Nervous System: Sense of Taste

SC Academic Standards: 7.L.3B; H.B.2A-C.

NGSS DCI: MS-LS1.A; HS-LS1.A.

Science and Engineering Practices: S.1A.1; S.1A.3; S.1A.4; S.1A.5; S.1A.6; S.1A.7

Crosscutting Concepts: Cause and Effect: Mechanism and Explanation; Structure and Function; Scale, Proportion, and Quantity; and Systems Models.

Conceptual Understanding: Plants and animals have physical characteristics that allow them to receive information from the environment. Structural adaptations within groups of plants and animals allow them to better survive and reproduce.

The Animal Kingdom includes a diversity of organisms that have many characteristics in common. Classification of animals is based on structures that function in growth, reproduction, and survival. Animals have both structural and behavioral adaptations that increase the chances of reproduction and survival in changing environments.

Multicellular organisms (including humans) are complex systems with specialized cells that perform specific functions. Organs and organ systems are composed of cells that function to serve the needs of cells which in turn serve the needs of the organism.

Focus Question: How do we perceive flavor? How do our taste buds work?

Background: Taste quality is just one way that you experience a certain food. Another chemosensory mechanism, called the common chemical sense, involves thousands of nerve endings, especially on the moist surfaces of the eyes, nose, mouth, and throat. These nerve endings give rise to sensations such as the coolness of mint and the burning or irritation of chili peppers. Other specialized nerves create the sensations of heat, cold, and texture. When you eat, the sensations from the five taste qualities, together with the sensations from the common chemical sense and the sensations of heat, cold, and texture, combine with a food's aroma to produce a perception of flavor. It is flavor that lets you know whether you are eating a pear or an apple.

Most people who think they have a taste disorder actually have a problem with smell. When you chew food, aromas are released that activate your sense of smell by way of a special channel that connects the roof of the throat to the nose. If this channel is blocked, such as when your nose is stuffed up by a cold or flu, odors can't reach sensory cells in the nose that are stimulated by smells. As a result, you lose much of our enjoyment of flavor. Without smell, foods tend to taste bland and have little or no flavor. Have you ever tried to guess what flavor / color lifesaver you were eating, when you ate it with your nose plugged and eyes closed?

Your ability to taste comes from tiny molecules released when you chew, drink, or digest food; these molecules stimulate special sensory cells in the mouth and throat. These taste cells, or gustatory cells, are clustered within the taste buds of the tongue and roof of the mouth, and along the lining of the throat. Many of the small bumps on the tip of your tongue contain taste buds. At birth, you have about 10,000 taste buds, but after age 50, you may start to lose them.

According to common <u>mis</u>understanding, the tongue has distinct regions, each responsible for the detection of one of the four primary tastes. This outdated "tongue map" on which sweet is tasted at the tip, sour and salt at the sides, and bitter at the back of the tongue is based on an overly simplified interpretation of 19th century German research. More recent research shows that all areas of the tongue respond to each of the primary tastes to varying degrees. The four primary tastes, which are bitter, sour, sweet, and salty, have been extended to include a fifth taste, referred to as "*umami*". Taste perception begins when protein receptors, which are located on the plasma membrane of taste cells, are activated in response to physical contact with specific molecules. The activated receptor then triggers an intracellular signaling pathway, which triggers other events that eventually relay a signal to the brain.

External sensory information is processed by several types of **sensory receptors** in the body, such as the taste buds on your tongue. These receptors respond to external stimuli (like the chemicals in your food, the taste), and that information is **transduced**, or changed, into an electrical signal that is transmitted via **afferent pathways** to the central nervous system. This transduction of the signal initially occurs by activation of a receptor. Receptor activation stimulates the opening or closing of **ion channels**, which generates an **action potential**. The CNS, or integrating center, processes the information and then sends a response via **efferent pathways** to **effector systems.** When the taste cells are stimulated, they send messages through three specialized taste nerves to the brain, where specific tastes are identified. Taste cells have receptors that respond to one of at least five basic taste qualities: sweet, sour, bitter, salty, and umami. Umami, or savory, is the taste you get from glutamate, which is found in chicken broth, meat extracts, and some cheeses.

