CHEMICAL ECOLOGY

Talking in Nature's Language

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Our planet is made of chemistry. All life, from microbes to plants to animals, uses chemicals to communicate with their world. Chemical cues allow us to communicate with the largest elephants and the smallest bacteria; and can be used to protect crops from pests, identify novel pharmaceuticals, or prevent the spread of disease. In this article, the author examines the role of chemical interactions between living organisms and their environment.

Identifying objects in the world around us is essential for organisms to survive. All living things need to know what to eat, what not to eat, and who might want to eat them. We identify objects using our senses. But what if you couldn't see? Or hear? Or touch? How would you find things in the world around you? And once you found them, how would you know what they are?

This is the dilemma that many organisms face every day. Many insects, for example, can't hear sounds the way we can (they detect vibrations). Bacteria cannot see. And plants can't even move! So how are they able to survive? How can they tell food from poison, or safety from danger?

In fact, there is one sense that is shared by all living organisms. All life, broken down into its fundamental units, is a result of chemistry. Every creature on this planet is essentially a large group of chemicals, all binding and working together. Thus, we all live in a world of molecules. In turn, all organisms can detect chemicals – this is the means by which all life on this planet communicates with each other.

The language of chemistry

If we could hear the language of chemistry like we hear sounds, our world would be deafening. At any given moment, every leaf, every fungus, every insect, every fish and every mammal is detecting or sending out chemical signals in the environment. To give some examples of the universal language of chemistry, let's discuss some ways organisms use chemicals for survival.

Finding mates

One of the earliest known experiments to detect chemical communication was performed by Sir John Ray in the 17th Century. Sir John was studying the peppered moth (*Biston betularia*), and noticed that a female moth he had trapped in a cage attracted two male moths who flew in through the window. Since the female could not be seen or heard, Sir John surmised that the males were attracted by the scent of the female. Although he had no way to identify these cues at the time, Sir John was right.

It was not until 1959 that Adolf Butenandt first identified a chemical released by female silk moths to attract males. Chemicals that are used to transmit information between members of the same species became known as pheromones. By 1995, scientists had identified the pheromones used by females of over 1500 species of moths[1]. We also know that females can attract male moths from tens of meters even in dense forest[2]. Today, we also know that animals use pheromones not only to attract mates, but for a range of purposes, like sending out warnings of danger or calling other individuals together.

The *Puccinia* rust fungus uses a different method. In order to reproduce sexually, the fungus must outcross, or fertilize a different population. To do this, the fungus becomes a master of disguise. First, it infects plants and causes them to produce 'pseudo-flowers' that not only look like yellow flowers, but also smell like flowers, and produce a sugary solution somewhat like nectar. Pollinators (such as bees and butterflies) are attracted to these 'flowers', pick up some of the fungus, and transport it to another pseudo-flower, helping the fungus reproduce[3].

Finding food

Bacteria such as *E. coli* require chemical cues to locate food. Without eyes or ears, their main way of sensing their world is through chemical cues. In the presence of food such as sugars, the bacterium uses its flagellum to swim towards it. It locates the source by swimming in the direction where it senses a greater concentration of sugar. This is functionally similar to how we find a lost cell phone by calling it and going to where the ring tone is loudest. For chemicals, directed movement to higher concentrations is known as 'positive chemotaxis'.

Teaching Tips

1. For concepts: When you discuss the wonder of chemical ecology with your students, have them taste mustard, cabbage and chili. Ask them what they taste, and ask them if they know what makes up this taste (chemicals). Then, ask students if they can guess why the plant makes these pungent chemicals – you might be surprised what they come up with!
2. For class experiments: Bring several covered jars of spices. Make sure students cannot see the spices. Ask them to open the jars and guess the contents. Then, discuss what it makes them think of – a particular food? A memory?

3. Go outdoors: Take your students outside. Have them observe insects – ants, flies, anything. Talk with them about how these insects might communicate with each other (given their tiny eyes and no ears!). Also talk with them about what kind of information insects might need to know – where is food, where are their mates, where are their enemies, etc. Encourage them to see if they can observe any of these behaviours in action!
4. Individual research: Have students choose a spice. Ask them to research this spice on the Internet to identify what plant the spice comes from, and why the plant produces the compounds we detect in the spice (use mustard and chili as examples).

