More Than Attraction: What Bees See in Flowers

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And other eyes than ours
Were made to look on flowers
—Christina Rossetti (1830–1894), "To What Purpose This Waste"

That not for man is made
all colour, light and shade
—Edmund Gosse (1849–1928), "The Farm"

Conventional wisdom holds that bees are attracted to flowers entirely by instinct: that they are drawn to them, in a sense, like a magnet attaches itself to steel. Recent research reveals that the truth is infinitely more complex: Visiting a flower is a rich multisensory experience for a bee, involving color sensations that we can't see, linked to a bouquet of smells, the sweetness of nectar, and even electric fields surrounding the flowers. Bees' preferences are guided by a library of memories—experiences of other flowers, learned skills of how to extract nectar and pollen rewards, and the acquired knowledge of the flight path from the nest or hive to the flower patch. There is evidence that bees can imagine flower shapes in their minds. Might they even have a sense of beauty?

Insects, with their armor-like exoskeletons and their rigid mask-like faces, have long been thought of as the robots of the animal kingdom. The flower-visiting bees are no exception—while people have appreciated the sweetness and light brought to us by bees' activities in making honey and wax, they have often thought that bees are guided to flowers by entirely robotic processes. This is encapsulated in the often-heard phrase that bees are "attracted" to flowers—their colors, their scents and patterns—as if they somehow can't help dropping out of the sky whenever they see a flower-like target.

When bees embark on their maiden flights, they do have some preferences for certain colors over others—but as it is for humans, there is variation among individual bees in their favorite colors, and these preferences can be quickly overwritten by learned ones. There is also "personality variation" between individuals in terms of how quickly they learn, and how neophilic or neophobic they are in response to unfamiliar flowers.

In fact, we now know that bees are more like amateur economists in the market of available flower species. There might be several dozen species in the flight range of any hive or nest. Naive bees have little idea which might be most rewarding; hence, they typically sample multiple different species and carefully evaluate what's on offer—the quantity and quality of nectar and pollen. They memorize the signals that advertise the rewards—the color of the flower, for example—very much like a careful human shopper memorizes the packaging of a product that they have experienced as having good quality for a reasonable price. Then, human shoppers (and bees!) often stay faithful to the same product (of flower species) unless the quality goes down or a better option becomes available. Many flowers are natural puzzle boxes—think snapdragon or monkshood, for example—and bees need to improve their handling skills with experience over dozens of flower visits. No innate sense can guide bees to a particular rewarding flower patch that might be several miles from their home base—they have to learn the route, its compass direction (for which they use the sun as a reference), and the landmarks that mark the way.

Bees see the colors of flowers wholly different from how we see them. We humans see a range of colors from violet to red—the familiar colors of the rainbow. But there is of course electromagnetic radiation beyond this range: think ultraviolet and infrared, X-rays, gamma rays, FM and AM radio waves, and so on. No animal perceives the entire range of that radiation, but it turns out that humans are unusually narrow in their sensory capacities. Some animals can sense infrared light, and the majority of animals, bees included, can see ultraviolet. This is a healthy reminder that the world we perceive is neither "complete" nor a direct representation of reality or physics. The world we see is filtered through our particular sense organs, and animals such as bees have very different eyes, which enable them to see what for us remains wholly invisible.

The flowers of many plant species have evolved to address the ultraviolet sensitivity of pollinators. They display patterns that to us can only be made

apparent through specialized camera equipment that makes the UV parts visible. Using such equipment, we have found out that many flower patterns that look unicolor to us are actually multicolored for bees (figure 1). Part of these flowers' advertising strategy is to display complex patterns that can be memorized by bees, to help guide them to the nutrition they are after—nectar and/or pollen. Note that terms like *ultraviolet* and *infrared* are entirely anthropocentric and have no physical basis; they just denote that these qualities are outside our range of sensitivity. Bees, on the other hand, don't see red as well as we do—their visual spectrum ends around where we see yellow light. So if there were scientists among the bees, they might coin a term for "infra-yellow," and might think it fascinating that other creatures, such as humans, can see what to them is invisible.