Taste receptor proteins and their associated pathways can be broadly categorized into two types: those that change the permeability of the cell membrane to ions, and those that activate proteins that are found inside cells. For example, salt sensation is a result of $Na+$ flow through ion channels. Sour sensation is initiated when acid ($H+$) triggers cation movement through an **a**cid-**s**ensing **i**on **c**hannel (ASIC). Sweet tastes result from sweet molecules binding to certain types of **G**-protein **c**oupled **r**eceptors (GPCRs), which in turn activate downstream "second messenger" enzymes. Bitter compounds bind to and activate other GPCRs. The 5th primary taste *umami*, which means meaty or savory in Japanese, results from glutamate activation of a specific GPCR. Meat, cheese, mushrooms and fermented food are rich in glutamates, and the flavor additive monosodium glutamate (MSG) is used to enhance the taste of various food products.

The activation of taste buds serves as an excellent example of cell-signaling. Regardless of the different "taste" activation of taste cells (occurring when the **ligand**, or taste, binds to receptor proteins in the taste bud cell membrane) results in electrical changes in the taste cell, which are relayed to a neuron in the tongue when the taste cell releases neurotransmitters. In order for the sensation to reach the brain, a chain of neurons is required, each communicating with the next via neurotransmitters. In humans, the different types of taste cells are scattered throughout the tongue. Basically, just like any cell, taste bud cells have receptor proteins embedded in the cell membrane. Many of them, and many types. If you have a receptor protein for the salty taste, and something salty (the **ligand**) binds to the receptor protein, then a signal will be sent to the brain telling you that you are tasting "salt". Now, if your taste buds lack the receptor protein for salt, (or if that receptor is "busy" – inhibited because something else is bound to it - and you are eating salty food, you won't taste it because there is no signal sent if there is no receptor – signal binding. Another good example is adenosine. You produce adenosine molecules (the ligand) when you are tired, and these molecules bind to adenosine receptors in brain cells and cause that sleepy feeling. But, caffeine molecules mimic adenosine! If you drink caffeine (ligand) the caffeine binds to the adenosine receptors in your brain instead (it inhibits adenosine) and you don't get the tired feeling. In addition, the same signal (caffeine) may cause a different reaction elsewhere: your heart has caffeine receptors, and when caffeine is in your bloodstream, and binds to the receptors in heart cells, the signal tells your heart to beat faster. So caffeine wakes you up in a couple ways. Another example is with the plant hormone auxin: when plant stem cells detect light (the signal), the hormone auxin is produced and auxin causes the cell to grow faster / larger. So – for taste: if you have the receptor you can taste when the receptor is bound to the chemical signal (the food). But if something blocks the receptor, even when you eat the food, you won't register the taste.

Neural response to primary tastes is critical given that it is associated with substances that are either life-sustaining or life-threatening. Specifically, sweet perception signals the taste of sugar-rich foods, *umami* signals protein-rich foods and bitter signals potentially toxic substances. Taste is an area of active research. Accordingly, there is mounting evidence for a potential sixth basic taste that responds to fatty substances. **Taste aversion** is an evolutionary adaptation that is meant to prevent the consumption of the same substance (or something that tastes similar), thus avoiding further poisoning. Maybe this explains why children aren't very adventurous eaters – young children, who put an awful lot of strange things in their mouths, need to be able to detect something that might be toxic (bitter tastes) quickly so they can spit it out and hopefully not get sick or poisoned.

In this lab you will experience how the primary tastes are combined to produce overall taste. You will compare your qualitative primary taste experiences to salt, sugar, aspartame, chocolate, and sweet-sour candy before and after sampling of an herbal tea, which will have a profound effect on your tastes. Although each student will serve as his/her own subject in this study, you will compare and discuss your observations with your lab mates.

Materials: *Gymnema sylvestre* tea leaves (not the capsule) (from Starwest Botanicals , 1 pound bag $14); water, pitcher, cups (2 per student), salt, sugar, aspartame ('Equal'), M&Ms, sour Skittles or sweetarts, MSG ("Food Accent", next to salt in the grocery).

