A Sting of I

BILL WIEGAND

Gene Robinson is an entomologist at the University of Illinois at Urbana-Champaign. Robinson studies honeybee behavior.

By Alison Davis

Gene Robinson was sick of picking grapefruit.

Robinson was 18 years old, volunteering on a kibbutz in Israel, and he decided to look for something else to do. Along with grapefruit, this kibbutz was also a commercial honey producer. How about working with bees instead?

"Why not?" Robinson wondered at the time. Can't be much worse than picking grapefruit, he thought, and he ventured over to the hives.

It was love at first sight, recalls Robinson, who is now a biologist at the University of Illinois at Urbana-Champaign. In less than 2 weeks he developed a lifelong infatuation with the honeybee.

Order in Chaos

Robinson knew nothing about the honeybee, or about bees in general, but between the stings and the swarms he realized that things were not what they seemed.

He saw chaos in the hive. Bees were coming and going, without apparent order or meaning. But like so many closets that are a complete mess to someone else, if you know where everything is, it's not a mess at all. There is order amid the chaos, and Robinson saw it.

Thirty years after his introduction to the honeybee, Robinson still studies the insects. In fact, he does it for a living: Robinson runs a research lab dedicated to studying the biology behind social behavior in, you guessed it, bees.

"I realized that I really loved the bees—not so much the industry aspects—but the science, the questions," says Robinson.

"How is their society organized? How are they able to do everything that they do?"

Today, Robinson admits that his early questions about bees were somewhat simplistic and not very testable. But over time, Robinson has developed a sophisticated research endeavor to uncover brain molecules that drive the behavior of these incredible creatures.

Robinson had spent so much time observing honeybees in their natural environment that he knew that the very social way these insects live has to be a necessary part of their existence. He knew that the order of the hive is part of the bees' social construct.

But how could he figure out exactly what was going on?

Honeybees are a versatile experimental system since they can be studied in the lab or in the wild.

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Robinson knew that in order to dig deeply into the topic of learning about how certain bee behaviors could be hard-wired, one of the first places to look was in the brain. Honeybees do have brains (see photo below), albeit not nearly as sophisticated as ours. There is no evidence, for example, that bees are conscious or that they think about the future.

Robinson suspected that there must be an underlying molecular logic—the coordinated actions of genes in the brain—to account, at least in part, for social behavior in beehives. He decided to find the brain genes involved.

At the time, searching for the genetic underpinnings of social behavior was not exactly a mainstream idea.

In fact, Robinson remembers being very unsure about having such radical research ideas as a graduate student. He didn't have the confidence that often comes with time and experience, and he really wondered whether his ideas were too naïve.

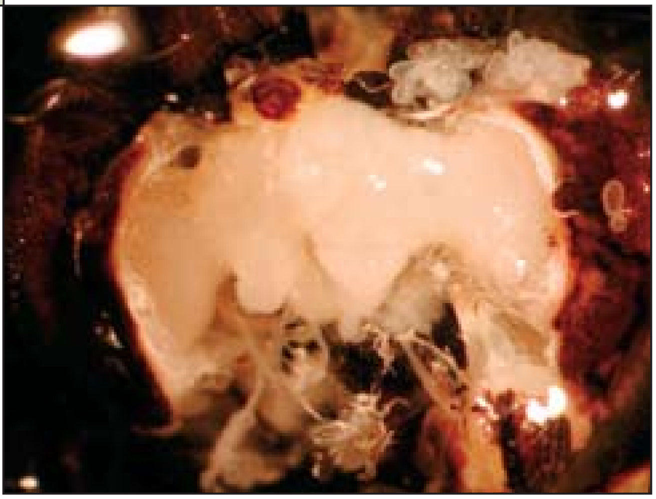
"Sure, it's a new idea," Robinson recalls thinking, "and no one has ever done it. But maybe there's a good reason no one has ever done [these experiments]!"

Nevertheless, Robinson pressed on and sought support from advisors, among them John Hildebrand (then an insect scientist at Columbia University in New York City), who now runs a research lab at the University of Arizona

From Kibbutz to Cornell

Time, experience, and hard work landed Robinson at Cornell University in Ithaca, New York, where he pursued a Ph.D. in entomology (the study of insects). Before long, Robinson settled into a research project investigating how hormones and nerve circuitry influence social behavior in honeybees.