Until recently, insects including bees were thought to have very poor spatial vision—but now it turns out that they may have a special "superpower"

Figure 1. **Ultraviolet patterns in flowers.** A flower of the species *Iris pseudacorus* photographed in the visible human light spectrum (left) and through an ultraviolet filter (right). In the left image, the bee touches with its antennae a region of the flower that appears to have just a subtle contrast in the human-visible yellow. What the bee finds of interest becomes apparent in the right photo, taken through a UV filter: The center of the flower is strongly UV absorbing and appears as black, whereas the periphery reflects UV light. (Photos by Prof. Klaus Lunau, with permission.)

called hyperacuity. Bees' compound eyes contain a few thousand individual sensing units called ommatidia, each with its own lens. Each such unit was thought to correspond to one "pixel" in the image that they can see. Your phone camera probably has over ten million pixels—you really wouldn't want to buy one that has just a few thousand—yet common thinking among scientists continues to be that this is what bees have to make do with (figure 2). This would render them virtually blind to many of the fine-grained patterns that some flowers display. But it turns out that the notion that insect sight is constrained by the optics of their eyes is too simple. Recent research shows that insects make fine-grained scanning movements while in flight; they move their heads, their retinae, and even individual photoreceptors (specialized nerve cells in the eye that convert light stimuli into electrical signals). Doing so, they can integrate information over time (and they can see way faster than humans!) and so acquire a much more fine-grained image than would be available if their eyes were simply a static camera device. This hyperacuity might enable bees to discern fine-grained patterns in flowers whose adaptive function was hitherto mysterious.

Can bees picture the shapes of flowers in their minds? At first glance, this seems like a trivial question: Surely if bees can recognize a flower shape, they must also be able to imagine it. But neural-computations models show that images can also be recognized by so-called simple feature detectors: specialized nerve cells that measure edge orientation, color, contrast, and so forth. Your smartphone, too, can recognize your face, but it can't imagine it. One way to test if an animal has a mental representation of a shape is to test whether they can recognize it in a different sensory modality.

You might remember a birthday party game from childhood where you had to reach into a bag and identify an object by touch that you had previously only seen—for example, a spoon, a key, or a coin. This requires you to be able to picture the object in your mind, and to think about how the correct shape might feel. Bees can be trained that balls, but not cubes, are linked to a sugar reward by seeing these shapes through Plexiglas—in a "look but don't touch" situation. Such bees can subsequently identify the same shapes by touch alone. We tested bees in complete darkness, viewing the bees' behavior with infrared equipment (such conditions are not unusual for bees, since their nests are naturally dark), and they correctly identified the shapes they had previously only seen (figure 3). Bees trained to tell cubes from spheres in darkness could also later identify the correct shapes when seeing but not touching them, indicating a form of mental image that can be accessed with more than one sensory modality.

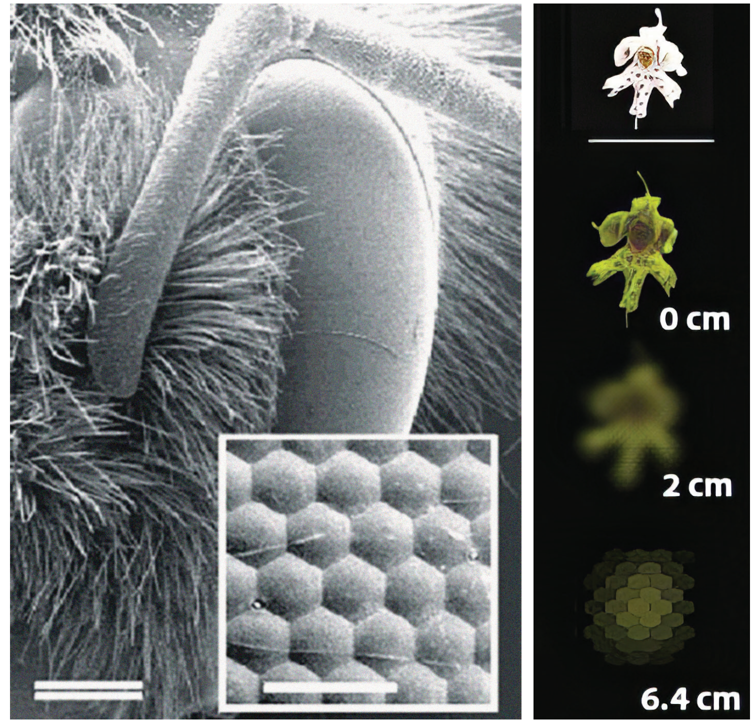
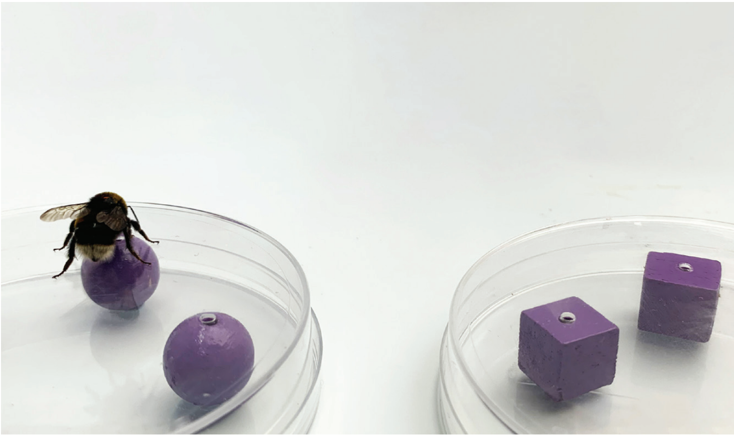