> *** Note** – Students with diabetes should be encouraged to refrain from participation, as it may change blood sugar levels. Blindfolding the students is not necessary.
>
> **Preparation**: a couple of hours (not more) before your experiment, prepare the *Gymnema* tea by steeping ¼ cup of the cut/ dried leaves in 1 qt. boiling water for ten minutes. Strain the tea through a coffee filter to remove leaves. The tea can be served cold, warm, or hot. The effects of the tea are reversible and last only about 30 minutes to an hour.

Previous Knowledge: (Herbology): The Indian herb *Gymnema sylvestre* reversibly inhibits the sensation of sweet presumably by blocking sucrose receptors. The herb has dual mechanisms of action, evidenced by the fact that it has been used for centuries in Ayurvedic medicine for the treatment of diabetes. Several studies have attributed the hypoglycemic effects of ingested *Gymnema* extracts to reduced intestinal glucose uptake and increased insulin release.

Procedure: Each student (subject) will be given samples of salt, aspartame (Equal), sugar, M&Ms, Sour Skittles (or sweetarts) and MSG. **Note**: **It is important that you sample the substances in this order.** As a way of introducing controlled variables, you will also want to taste the same color, for foods that come in different colors (M&Ms for example, taste a blue M&M before tea, then a blue one after tea).

1. Taste each substance in this exact order (rinsing mouth with water **between** tasting substances): salt, aspartame (Equal), sugar, M&Ms, Sour Skittles and finally MSG. Rate each substance for the perception of sweet, sour, bitter and salty on a scale of 0-10. A rating of "0" represents no perceived taste; a rating of "10" represents a very intense taste.

2. Swish an ounce of herbal tea in the mouth for thirty seconds. It is not necessary for the tea to be swallowed; however, optimal results will be obtained if all areas of the mouth are thoroughly coated. Wait one minute then Rinse mouth with water.

3. Beginning with salt, re-taste each substance in the same order (and color) and rate and record your perception of salt, sweet, bitter and sour tastes. It is important to rinse mouth with water between tasting substances to avoid any aftertaste confounds on subsequent ratings. Make sure to write down all your taste perceptions.

4. Check with your lab mates to see if the sensations are consistent among the class.

Pre-tea rating	Salty		Sweet		Bitter		Sour	
	Your rating	Class avg	Your rating	Class avg	Your rating	Class avg	Your rating	Class avg
Salt								
Equal (Aspartame)								
Sugar								
M&Ms								
Sour Skittles								
MSG								

Table 1. Pre- tea rating of tastes.

Post-tea rating	Salty		Sweet		Bitter		Sour	
	Your rating	Class avg	Your rating	Class avg	Your rating	Class avg	Your rating	Class avg
Salt								
Equal (Aspartame)								
Sugar								
M&Ms								
Sour Skittles								
MSG								

Table 2. Post-tea rating of tastes.

Data Analysis: Graph the average rating for each substance using a bar graph: sweet, salty, sour and bitter tastes on X, average rating on the Y axis. You will have 6 graphs, one for each food item: aspartame, salt, sugar, M&Ms, sweetarts (or sour skittles), and MSG. You will have two bars for each taste (sweet, sour, salt, bitter) – one for the pre- and one for the post- rating. So – tasting M&Ms, pre-tea: did you rate it high for sweet? Low for bitter?

Extensions: Taste Receptors: Take a small glass of milk or a spoonful of ice cream and stand in front of a mirror. Coat your tongue with the milk or ice cream and immediately look at your tongue in the mirror. You will notice rounded bumps that rise above the milky surface of your tongue. These are the papillae that contain taste buds. The smaller bumps do not contain taste buds.

Sensory Aspects of Taste: You'll need a friend to help you with this demonstration. First, gather a number of stimuli to test. For instance, cut up equally small pieces (without skin) of an apple, a pear, an onion, and a raw potato. Close your eyes and hold your nose. Have your friend take a piece at random and place it on your tongue. First, try to guess the food without chewing. Next, chew on the piece of food and try to guess what it is. In each case, try to label the taste experience. You should find that it's difficult to identify the foods based solely on taste. You are more likely to be able to distinguish the foods based on tactile information as you chew!