Gene Robinson looked to the honeybee brain (photo) to find genes involved in bee behavior.



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The fact that honeybee societies exhibit complex behavior—not just knee-jerk reactions to their environment—means these insects have a pretty high level of functioning, says Robinson, adding that honeybees cannot survive without the social structure of a hive.

"Many people think of insects as simple, little robots that respond to stimuli," Robinson says. Instead, he notes, because their behavior is controlled in part by hormones, insects like bees have a lot in common with larger and more complex organisms like vertebrates (animals with backbones).

in Tucson. Hildebrand had a passion for studying the sense of smell in moths, and he urged Robinson to pursue his ideas, wacky as they may have seemed.

Hive as Laboratory

Robinson found himself naturally drawn to just watching bees, but he also recognized the species as an extremely practical experimental system. You can study them in the lab, and you can study them in the wild. You can willfully alter the social structure of a hive community and see what happens.

The beehive, a society that rivals our own in complexity, exhibits a clear division of labor. Just as in our world, there are individuals with specialized job descriptions, such as caretakers, builders, and gatherers. One hive member, the queen, handles the job of reproduction.

While the queen bee lives for 2 to 5 years, the other females (the "worker" bees) and the male "drones" only live about 1 month. It takes about 3 weeks for a baby bee to mature into an adult hunter, called a forager.

What's interesting about bees is that rather than being stuck in a particular job, a hive adjusts its workforce according to need, such as the availability of food. A builder can switch to become a gatherer, or vice versa. Robinson's research has taught him that the changes in honeybee job descriptions are strongly influenced by the environment.

Robinson discovered that manipulating the social structure of the hive could alter the makeup of the hive workforce in a flash. By removing forager bees from the hive, all of a sudden the younger, "nurse" bees acquired foraging abilities at ages as young as 1 week old. Similarly, Robinson explains, given a shortage of nurse bees to care for the babies in the hive, some of the bees never grow up, instead becoming "Peter Pans" to care for the youngest hive dwellers.

"So there's social regulation for how fast a bee grows up," says Robinson, adding that some developmental changes associated with the growth of certain brain regions are known to be genetically determined.

Rhythm in the Genes

Robinson discovered that a gene called *period* was socially regulated in honeybee brains. This was the very first demonstration of social behavior affecting a gene that controls biological rhythms. The findings brought Robinson one step closer to his dream: understanding how genes orchestrate brain activity to give rise to social behavior.

Organisms as diverse as insects, mice, and humans act to some degree according to an underlying regularity. For many years, scientists have been fascinated with studying biological clocks, and an entire field is devoted to understanding so-called circadian rhythms (see sidebar, page 7).

In people and animals, circadian rhythms help control sleeping, eating, and other behaviors. Scientists have uncovered a genetic underpinning for circadian rhythms, and one of the pivotal molecular players is the *period* gene. Versions of the *period* gene have been found in almost all animal species.

To his surprise and delight, Robinson found that in forager bees, the *period* gene was ragingly active, whereas in nurse bees the activity of this gene limped along.

Makes sense, if you think about it: Nurse bees work around the clock, without rhythm. This is just the kind of behavior that suits the needs of babies who may get hungry any time of the day or night. The behavior of forager bees, on the other hand, is distinctly rhythmic as they hunt for nectar and pollen according to the availability of outside light, the ambient temperature, and other aspects of the bees' surroundings that tend to fluctuate rhythmically on a daily basis.


This adult hunter bee is foraging on an aster flower.

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Robinson had found a link between the complex, socially regulated foraging behavior of bees and the activity of a specific gene. He and others have since discovered that the activity of more bee genes coincides with foraging and other insect behaviors.

Put It to the Test

Robinson got busy teasing apart the molecular details of how a gene's activity could respond to social activity. In the case of the forager bees, what was it that caused the hive to reshape itself? What was the environmental trigger that forced bees in a hive deprived of foragers to turn up the volume of the *period* gene and acquire the ability to hunt for food?

Robinson came up with three ideas and tested each in the hives.

Maybe it's as simple as detecting a food shortage. With few foragers, the amount of food entering the hive goes down and young bees get into gear as they become hungry. Robinson refers to this potential scenario as "decentralized," since it doesn't involve any sort of top-down instructions from the queen bee.