Figure 2. **More pixels than meet the eye?** Left: Electron micrograph of a bumblebee eye (double scale bar: 0.5mm). The eye contains about four thousand ommatidia (individual eyelets) each with a hexagonal lens (see inset; scale bar 50μm). The historical view purports that a bee can, at best, see as many pixels as it has ommatidia. Right: A flower of the orchid *Traunsteinera globosa* (scale bar = 1 cm) as it appears for humans (top) and the image detail as a bee might see it from various distances. Given a static view of the eye, the detail of the flower would be all but invisible unless the bee is actually on the flower. However, we now know that insects can achieve hyperacuity (better resolution than is available through static eye optics) using scanning movements of the body, head, retinae, and photoreceptor cells.[1] (Images by Johannes Spaethe.)

Bees' sensory experience when visiting a flower extends far beyond just vision. For example, they can sense the electric field of a flower. Such electric fields change every time a flower is visited, and so bees can use this to gauge if the flower has recently been emptied of rewards by a competing pollinator. Using their antennae, they also have a rich sense of smell—again, odors are not just "attractants" in the conventional sense—and bees can learn to associate pretty much *any* scent with food rewards. The scent gains its attractiveness only through individual experience. Using a bouquet of chemicals, flowers often display a whole scent landscape. Different parts of the flower



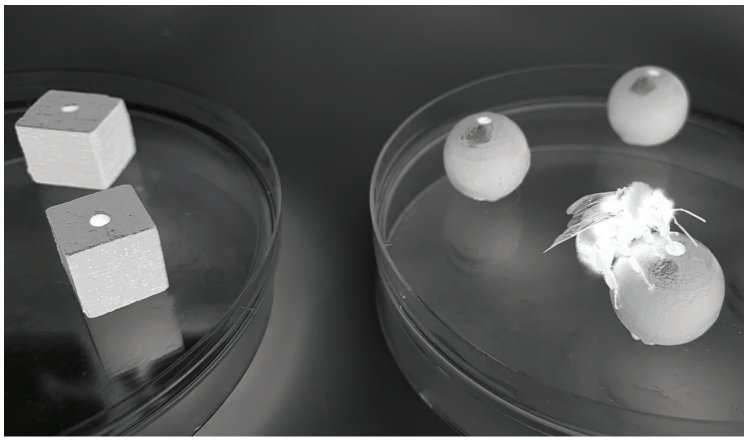


Figure 3. **Can bees "picture" shapes in their minds?** Bumble bees in a cross-modal object recognition task: Bees learned to associate reward to one shape (here: a ball) in a "look but don't touch" situation in the light, where a Plexiglas lid prevented them from feeling the shape. Bees subsequently recognized the same shape in darkness (under infrared light, invisible to bees), when they could feel but not see the shapes. The same experiment was also repeated the other way around, in which bees were first exposed to the objects in darkness, and subsequently had to find the right object shape in the "look but don't touch" situation. (Photos by the author.)

can have different scents, and so while bees move inside a flower, they may literally experience something of an odor movie.