Figure 1. *Puccinia* pseudo-flowers produced on *Arabis*. Source: An Ian Walker photo, uploaded by Lesfreck at English Wikipedia. URL: https://commons.wikimedia.org/wiki/File:Puccinia_on_Arabis.jpg.

Chemical Ecology

The study of how organisms use chemicals to communicate with their environment is called 'chemical ecology'. Chemical ecology is a relatively new field. The term was first used in the 1960s in the US, although scientists have known that chemicals can be used by organisms to communicate for centuries. Because chemical ecologists can study any living organism, their research can involve nearly every aspect of biology – even medicine. However, the two things that tie all chemical ecologists together are in the name: chemistry and ecology. Ultimately, chemical ecologists are interested in what chemicals are used, and how those chemicals affect the life of the organism. To become a chemical ecologist, a strong background in both chemistry and biology is helpful. But most of all, chemical ecologists must be fascinated by the natural world. Are you interested in animal behaviour? Do you like growing plants? Have you ever wondered why plants make cinnamon, or cloves, or vanilla? Or why we think some smells are bad, and some are good? If so, then you too can become a chemical ecologist!

For the *Bolas* spider, food is a nice juicy moth. These spiders are named for the sticky ball of silk, called bolas, which they swing into the air to catch a flying insect, much like a cowboy lassoes cattle. Some species even trick their prey with smell. One such spider, *Mastophora hutchinsoni*, adds chemicals to her bolas that mimic the pheromone of several species of female moths. Male moths are attracted by the smell and fly towards the bolas expecting to find a female. Instead they get caught in the sticky ball and become the spider's dinner[4].

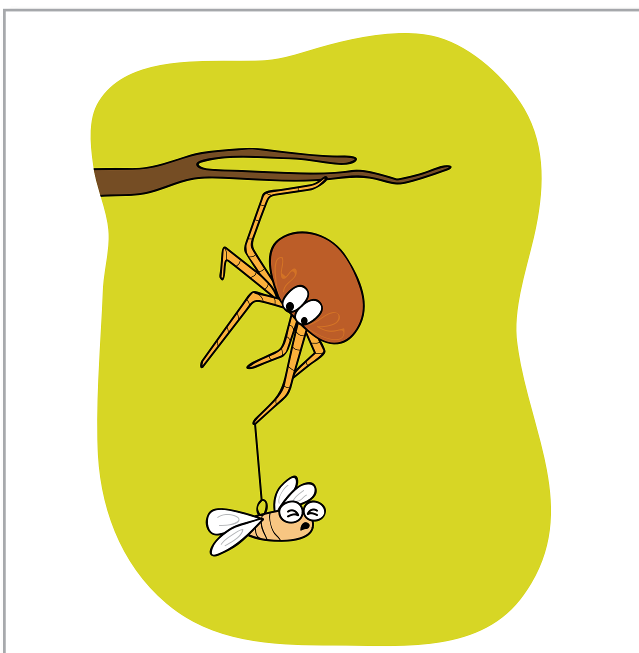

Figure 2. Bolas spider lassoing its prey.

Avoiding Enemies

For organisms like plants, that cannot run away, avoiding enemies is a tricky business. Who is a plant's enemy? Generally speaking, it is anything, like insects and microbes that either eat the plant or make it sick. Since they cannot run away, many plants defend themselves by producing toxins or deterrents that can harm or repel their predators. One common example of such a toxin is found in plants like mustard, cabbage and horseradish. The famous pungency you taste when you chew mustard or cabbage is caused by the break-down of chemicals called glucosinolates into isothiocyanates. These pungent isothiocynates are repellent or toxic to many insects and microbes.

