NATIONAL CENTER FOR CASE STUDY TEACHING IN SCIENCE

Early Modern Human Migrations: A Simulation Game

by

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What secrets does your DNA hold about where your ancestors came from?

Have you, or anyone you know, taken a DNA ancestry test? If so, you probably know it involves spitting in a tube and mailing your saliva to some scientists. After a few weeks, your results arrive, telling you about your ancestry and where your relatives might have been thousands of years ago. You may know scientists extract DNA from some of your cheek cells in the saliva sample. But how does your DNA hold secrets of your ancestry? How can scientists use your DNA to predict that you had ancestors from halfway around the world thousands of years ago? This case study will take you on a journey to discover how humans migrated across the face of the Earth over the last 100,000 years and how DNA sequences provide evidence for how this migration occurred. As you will see, all modern humans originated in Africa and then migrated to populate the world over the course of 100,000 years.

How does DNA sequence relate to ancestry?

DNA is a fascinating molecule. In one aspect, it is relatively simple. A DNA molecule can be represented by a string of four letters (G, A, T, and C) that scientists call nucleotides. For example, ATTGCT is a short DNA sequence of six nucleotides. In other ways, DNA molecules are very complicated. For example, DNA sequences are generally massive in size: each complete human DNA sequence (the human genome) is about 3,000,000,000 nucleotides long.

Furthermore, your genome sequence is not random. Your nucleotides are in a specific order, providing a code that is your genetic makeup. Despite being very large, DNA sequences between humans are similar, generally differing in only one in every 10,000 nucleotides. That said, your genome is unique. No two humans, not even identical twins, have identical DNA sequences (Jonsson et al., 2021).

As you may know, DNA molecules contain genes. Genes are DNA sequences that are blueprints for making proteins. Proteins are the factors that determine human traits, and the genes you inherit from your parents determine your biological characteristics (Campbell & Eichler, 2013).

The most common genetic differences (or polymorphisms) between two humans are differences in single nucleotides. These changes are called single nucleotide polymorphisms (SNPs), and about 14 million SNPs are located throughout the human genome that have accumulated over time. Most SNPs seem to have little biological effect, either because they occur outside of gene sequences, or when they do occur occur inside a gene sequence, they do not affect gene function significantly. When SNPs are present at substantially different frequencies in populations that originated in various parts of the world, they are called ancestry-informative markers (AIMs).

As humans slowly spread worldwide, they reproduced, passing their DNA from one generation to the next. Over generations, existing SNPs became passed to new generations, and new SNPs emerged. By sequencing the DNA of modern humans, scientists can see which SNPs are shared between different human populations to see how closely those populations are related.

For example, in the hypothetical example shown below in Figure 1, each line represents a DNA sequence from a different human. The names represent modern human populations, and there are four individual people represented from each population. There are eight SNPs indicated at the top of the figure. SNPs 4 and 5 are considered AIMs because they differ between human populations originating in different geographical locations. SNPs 1–3 and 6–8 in this example would not be regarded as AIMs because, while they differ between people, they do not consistently track with human populations that originated in different places. The figure is simplified compared to the actual data. Because the human genome is enormous, AIMs are not typically grouped in such close proximity. (For a more specific discussion of AIMs, see Mekhfi et al., 2024.)

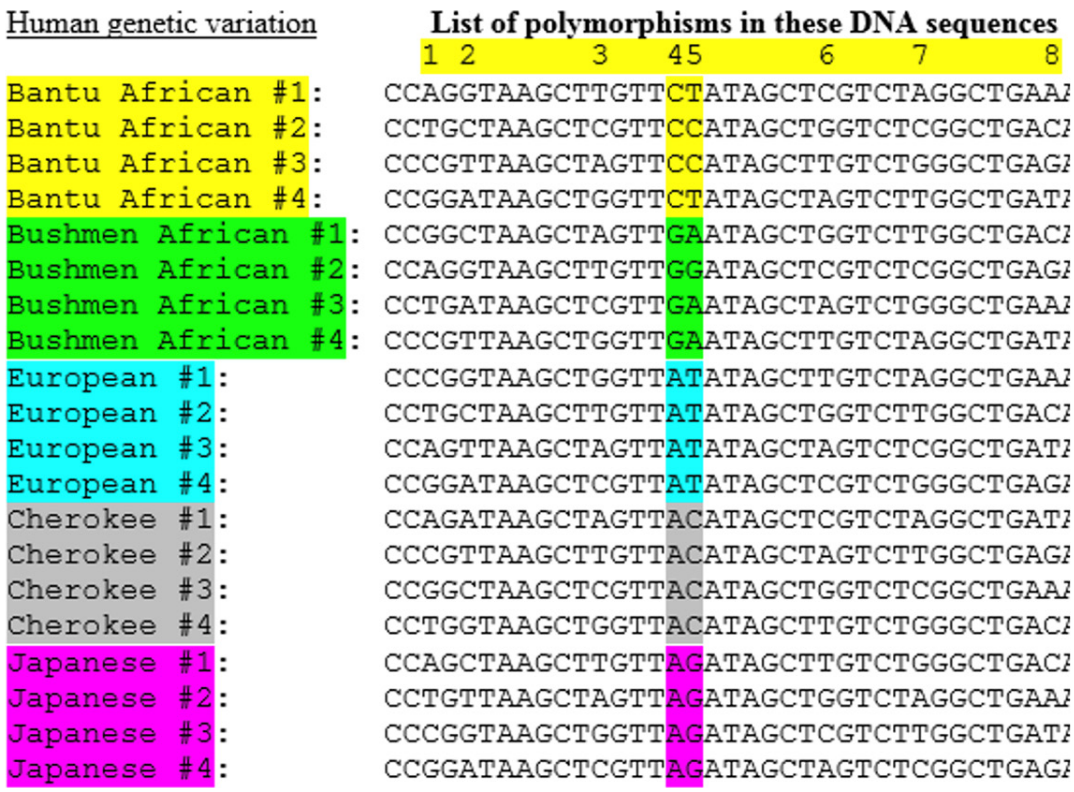

Figure 1. A hypothetical representation of ancestry-informative markers.

