lesson and apply it to these two questions. Good luck, and keep learning.

Hi, I hope you enjoyed the BLOSSOMS lesson that I did for you and that it's useful for your classes. The reason I chose the topic of human evolution was really because, for the past 10 years, I've been teaching evolution and I've never covered the topic of humans, which I really felt was a disservice to my students. They're always so interested in themselves and things about them that I thought, what a great idea to start covering humans in my curriculum-- and thus the reason I decided to do this BLOSSOMS lessons about human evolution.

Since you've already seen the video, I thought I'd go over some prerequisite knowledge that your students should have before engaging in this lesson. My guess is you've already covered the central dogma-- meaning DNA is made to RNA made into proteins, and those proteins determine traits. You also you should have gone over the concept of DNA mutations and how that's really a result of copying errors or environmental issues. I would also think that the students would have gone through all of protein synthesis and how proteins are made and possibly mutated.

And finally, this is a lesson that would fit in really well at the end of evolution, after you've covered things like Darwin and natural selection. So I hope this fits in well to your curriculum. I want to take a minute to explain the three activities that the students will do so that you feel more comfortable with the material yourself.

The first activity is a map analysis. The idea is to have the students decide and really look at a correlation between environment and traits. I want them to have an appreciation that the environment really does impact survival, and thus the traits are displayed in that population more frequently. At the end of the activity, I ask students to identify the prevalence of lactose tolerance in the area that they live.

My hope is this activity not only serves as a way for them to understand the material better, but also acts as maybe a hook or a link so that they feel personally connected. They're finding out how lactose tolerance is representative in their area of the world. And maybe they can identify how that relates to their own traits, or maybe the traits of their friends and family.

So the modeling natural selection activity, it describes the activity and suggest you do it outside on a grassy surface with tri-color pasta-- meaning there's white, orange, and green. But you say, maybe I don't live in an area that has a lot of grass, or maybe it's the middle of winter. So I thought of a few variations.

If you live in an area that's very sandy, I thought maybe you could do it with different color dried beans. We can contrast have contrast there with the sand and with the bean coloration with having some actually mix in and kind of show the color of the sand a little bit more so they would blend into the environment. Another thing I've done-- because Massachusetts has very long winters in which we don't see the grass very much-- what I've done is I've bought big tablecloths that are multi-colored. Maybe they have flowers on them, maybe some of the backgrounds look like leaves. And I've had the students scatter the pasta, the tri-color pasta, out on those surfaces. And what we've noticed is they blend in very well, and the activity is unchanged.

Finally, the last activity is a simulation of survival, and it looks at the relationship between high altitude and blood oxygen content. The reason I wanted to do this as a wrap up is to connect the idea of gene variation and alleles to survival, something that wasn't done before in the modeling natural selection activity. The class is going to be split into two populations in different environments-- one at sea level and one at high altitude.

They're going to determine their allele combinations by flipping a coin. You have maybe done a similar activity in their genetics unit, where they flip coins to determine allele variations. And so again, this is an important process, because it reinforces the idea of randomness, the fact that you can't always get the alleles that you want. It's very much like flipping a coin.

And then finally, linking genotype to the environment. This is, again, something we didn't do before. We saw that phenotype was linked to environment, but never when we saw-- we are now looking at genotype and environment, and whether or not that allows them to survive. Finally, the way that we're going to wrap up the lesson is by me posing two open-ended questions to your students.

And they are, what do you think human evolution will look like in the future? And also, what sorts of selective pressures will continue to affect our own patterns of survival and reproduction? My hope is that your students will be able to engage in a lively debate or conversation altogether about what they've learned. But not just about what they've learned, think about what the future is really going to look like, remembering that none of us know that.

They can think of things such as pathogens, environmental changes with global warming, and really anything is possible. And it's just going to be interesting for you to hear what they have to say and what they think will affect our future survival and changes that we'll see in the future. If you're at all interested in looking at the standards that I've identified for this lesson, I've focused on both Massachusetts state standards and some next generation science standards. I'll include those in the teacher segment.

I really appreciate you taking on this lesson. And I hope that you find a way to incorporate it into your classroom and curriculum for years to come. Thank you.