Another way plants can avoid enemies is by crying for help. Since they have no way to make sounds, they cry for help with chemicals. When damaged by

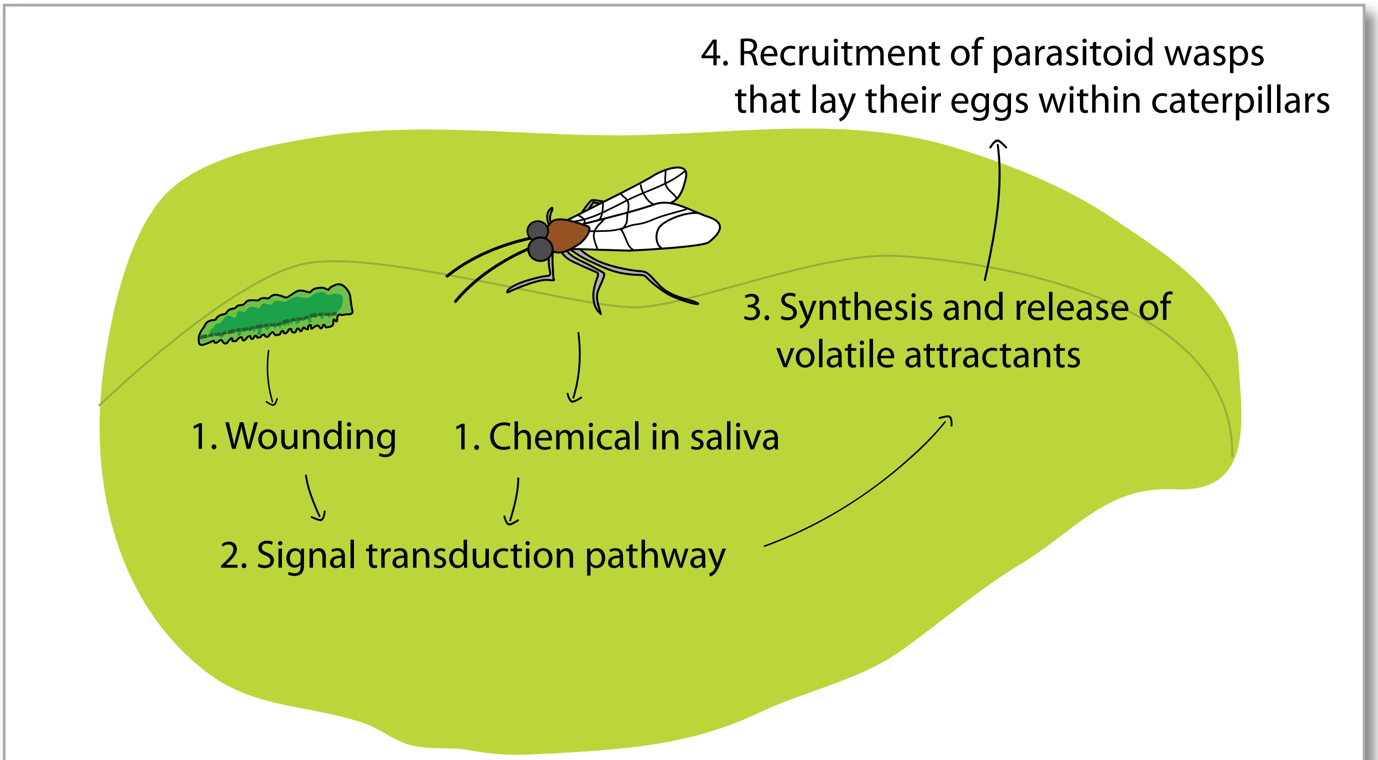

Figure 3. A young corn plant uses chemical cues to recruit parasitoid wasps as a defence mechanism against Egyptian armyworms.

insects such as caterpillars, some plants emit certain smells that attract predators of the caterpillar, such as wasps. For example, when the Egyptian armyworm feeds on young corn plants, the plants emit a number of chemicals into the air that attract a wasp that is parasitic on the armyworm[5]. In this manner, the plant calls in reinforcements to take care of the enemy on their behalf. The parasitic wasp, in turn, is able to find its host.