Twenty years ago, I collaborated with installation artist Julian Walker, who at the time studied people's responses to paintings in museums (asking questions such as, *How long did they spend in front of paintings? Which details did they inspect?*). Over a few beers, we came up with the idea to test bumblebees in a similar manner, by offering various posters of paintings in a flight arena where bees usually found artificial flowers with nectar. Somewhat amusingly, bees had a strong preference for van Gogh's *Sunflowers* (figure 4), in comparison to Paul Gauguin's *A Vase of Flowers*, Patrick Caulfield's *Pottery*, and Fernand Léger's *Still Life with Beer Mug*. The project was essentially designed to provoke thinking about the implications of biology in human aesthetics and the relationship between object representation and its biological connotations.[2]

But another question frequently came up in discussions of the project, especially with nonscientists: could it be that bees, like humans, appreciate the beauty of flowers—could they have an aesthetic sense? Animal behavior scientists are indoctrinated not to anthropomorphize, and so to me this seemed like a strange question at the time: unanswerable at best, but a bit silly at worst. The notion that insects might experience any form of emotion was considered downright unscientific.

Figure 4. **Do bees like van Gogh's "Sunflowers"?** Bumblebees inspecting a detail of a copy (painted by Julian Walker) of the famous painting. (Photo by the author.)

Times have changed. It is still impossible to acquire formal certainty about the question of whether an animal experiences emotions, since they simply cannot inform us about their inner states verbally. But scientists now agree that one can at least gather psychological evidence that makes it plausible that an animal experiences emotion-like states. Insects are no exception. In the last twenty years, evidence has accumulated indicating that bees can experience negative emotion-like states such as pain, but likely also positive states like optimism: When they encounter a surprise sugar reward, this gives them a dopamine hit that makes them respond more positively to ambiguous stimuli, and also more resilient to the trauma that might be experienced as a result of predator attacks. Dopamine even increases in the brain when bees just *anticipate* receiving a reward in the near future—showing that bees are anything but robotic creatures merely responding to currently present stimuli.[3] They may predict the future, and they experience emotions that come with anticipating a rich food bonanza.

Bumblebees have also been found to engage in play-like behavior: When offered little colored balls, they roll them around extensively, even though there is no food on offer. It appears that they enjoy the activity in itself. Given all this evidence for positive emotion-like states—a sense of enjoyment—the question of whether bees appreciate the beauty of flowers appears in a new light. Flowers are valued by humans for their symmetry, their highly contrasting colors, their stunning color patterns and elaborate shapes. Why should this not be all the more so the case for bees? Flowers contain all the nutrition that bees require. In us, the sense of beauty is at many levels linked to our biological needs. Edward O. Wilson suggested, for example, that humans' appreciation of landscape attractiveness is intricately linked to an assessment of safety from predation and fertility.[4] Our sense of beauty in potential romantic or sexual partners is linked to their biological fitness. The question of whether other animals have a sense of beauty was discussed at length by Charles Darwin in the context of mate selection.[5] Against this background, the notion that bees might actually experience the visual and olfactory display of highly-rewarding flowers as aesthetically pleasing gains at least some plausibility. Scientists are sometimes attacked by their peers for being overly speculative—but without the courage to air what might be perceived as crazy ideas, science is much less likely to progress in interesting directions.

Artists may be considerably bolder in this regard. For her project entitled *Pollinator Pathmaker*, artist Alexandra Daisy Ginsberg conversed extensively with scientists like myself about bees' interactions with flowers, their color vision, their spatial movements, and their psychology. She subsequently

created an "artwork for pollinators, planted and cared for by humans"—an "interspecies artwork"—composed of gardens with elaborate, spatially arranged mixtures of flowers of different species.[6] Whether or not pollinating insects truly appreciate the beauty of the diverse meadows planted in this manner remains as yet unknown, but the point is to get viewers to ponder what a garden might look like if it was designed by the animals for whom flowers are actually the intended signals, the pollinators.

Do bees ever make their own art? Now we are truly in speculative territory. Of interest in this regard are bees of the South American tropical genus *Partamona*. These bees build very elaborate nest entrances, often manufactured from materials that need to be collected from afar, such as white sand and tree resin, and assemble them into funnel-shaped structures that allow bees to enter the nest at high speed, thus evading predators lurking near the nest entrance to intercept landing or departing bees. Often, these structures have star-shaped, quasi-symmetrical elaborations that make them look like strange flowers (figure 5). Could it be that these structures reflect aesthetic preferences of the bees that were shaped in the context of flower visitation?

