CHAPTER 2:
Is My Sense of Taste Controlled By My Genes?

INTRODUCTION

As you learned in your exploration of traits in Chapter 1, many of your features are at least partially controlled by your genes, including your eye color, hair color, and height. But what about things that you can't easily see, such as your blood type or the way you react to blood thinners or pain medication? How do your genes factor into these unseen traits?

Genes play a role in many aspects of your health. For example, scientists recognize that different medicines affect people in different ways, based in part on their genetics. To better meet individual needs, researchers are working to create precision medicine tailored to each patient's genetics and lifestyle. By exploring how genes influence our health, scientists hope to help doctors keep their patients healthy and create better treatment plans for those who are ill.

ACTIVITY: Rate the Bitterness of These Foods

To explore how genes affect hidden traits like how we react to medicines, you're going to examine a different "hidden" trait—our sense of taste. You probably like some foods and dislike others. Some of your friends might love olives while you despise them, or vice versa.

Have you ever thought about why? Are "picky eaters" simply unadventurous types who don't want to try new foods, or do they actually taste things differently from other people? You may love some foods that taste bitter—such as coffee, olives, or bitter melon—or you may absolutely hate them.

In this activity, you will explore one aspect of your sense of taste—your perception of bitter tastes—and consider how your genes might influence this trait. You will also make an inventory of how various foods taste to you.

MATERIALS

For each student:

- 1 copy of **My Bitterness Ratings (RM 2.1)**

PROCEDURE

As your teacher shows each slide depicting a food, use the table on **My Bitterness Ratings (RM 2.1)** to rate the bitterness of that food on a scale of 1 to 3, with 1 being "Very bitter" and 3 being "Not at all bitter." When rating each food, imagine you are consuming it raw and without any condiments. After you've rated the bitterness of each food, decide which taste word you would use to describe it: salty, sweet, sour, bitter, or umami (savory).

ACTIVITY: Can You Taste It?

In 1931 in a laboratory at the DuPont chemical company, chemist Arthur Fox accidentally spilled a powdered chemical called ***phenylthiocarbamide (PTC)***. As the powder swirled in the air, a nearby scientist complained that the dust tasted bitter. However, Fox didn't taste anything. Fox was curious as to why he couldn't taste the PTC and his colleague could, so he began to run tests on others. Fox asked his friends and family members to taste the chemical and tell him how it tasted. He found that some people didn't taste it at all, some had a mild sensation of bitterness, and others found the taste unbearably bitter.

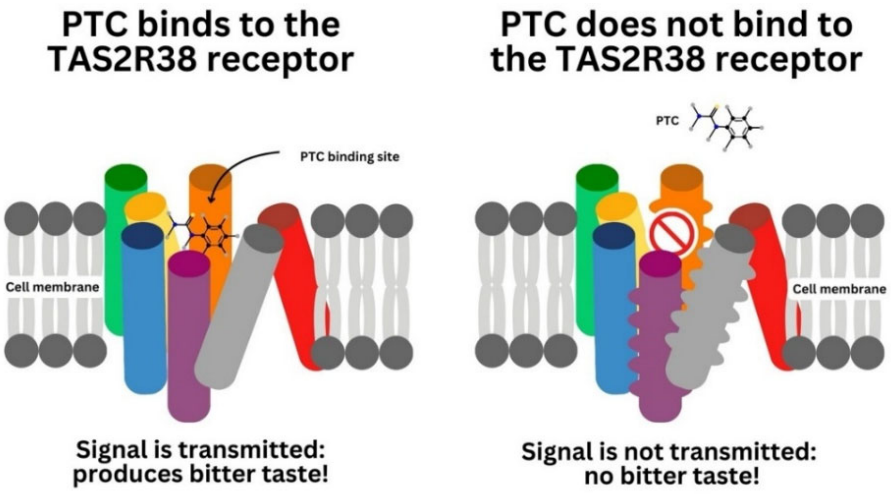
Bitter is only one of five basic tastes that humans recognize. The remaining four are:

- Salty
- Sweet
- Sour
- Umami

But how do you perceive these tastes? When food enters your mouth, the taste chemicals interact with receptors on your tongue. Each taste has its own type of receptor cell. Taste chemicals bind to the receptor cells on your tongue, and these cells send signals to your brain. Then your brain interprets the signal, and you taste the corresponding flavor. If the taste chemical doesn't bind to the receptor cell, you won't taste the chemical.