Chemicals in Action: Some like it hot

If you have ever smelled a fruit to determine if it's ripe, or spat out milk that has gone sour, then you too have used your chemical senses. Humans detect chemicals travelling through the air as smells, and through liquid or solids as tastes. To detect chemicals, we have special proteins in the neurons of our nose or on our tongue called 'receptors' that bind to chemicals and then send a signal through the neurons to our brain.

Although they don't all have noses or even brains, all living organisms - from bacteria to trees - detect chemicals from the environment using such proteins. One amazing example of how plants use these receptors to communicate is the story of the chili pepper. Native to South America, the chili pepper is a staple ingredient in Indian cooking. Indeed, a pinch of chili powder will immediately be met with a sensation of heat. But, have you ever stopped to think why the chili pepper tastes hot?

In fact, chili is actually 'hot', at least to our brains. The heat is due to a single chemical known as capsaicin. This chemical isn't hot by itself, but binds to a special receptor protein in humans known as TRPV1 (Transient Receptor Potential), which is capable of detecting high temperatures. When bound to capsaicin, this protein sends a signal to our brain that says 'Hot!' Interestingly, the same type of temperature receptor in birds does not respond to capsaicin[6]. This means that birds can eat chili peppers without feeling any of the heat. Is there an advantage to having mammals detect the capsaicin, and not birds? Some scientists think so, and they think it might have to do with the role that the pepper serves for the plant.

Chili Peppers are fruits of the chili plant. Like all fruit, they contain seeds. Nice juicy fruit get eaten by animals, who then release the seeds, through their faeces, into the soil where they can grow into new plants. Thus, through its fruit, seeds of the chili are spread far from the parent plants. In 2001, Tewksbury and Nabhan found that when small mammals, such as mice and packrats, were fed chilies (which they would

Figure 4. An arrangement of jalapeño, banana, cayenne pepper, chili, and habanero chili peppers – none of which are 'hot' to birds! Source: Ryan Bushby (H at English Wikipedia). Wikimedia Commons, CC-BY. URL: https://commons.wikimedia.org/wiki/File:Arrangement_of_jalape%C3%B1o,_banana,_cayenne,_chili,_and_habanero_peppers.jpg.

eat only if they hadn't tasted them before), the seeds would not germinate (grow into plants). In contrast, when birds were fed chilies, the seeds would grow properly. Moreover, birds were not repelled by the chilies. These scientists proposed that capsaicin might be the chili's way of repelling animals that destroy their seeds (mammals), while animals that can spread their seeds (birds) are not repelled[7].

Tewksbury later found that besides mammals, capsaicin also repelled another unwanted organism that kills seeds – a fungus known as *Fusarium*. Chilies are already known to possess antimicrobial properties, and Tewksbury found that the capsaicin in their fruit protects the seeds from this fungal pathogen[8]. Thus, the hotness of chili protects the precious seeds of the plant from dangers big and small.

Listening to nature

The chemical language of nature is all around us, but we know very little about what and how organisms on our Earth communicate. Unlocking their molecular conversations can not only help us to learn more about our fellow creatures, but can also reveal new ways to interact with our world. Indeed, the 2015 Nobel Prize was jointly awarded to William C. Campbell, Satoshi Ōmura and Youyou Tu for discovering chemicals that treat diseases caused by roundworm and malaria parasites. These chemicals are natural products produced by bacteria and plants likely for repelling enemies such as microbes. By listening into their conversations, these Nobel Lauriates discovered a new way to treat disease.

Next time you stop to smell a flower, or taste a ripe, juicy mango, I hope you will take a moment to appreciate the amazing chemical language they are using, and try to listen to the sweet story they are telling you.

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Shannon Olsson grew up in the countryside of northern New York State. She was always fascinated by the world around her, and often wondered how organisms in nature were able to live and work together so elegantly. Shannon studied chemistry in college, and in her last year she was able to synthesize a pheromone for the first time. When she saw that something she had created could affect another living organism's behaviour, she became fascinated with chemical ecology. She followed her interests to Sweden, Germany, and is now in India, where she focuses on understanding the chemical ecology of India's immense biodiversity.