We have all learned that many bee species are in trouble in many parts of the world because of habitat loss, overuse of pesticides, and climate extremes (among other factors). Worries about such population declines are typically motivated by arguments of utility: We need bees to pollinate our crops and

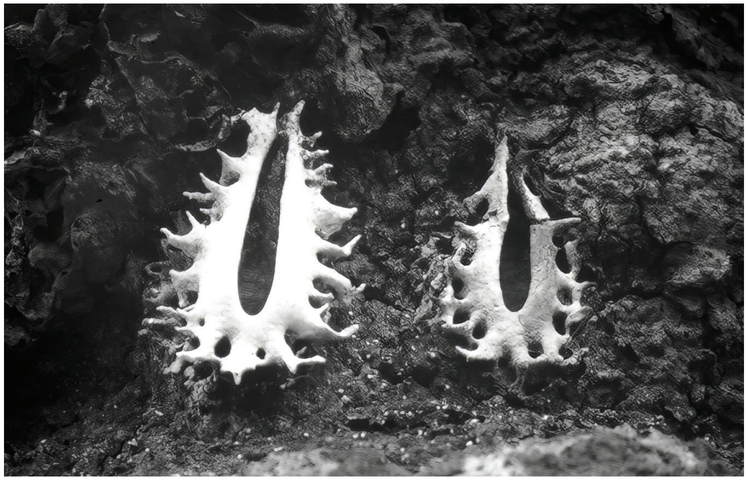


Figure 5. **Do bees make art?** Neotropical bees of the genus *Partamona* build nest entrances that look distantly like flowers. Two neighboring nest entrances are shown here, each connected via a tunnel to a nest, built inside cavities excavated from a termite nest. (Image by João M.F. Camargo.[7])

garden flowers, hence we need to conserve them. However, once you realize that we humans are thinking, feeling, enjoying, and suffering beings surrounded by many other thinking, feeling, enjoying, and suffering beings, a different motivation for these animals' conservation arises. Where it is in our power, we have the responsibility to protect the environments that have shaped these animals' unique minds and allow them to thrive.

Fortunately, in the case of bees, there are many things we can easily do to contribute to their wellbeing: minimize the use of pesticides and herbicides, allow flowers to thrive on our lawns or balconies, and plant the kinds of flowers that bees require, rather than the ones bred by humans for showiness and size. The bees will reward us by coming to visit the flowers, allowing us to contemplate the psychology involved.

I hope to have convinced readers that bees' responses to flowers are substantially more complex than a mechanical attraction to colors, shapes, and scents. The next time you see a bee crawl into a flower, think of the riot of multisensory experiences in the bee's mind, formed from memories and current input from her sense organs; that her preferences are shaped by experience rather than just innate predispositions; and that she might even perceive a strange beauty in flowers, as experienced through her sense organs so vastly different from yours. Every spoon of honey you consume and every beeswax candle you light are the result of the learning, memory, and hard work of dozens or hundreds of bees, all with different individual experiences and personalities.

NOTES

1. Images first appeared in Natalie Hempel de Ibarra, Keri V. Langridge, and Misha Vorobyev, "More Than Color Attraction: Behavioral Functions of Flower Patterns," *Current Opinion in Insect Science* 12 (2015): 64–70, https://doi.org/10.1016/j.cois.2015.09.005.
2. For a fuller explanation of the study, see Lars Chittka and Julian Walker, "Do Bees Like Van Gogh's *Sunflowers*?" *Optics and Laser Technology* 38 (2006): 323–328, https://doi.org/10.1016/j.optlastec.2005.06.020.
3. Jingnan Huang et al., "Food Wanting Is Mediated by Transient Activation of Dopaminergic Signaling in the Honey Bee Brain," *Science* 376, no. 6592 (2022): 508–512, https://doi.org/10.1126/science.abn9920.
4. Edward O. Wilson, *Biophilia* (Cambridge, MA: Harvard University Press, 1984).
5. Charles Darwin, *The Descent of Man, and Selection in Relation to Sex* (London: John Murray, 1871).
6. Alexandra Daisy Ginsberg, "Pollinator Pathmaker," https://www.daisyginsberg.com/work/pollinator-pathmaker.
7. The image appeared first in Lars Chittka, Jens Schorn, John M. de Souza, Dora F. Ventura, and João M.F. Camargo, "The Nest Entrance Signal of the Amazonian Bees *Partamona pearsoni*—A Case Where Insects Design Their Own Flight Targets" in *Proceedings of the Colloquia on Social Insects*, Vols. 3–4, ed. V.E. Kipyatkov (1997): 107–116.