Today, scientists know that there is a connection between your genes and your ability to taste certain flavors. One of the taste genes—called Taste Receptor 2 Member 38 or TAS2R38—allows you to taste bitter foods. There are several versions of this gene; humans carry two variations (genotype), which influence their abilities to taste bitter compounds (phenotype). If you can taste bitter flavors, it's likely you can also taste PTC. If you are a bitter taster, PTC binds to the bitter-taste receptor on your tongue and sends a signal to your brain and YUCK! (See **Figure 2.1**.) While you will not know your genotype for certain until you complete the labs in Chapters 3–6, you will know your bitter-tasting phenotype after tasting PTC.

Figure 2.1: PTC tasting mechanism



Can you taste PTC? Let's find out!

MATERIALS

For each student:

- Control taste paper
- PTC taste paper
- 1 cup of water (this should be drinkable water—you will use it to rinse your mouth)
- 1 copy of **Can You Taste It? (RM 2.2)**

PROCEDURE

1. Place a piece of control taste paper on the tip of your tongue. **Don't swallow it!** Record its taste on **Can You Taste It? (RM 2.2).**
2. Remove the control paper from your tongue and dispose of it in the solid waste container. Rinse your mouth with water and spit into your team's liquid waste container.
3. Place a PTC taste paper on the tip of your tongue. If you don't taste anything at first, leave the paper on your tongue for a few more seconds. **Don't swallow it!** If you sense a bitter taste, then you are a PTC taster. Due to genetics, there is a gradient of PTC tasting ability:
    - If the paper tastes awful, you are a strong taster.
    - If you perceive only a slight bitter taste, you are a weak taster.
    - If it tastes like the control paper, you are a nontaster.
4. Remove the PTC taste paper from your mouth and dispose of it in the solid waste container. Rinse your mouth, if needed. Spit your rinse water into your team's liquid waste container.
5. Record if you are a strong taster, weak taster, or nontaster in the table on your reproducible master.
6. Check with your teammates and record their statuses in the table as well.
7. As your teacher calculates the class totals, record them in your table. Calculate the percentage of students with each phenotype.
8. Make a bar chart showing the number of students with each phenotype on **RM 2.2**.

REVIEW: Genetics Concepts

MATERIALS

For each student:

- 1 copy of **Genes, Traits, and Environment (RM 2.3)**

Earlier, you considered the connection between our genes and how we respond to medications. Do all medications work for everyone in exactly the same way? The answer is no. A number of factors can influence how a patient responds to medications, just as various factors affect whether a person enjoys bitter foods.

Let's review some important genetics concepts:

1. Watch *What Is a Gene?* from Stated Clearly, starting at the 0:05 timestamp, and then answer the questions on **Genes, Traits, and Environment (RM 2.3)**.
2. If your teacher has assigned it, read the article "Mamas, Don't Let Your Babies Grow Up to Be Broccoli-Haters" by Lisa Bramen (*Smithsonian Magazine*), then answer the questions on **RM 2.3**.

READING: Prepare for the Next Lab

In the upcoming lab, you will extract your own DNA from your cheek cells. Then you will use a technique called ***polymerase chain reaction (PCR)*** to make many copies of a very small portion of your DNA to use later in the module. To help you prepare for the lab, read about what you will be doing and answer some questions.

DNA EXTRACTION

In the first part of the lab, you'll collect some dead skin cells from the inside of your cheek, then boil them. This will cause the breakdown of their cellular and nuclear membranes in a process known as ***lysis***. Once these membranes are broken down, components that are normally in the cytoplasm of the cell will mix with the DNA. These components include enzymes called ***DNases***, which break down DNA. DNases require metallic ions called ***cofactors*** to assist in their activities. These metallic ions are also found inside cells. In the lab, you will combine your DNA with Chelex, which is a ***chelating*** (binding) agent often used for DNA extraction. The Chelex resin will bind to these metal cofactors so they are not near the DNases.

POLYMERASE CHAIN REACTION (PCR)

WHAT IS PCR?