Modifying Taste Perception- Adapting to Salt in Saliva: Take a quart jar, fill it with water, and add 1/2 teaspoon of salt. Stir the solution until the salt dissolves. Take four small glasses and fill the first with the solution. Fill the second glass 3/4 full, the third 1/2 full, and the fourth 1/4 full. Add water to these last three glasses until they are equal to the first glass, and then mix the solutions thoroughly.

- Take a sip of the solution in the fourth glass, swish it around in your mouth, and determine whether or not you detect any trace of saltiness. If you do, mix proceeding.
- If you do not taste saltiness in the fourth glass, test the third glass to determine if you detect saltiness. Continue with the second and first glasses until you can just barely notice the salt. Keep in mind the glass that contains a barely noticeable amount of salt.
- Now rinse your mouth thoroughly with water. Use distilled water if possible, because tap water may be somewhat salty. Keep rinsing for about a minute. Repeat the threshold-measurement process. Your threshold should now be lower, so that you detect lower concentrations of salt.

Reflection Questions:

- **How does taste aversion explain the effectiveness of this herbal tea to treat sugar cravings and obesity?**
  (**Ageusia** is the Inability to taste (not quite the same as the inability to smell, though related - many taste issues result from problems with olfaction, and not taste at all. This is because the tongue can only indicate texture and differentiate between sweet, sour, bitter, salty, and umami, most of what is perceived as the sense of taste is actually derived from smell).

  High-calorie foods can be as addictive as cocaine, tobacco and other drugs. If you have a "sweet tooth," you may find it nearly impossible to resist sugar cravings. *Gymnema* helps to make sweet foods less satisfying, thereby curbing the body's tendency to crave them.

- **Name one pathological condition that directly affects taste perception?**
  Tissue damage to the nerves that support the tongue can cause ageusia, especially damage to the lingual nerve and / or the the glossopharyngeal nerve. The lingual nerve passes taste for the front two-thirds of the tongue and the glossopharyngeal nerve passes taste for the back third of the tongue. Neurological disorders such as Bell's palsy and MS cause similar problems to nerve damage. Deficiency of vitamin B_3 (niacin) and zinc can cause problems with the endocrine system, which may cause taste loss or alteration. Disorders of the endocrine system, such as Cushing's syndrome, hypothyroidism, or Diabetescan cause similar problems. Local damage and

inflammation that interferes with the taste buds or local nervous system such as that stemming from radiation therapy, tobacco use, and denture use also cause ageusia. Other known causes include loss of taste sensitivity from aging (causing a difficulty detecting salty or bitter taste)

- **What pathological conditions lead to taste aversion? How does someone become averse to a taste?**
  (The "Garcia Effect": Generally, taste aversion is developed after ingestion of food that causes sickness or vomiting. The ability to develop a taste aversion is considered an adaptive trait or survival mechanism that trains the body to avoid poisonous substances (e.g., poisonous berries) before they can cause harm. This association is meant to prevent the consumption of the same substance (or something that tastes similar) in the future, thus avoiding further poisoning. However, conditioned taste aversion sometimes occurs in subjects when sickness was merely coincidental and not related to the substance that caused the sickness (for example, a subject who becomes very sick after consuming vodka-and-orange-juice cocktails may then become averse to the taste of orange juice, even though the sickness was caused by the overconsumption of alcohol, or, another example – with chemotherapy patients, who become nauseated because of the drug therapy but associate the nausea with consumption of food).

- **Explain how your taste buds normally work (with taste receptor proteins) and how the normal workings were disrupted by the tea.**
  (Normally, a receptor protein in the tongue's taste buds will bind with the food, sending a signal to the brain that you are tasting "X" flavor. *Gymnema* inhibits this process by binding with the protein receptor, and not letting (not leaving room) the taste to bind. The herb's impairment of sweet sensation is profound and dramatically alters the perception of sweetness in sugar, chocolate, and candy without altering the perception of the other primary tastes. The exercise has an indelible effect on students because the herb's intense effect compels students to rely on their unique personal experiences to highlight the principles of gustatory sensation).