Another similar, decentralized possibility might be that the young bees sense the absence of older bees, perhaps through some type of pheromone (or lack thereof) circulating throughout the hive. A pheromone is a chemical (a type of hormone) released by an insect or other animal through which it communicates with another individual of the same species through the sense of smell.

Finally, there could be a leader-follower type of response, in which some of the bees have special access to information—for example, environmental conditions—and these bees pass on the news to the rest of the hive. Robinson views this sort of scenario as "centralized," since it reflects a single bee (or a select few bees) putting out a call for change, sort of like having a command center within the hive.

Robinson interpreted the results of his experiments to conclude that there does not appear to be any sort of centralized control.

He likens the decentralized hive activity to how our own brain functions. Or the stock market. The actions of many individuals affect stock prices, even though it appears that there is a general, integrated response.

Honeybees also clearly respond adaptively as an integrated unit, but it's not as if one bee is sending out the orders.

Honeybees acquire different job descriptions as they age. Normally, it takes about 3 weeks for a baby bee to mature into an adult hunter, called a forager (left). Undertaker bees (right) are usually around 14 days old, in the transition from nursing to foraging. This undertaker bee is carrying a dead bee out of the hive.

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The queen does largely control the size of the bee population, but she isn't entirely running the show.

"There is no executive committee of [bees] that know more than the others," Robinson explains.

The story is far from over, says Robinson, but he now has a good sense that molecular signals, communicated via pheromones, are what's triggering the changes in hive behavior. Robinson has evidence, for example, that certain pheromones can directly cause changes in the activity of certain genes.

Nature or Nurture?

So what's the answer to the perennial biological question about the impact of nature versus nurture? Do genes or the environment make us unique? Are we born to be funny, or musical, or athletic? Or do practice and being in the right place at the right time matter more?

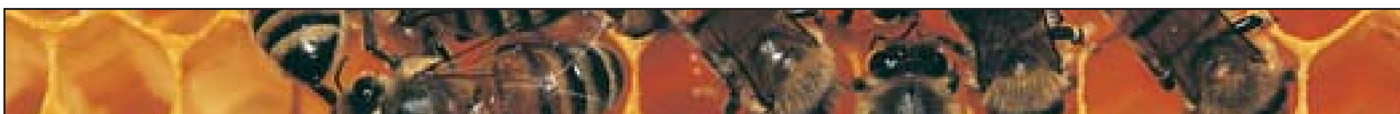
It's both, says Robinson, but even that's too simplistic a notion. He likes to take things a step further.

By interrupting the natural order of his "lab"—the honeybee hive—Robinson made the fascinating discovery that social environment does appear to be able to mold the function of genes, and vice versa. Robinson calls this new area of research "sociogenomics."

In his view, sociogenomics is "beyond nature and nurture." We're all born with one version of a human genome, Robinson says, but it's not carved in stone. Our genomes are influenced by both heredity *and* environment, and sculpted by our social interactions.

While the findings don't translate directly to humans—communities are social but certainly not exactly hives—Robinson's research provides a provocative new lens for seeing just what makes us who we are. ■

Dan Hogan and Jennifer White contributed to this article.



It's About Time

cir•ca•di•an (sur-**kay**-di-ăn) *adj.* of physiological activity occurring approximately every 24 hours.

Why do most heart attacks occur in the morning? Why does a transcontinental flight make you feel so rotten? How do the swallows of Capistrano, California, know exactly when to fly south every year?

Like some animal behaviors, the human body also functions according to an internal rhythm. Inside your brain sits a master biological clock. This molecular timepiece, made up of cells, is housed in a sliver of tissue called the suprachiasmatic nucleus, or SCN. It sits quite close to the optic nerve, which controls vision, and light signals are thought to play a big role in keeping the body clock "on time." The SCN helps to coordinate the actions of billions of mini-clocks located throughout your entire body. This is one of the main ways your body controls sleepiness.

Scientists know that many body functions aside from sleep, including the regulation of temperature, hormone levels, digestive secretions, and blood pressure, all vary slightly—but regularly—throughout the day and night. These processes and many others are thought to be affected by our biological clock. A clock that's offset can make us feel downright awful: Jet lag is a perfect example. Or seasonal affective disorder, in which some people become depressed during the winter months when abundant sunlight is scarce.

Researchers, many working with insect model systems, are uncovering genes that are critical for keeping biological time. One of these, called *period* (see main story), has been linked to a variety of unexpected biological phenomena, including some behaviors.—*A.D.*