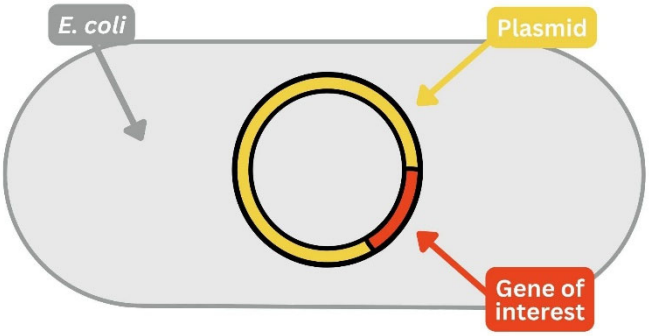
In the next part of the lab, you will use PCR to ***amplify***, or make many copies of, a specific region in your DNA. PCR is one of the most widely used techniques in biotechnology. Think of it as a molecular copy machine that can make multiple copies of genetic material (often several billion!).

PCR was first developed in 1983 by American biochemist Kary Mullis, who later received the Nobel Prize for his work. PCR has had a profound impact on biotechnology and is now used in many areas of research and applied biotechnology, including genetic engineering, forensics (the use of scientific tests or techniques in crime investigation), and medicine (such as in the laboratory tests used to detect COVID-19 infection).

Scientists are interested in making copies of specific genes—a process known as ***gene cloning.*** Two main methods for cloning are known as *in vivo* and *in vitro* cloning, each of which has different applications. Both methods use reagents isolated from living organisms to cut and copy DNA and/or to produce proteins, just as these living things do, but for different purposes.

Scientists clone genes ***in vivo*** (inside a living organism) by inserting a specific gene from one organism into another organism's DNA. This is often done using the gut bacterium *E. coli* by adding a gene to a small circular piece of DNA called a *plasmid.* ***Plasmids*** are circles of DNA found in bacteria and other microorganisms that are separate from chromosomal DNA and can replicate independently. This makes plasmids useful vectors for generating numerous copies of DNA encoding a specific gene. The process of introducing a plasmid to bacteria is called ***transformation.***

Figure 2.2: Bacterial transformation to produce protein from a gene of interest



To transform bacteria, scientists add a plasmid with a gene of interest to numerous identical bacterial cells. Then, each transformed bacterium begins replicating that gene of interest (**Figure 2.2**). As each transformed bacterium reproduces, its plasmid does as well, resulting in large colonies of bacteria, each containing the added plasmid. The added gene in each engineered bacterium is transcribed and translated to produce the encoded protein. Such proteins are ***gene products***. One gene product produced *in vivo* through this process is the human therapeutic protein, insulin.

While gene cloning *in vivo* produces a protein, gene cloning can also be carried out ***in vitro*** (outside of a living organism—for example, in a test tube) by using PCR. *In vitro* gene cloning uses the same enzymes and starting materials as living cells but produces many copies of a DNA fragment and no gene product. These fragments are just pieces of genetic material; they will not produce a protein unless they are introduced into a living cell.

NOTE: *In vitro* literally means "in glass," referring to the laboratory equipment originally used to carry out the necessary chemical reactions. Nowadays, much of *in vitro* research occurs in plastic labware, rather than glass test tubes!

PCR copies a specific region of DNA from a sample, then rapidly produces billions of copies of that specific region of DNA. Scientists call PCR "DNA amplification" because it makes many copies of a

small amount of DNA (almost like amplifying a quiet sound so that it can be heard). Those copies will vastly outnumber any other DNA fragments in a sample, making the sequence far easier to detect and analyze. Prior to the development of PCR, the only way to make multiple copies of a specific sequence of DNA was through biological amplification in bacteria, which was very expensive and took a long time. PCR is much less expensive and can be done very quickly in comparison.

PCR uses an enzyme—***DNA polymerase***—to replicate DNA. This is the same enzyme all organisms, whether unicellular or multicellular, use to assemble nucleotides into new strands of DNA prior to cell division. This process is known as ***DNA replication.***

Because most living organisms survive at temperatures between 25°C ("room temperature") and 37°C ("body temperature"), most enzymes are stable and active at these temperatures. To replicate DNA *in vitro*, first scientists must separate its two strands to expose the bases they want to copy. They do this by heating it, which creates a conundrum because heating DNA to separate it also destroys the enzymes necessary to replicate it. This fact made early PCR a long and laborious process, since researchers had to add fresh enzymes to the reaction after every heating cycle so the DNA could replicate.