  Students report that sugar feels like melting sand on the tongue; Sweetarts taste exceptionally sour; and M&Ms taste chalky, salty, and bitter.

- **What happens if the receptor protein in your taste buds is absent, or "occupied" by an inhibitor?** (You won't be able to taste that molecule).

Models and Explanations: In this lab we explored the sense of taste as a way to visualize cell signaling. **A student who demonstrates understanding** of this concept can discuss the common mis-conception that taste cells that respond to different tastes are found in separate regions of the tongue (i.e tongue – mapping). In humans, the different types of taste cells are scattered throughout the tongue.

When the taste cells are stimulated, they send messages through three specialized taste nerves to the brain, where specific tastes are identified. Taste cells have receptors that respond to one of at least five basic taste qualities: sweet, sour, bitter, salty, and umami. Now, if your taste buds lack the receptor protein for salt (the ligand), (or if that receptor is "busy" – inhibited because something else is bound to it), and you are eating salty food, you won't taste it because there is no signal sent if there is no receptor – ligand binding occurring. **This student can look at data** of pre-and post- tea taste tests and explain how the *Gymnema* tea inhibits the sweet taste.

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Student Worksheet:

According to common mis-understanding, the tongue has distinct regions, each responsible for the detection of one of the four primary tastes. This outdated "tongue map" on which sweet is tasted at the tip, sour and salt at the sides, and bitter at the back of the tongue is based on an overly simplified interpretation of 19th century German research. More recent research shows that all areas of the tongue respond to each of the primary tastes to varying degrees. The four primary tastes, which are bitter, sour, sweet, and salty, have been extended to include a fifth taste, referred to as "*umami*". Taste perception begins when protein receptors, which are located on the plasma membrane of taste cells, are activated in response to physical contact with specific molecules (the ligand, or signal, in this case, a taste). The activated receptor (receptor bound to taste molecule) then triggers an intracellular signaling pathway, which triggers other events that eventually relay a signal to the brain. What happens if the receptor protein is absent, or "occupied" by an inhibitor?

In this exercise, you will experience how the primary tastes are combined to produce overall taste. You will compare your qualitative primary taste experiences to salt, sugar, aspartame, chocolate, and sweet-sour candy before and after sampling of an herbal tea (*Gymnema sylvestre*), which will have a profound effect on your tastes. Although each student will serve as his/her own subject in this study, you will compare and discuss your observations with your lab mates.

Neural response to primary tastes is critical given that it is associated with substances that are either life-sustaining or life-threatening. Specifically, sweet perception signals the taste of sugar-rich foods, *umami* signals protein-rich foods and bitter signals potentially toxic substances. Taste aversion is meant to prevent the consumption of the same substance (or something that tastes similar), thus avoiding further poisoning.

Write a procedure for the taste test experiment:

DATA ANALYSIS
Record the ratings in the table below and compare with others in your class.

Pre-tea rating	Salty		Sweet		Bitter		Sour	
	Your rating	Class avg	Your rating	Class avg	Your rating	Class avg	Your rating	Class avg
Salt								
Equal (Aspartame)								
Sugar								
M&Ms								
Sour Skittles								
MSG								

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Salt								
Equal (Aspartame)								
Sugar								
M&Ms								
Sour Skittles								
MSG								

Table 2. Post-tea rating of tastes.

Now, make 6 bar graphs (one for each food item, salt, aspartame, sugar, M&Ms, sour skittles/sweetarts, MSG). Put the taste (salty, sweet, bitter, and sour) on the X and rating (1-10) on the Y. You will have two bars, one for pre-tea rating and one for post-tea rating.

Reflection:

1. How does taste aversion explain the effectiveness of this herbal tea to treat sugar cravings and obesity? What pathological conditions lead to taste aversion?

2. What happens if the receptor protein in your taste buds is absent, or "occupied" by an inhibitor?

3. Name one pathological condition that directly affects taste perception?

4. Explain how your taste buds normally work (with taste receptor proteins) and how the normal workings were disrupted by the tea.