In this case study, you will retrace the steps of *Homo sapiens sapiens* (modern human) populations over the last 100,000 years. Considering that one generation is approximately 25 years, 100,000 represents about 4,000 human generations. You will discover where different modern human populations came from and how they got to where they are now. Like your ancestors, you will migrate by walking. That's right; humans spread across the Earth over many generations by trudging one step at a time. As humans migrated on foot, environmental and ecological pressures affected different migrations in various ways. Some examples include physical barriers, such as mountain ranges and bodies of water, as well as the availability of resources. Population dynamics also played a role as human populations changed due to immigration, emigration, births, and deaths.

Luckily, your journey will be across a map of the planet about 700,000 times smaller than the actual Earth, which means considerably fewer steps. As a result, your migration will also take significantly less time: approximately 30 minutes compared to 100,000 years.

Where did your ancestors originate?

Genetic and archeological evidence supports the idea that modern humans originated in Africa as early as 350,000 years ago (López et al., 2016). There were several hominin species on the Earth back then, but *Homo sapiens* is the only one that still survives today (Harari, 2015).

Today's story begins more recently than that, starting in Africa 100,000 years ago with all the humans that will populate the modern world living. Imagine yourself as a human 100,000 years ago in what is now the Serengeti National Park in Tanzania, sitting under a tree to get some shade from the hot sun, trying to figure out how to make a hand ax by using one rock to chip away at another.

What would a human look like back then? Like all humans at that time, you would have had dark skin to protect you from the harsh African sun and a slim and athletic body because of your hunter-gatherer lifestyle.

What would you be thinking about? Most likely, it is where your next meal is coming from or how to hit that rock just right to make it a little sharper. Or perhaps you're thinking about the recent burial of a family member who just passed away or your young child who thankfully seems strong and healthy. You probably don't understand compass directions, but your tribe has been gradually migrating north in search of food these last few years. Unbeknownst to you, your tribe has just begun a migration that will last tens of thousands of years and spread your descendants across the globe.

Fast forward 100,000 years to the modern-day, about 4000 human generations later. One of the many descendants of that African person sits in the bustling city of Beijing in modern China, enjoying lunch at their favorite noodle bar. Incredibly, all human beings share some DNA sequences (AIMs) with their ancestors, which links them in an unbroken genetic chain to their earliest relatives in Africa.

Now imagine yourself as this modern-day descendant of that African human. What would you look like? Your skin would likely be less pigmented with melanin. Your skin is less melanated because your ancestors who settled in modern-day China have lived under less intense sunlight than in Africa, so natural selection favored skin with less melanin, allowing for more efficient vitamin D production (Nair & Maseeh, 2012; Jablonski, 2004). You could have any kind of body shape, as the rigors of hunter-gathering have been left in the past for an agrarian society. What would you be thinking about? Most likely, you are concerned with problems in the modern world instead of basic survival. However, despite the enormous differences in lifestyle between your ancestors and you, biologically, you are still quite similar.

Your journey begins ...

Today, we will investigate how this line of hypothetical ancestors got from under that tree in Africa to that noodle restaurant in Beijing. The evidence for human migrations comes from genetic evidence in DNA sequences and archeological artifacts. By comparing which AIMs are present in the genomes of different human populations, scientists can investigate which humans have many AIMs in common, suggesting shared ancestors.

Each student will receive a stack of cards that describe this 100,000-year journey, 10,000 years at a time. The face card of your stack reveals the name of a modern population, a map showing the location of that population today, and a friendly face representative of that modern population. Through this case study, you will discover how the people destined to become that modern population migrated there from their origins in Africa to where they reside today.

While it is true that all humans in the world today have ancestors that originated in Africa, it should be noted that indigenous people's cultures shown on your cards were formed over thousands of years after they left Africa. For example, the Inuit people of modern-day Siberia have a traditional lifestyle adapted to that region. Over thousands of years living in a frigid environment, Intuit culture developed skills such as trapping, fishing, and making fur garments to protect against the cold.

We will simulate this migration twice, the first time showing how populations moved across the Earth to get to where they are today, and the second time simulating how the AIMs those populations carried might have changed over time. These genetic differences have allowed modern-day scientists to track how different populations migrated and diverged.

If you look at the second card in your stack, it will tell you where your population was 100,000 years ago. You will then turn over each card as instructed to discover where your population traveled over the next 10,000 years on their journey. So, go to Africa, and let the journey begin.

Questions

Before class, answer the following questions by doing online research. Questions 1 and 2 are designed to help you think about how people could migrate across the world solely on foot. Questions 3 and 4 are designed to make you think about how different individual humans are genetically, and how genetic differences can be used to assess human family relationships.

1. Describe how coastlines have changed compared to how they looked during the most recent ice age.

2. If you traveled on foot without modern technology, how would the altered coastlines you described in the previous question have affected your ability to travel across the Earth?

3. According to modern geneticists, any two humans, regardless of race, are about 99.9% similar at the level of DNA sequence. To understand how humans differ from each other genetically, use the 99.9% number to calculate how many changes in DNA sequence there are (on average) between two humans. (*Hint:* The length of the human genome is three billion nucleotides.) Does this seem like a big difference or a slight difference?

4. After sending his saliva to an online genotyping company, Mario learns he has a previously unknown first cousin. What kind of data did this company collect from Mario's donation, and how do you think the data was used to reach that conclusion?

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