However, in the late 1960s, microbiologists discovered new microorganisms called ***thermophiles*** (heat-loving). Thermophiles live at much higher temperatures than other organisms, ranging from 55°C to a sizzling 121°C (much higher than the temperature of boiling water!). Strains of these thermophiles can be found anywhere warm, from compost piles to thermal vents in the ocean floor to the boiling hot springs in Yellowstone National Park.

Taq polymerase, a type of DNA polymerase, was discovered in the thermophile bacterium ***T****hermus* ***aq****uaticus*, which uses it to replicate its own DNA at the high temperatures of its environment. *Taq* polymerase, therefore, can function at the higher temperatures required for PCR. Without it, modern PCR would not be possible.

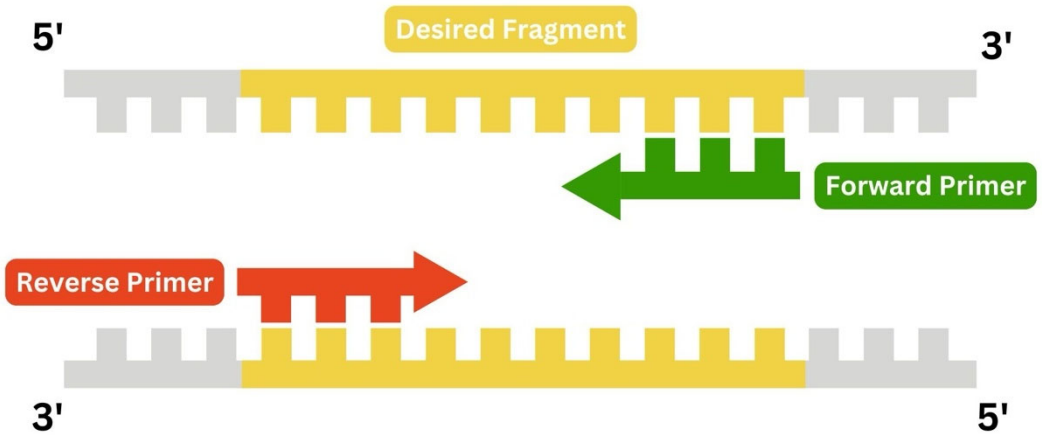
HOW DOES PCR WORK?

Like other biotechnology methods, PCR is based on basic scientific discoveries, in this case, DNA replication. PCR involves multiple rounds of DNA replication, resulting in the production of over 1 billion copies of a specific segment of DNA.

There are five ingredients required to set up a polymerase chain reaction:

1. ***Template DNA***—The pool of genomic DNA from which you will make copies
2. Forward and reverse primers—Short stretches of DNA designed to match the beginning and end of the section of genomic DNA that you want to copy (see **Figure 2.3**)
3. DNA nucleotide bases (dNTPs)—Loose "building bricks" used to build the new copies of DNA
4. *Taq* polymerase enzyme—A catalyst that aids in building the new DNA strands
5. A buffer—A chemical solution that creates optimal conditions for the reaction

Figure 2.3: Template DNA between the forward and reverse binding sites will be amplified by PCR



There are three phases of PCR:

1. **Denaturation Phase**

   At high temperatures, the hydrogen bonds between the bases in the two strands of DNA break, allowing the strands to separate, or ***denature*** (also known as melting). The melting temperature of DNA depends on its physical properties, but is generally above 70°C. In PCR, the mixture is heated to 94–95°C sufficiently to ensure that the DNA strands have separated completely.

2. **Annealing Phase**

   In this phase, the mixture is cooled, allowing the primers to ***anneal*** (attach) to the denatured single-stranded DNA. The annealing temperature is calculated based on the melting temperature of the primers being used in the PCR.

3. **Extension Phase**

   In this phase, the temperature is raised. *Taq* polymerase replicates the region of interest by adding dNTPs to the 3' end of the primers.

Did you know?

Commonly used formulas for approximating the melting temperature of primers are:

For sequences < 14 nucleotides:

Tm= (wA+xT)*2 + (yG+zC)*4

where w, x, y, z are the number of the bases A, T, G, C in the sequence, respectively.

For sequences > 13 nucleotides:

Tm= 64.9 +41*(yG+zC-16.4)/(wA+xT+yG+zC)

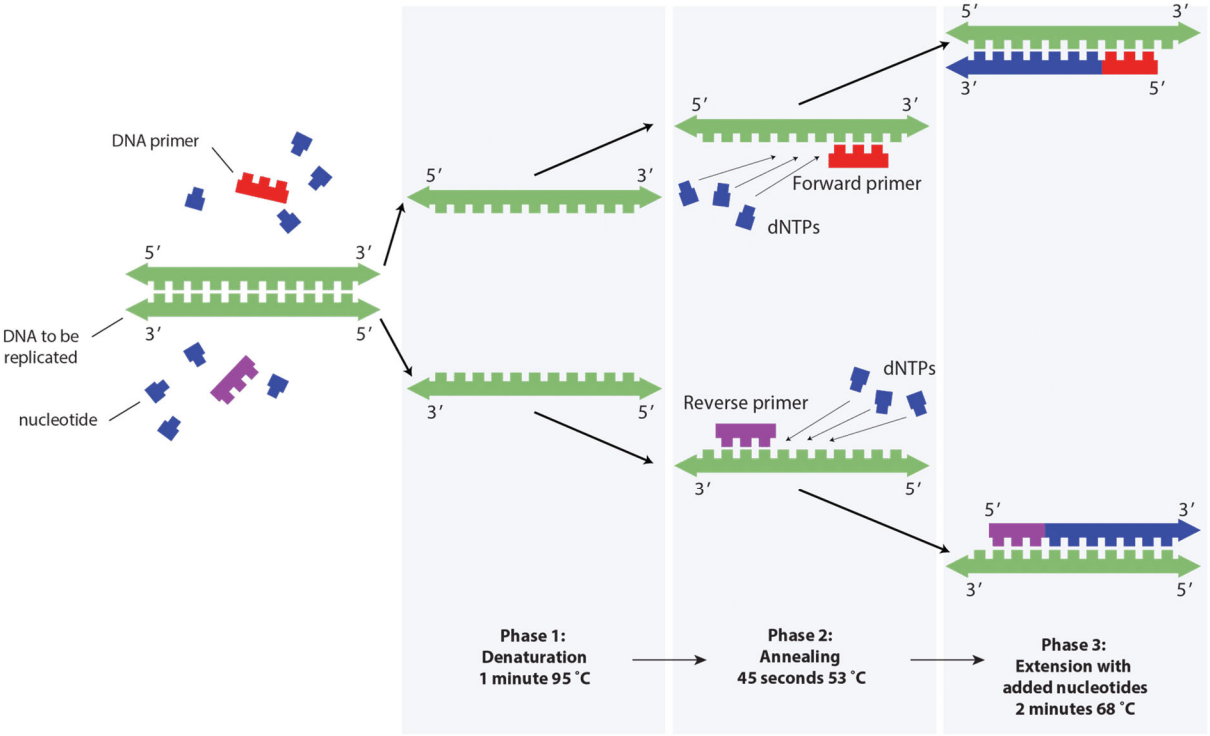
More complex algorithms exist for even more accurate melting point approximations.

These three phases complete one PCR cycle, and this cycle is then repeated numerous times to achieve amplification.

PCR is carried out in an instrument called a ***thermocycler***, which controls the temperature and length of time for each phase of the reaction. During each cycle, the number of copies of DNA from

the region of interest doubles. In the example that follows, one cycle would take approximately 4 minutes (see **Figure 2.4**). This cycle is then repeated to make more copies. A reaction that runs for 30 cycles can result in more than 1 billion copies.

Figure 2.4: A complete cycle of PCR



The success of the PCR is then determined by using ***gel electrophoresis*** to analyze the PCR products. (Gel electrophoresis is a laboratory technique for separating nucleic acids or proteins based on their relative size by applying an electric current that pulls materials through a gel in a buffer solution.) By comparing the PCR products to standard-sized pieces of DNA in a DNA ladder, it is possible to determine whether the reaction has been successful. For example, if a set of PCR primers were designed to bracket a single fragment of 1800 base pairs (bp) for copying, we would expect to see a single distinct band in the gel that is next to the location in the ladder that corresponds to 1800 bp.

Demonstrate your knowledge of PCR by completing **How PCR Works (RM 2.4)**.