The Amateur Scientist

When I was a kid I had a "lab." It wasn't a laboratory in the sense that I would measure, or do important experiments.

Instead, I would play: I'd make a motor, I'd make a gadget that would go off when something passed a photocell. I'd play around with selenium; I was piddling around all the time. I did calculate a little bit for the lamp bank, a series of switches and bulbs I used as resistors to control voltages. But all that was for application. I never did any laboratory kind of experiments.

I also had a microscope and *loved* to watch things under the microscope. It took patience: I would get something under the microscope and I would watch it interminably. I saw many interesting things, like everybody sees--a diatom slowly making its way across the slide, and so on.

One day I was watching a paramecium and I saw something that was not described in the books I got in school--in college, even. These books always simplify things so the world will be more like *they* want it to be: When they're talking about the behavior of animals, they always start out with, "The paramecium is extremely simple; it has a simple behavior. It turns as its slipper shape moves through the water until it hits something, at which time it recoils, turns through an angle, and then starts out again."

It isn't really right. First of all, as everybody knows, the paramecia, from time to time, conjugate with each other-- they meet and exchange nuclei. How do they decide when it's time to do that? (Never mind; that's not my observation.)

I watched these paramecia hit something, recoil, turn through an angle, and go again. The idea that it's mechanical, like a computer program--it doesn't look that way. They go different distances, they recoil different distances, they turn through angles that are different in various cases; they don't always turn to the right; they're very irregular. It looks random, because you don't know what they're hitting; you don't know all the chemicals they're smelling, or what.

One of the things I wanted to watch was what happens to the paramecium when the water that it's in dries up. It was claimed that the paramecium can dry up into a sort of hardened seed. I had a drop of water on the slide under my microscope, and in the drop of water was a paramecium and some "grass"--at the scale of the paramecium, it looked like a network of jackstraws. As the drop of water evaporated, over a time of fifteen or twenty minutes, the paramecium got into a tighter and tighter situation: there was more and more of this back-and-forth until it could hardly move. It was stuck between these "sticks," almost jammed.

Then I saw something I had never seen or heard of: the paramecium lost its shape. It could flex itself, like an amoeba. It began to push itself against one of the sticks, and began dividing into two prongs until the division was about halfway up the paramecium, at which time it decided *that* wasn't a very good idea, and backed away.

So my impression of these animals is that their behavior is much too simplified in the books. It is not so utterly mechanical or one-dimensional as they say. They should describe the behavior of these simple animals correctly. Until we see how many dimensions of behavior even a one-celled animal has, we won't be able to fully understand the behavior of more complicated animals.

I also enjoyed watching hugs. I had an insect book when I was about thirteen. It said that dragonflies are not harmful; they don't sting. In our neighborhood it was well known that "darning needles," as we called them, were very dangerous when they'd sting. So if we were outside somewhere playing baseball, or something, and one of these things would fly around, everybody would run for cover, waving their arms, yelling, "A darning needle! A darning needle!"

So one day I was on the beach, and I'd just read this book that said dragonflies don't sting. A darning needle came along, and everybody was screaming and running around, and I just sat there. "Don't worry!" I said. "Darning needles don't sting!"

The thing landed on my foot. Everybody was yelling and it was a big mess, because this darning needle was sitting on my foot, And there I was, this scientific wonder, saying it wasn't going to sting me.

You're *sure* this is a story that's going to come out that it stings me--but it didn't. The book was right. But I did sweat a bit.

I also had a little hand microscope. It was a toy microscope, and I pulled the magnification piece out of it, and would hold it in my hand like a magnifying glass, even though it was a microscope of forty or fifty power. With care you could hold the focus. So I could go around and look at things right out in the street.

So when I was in graduate school at Princeton, I once took it out of my pocket to look at some ants that were crawling around on some ivy. I had to exclaim out loud, I was so excited. What I saw was an ant and an aphid, which ants take care of--they carry them from plant to plant if the plant they're on is dying. In return the ants get partially digested aphid juice, called "honeydew." I knew that; my father had told me about it, but I had never seen it.

So here was this aphid and sure enough, an ant came along, and patted it with its feet--all around the aphid, pat, pat, pat, pat, pat. This was terribly exciting! Then the juice came out of the back of the aphid. And because it was magnified, it looked like a big, beautiful, glistening ball, like a balloon, because of the surface tension. Because the microscope wasn't very good, the drop was colored a little bit from chromatic aberration in the lens--it was a gorgeous thing!

The ant took this ball in its two front feet, lifted it off the aphid, and *held* it. The world is so different at that scale that you can pick up water and hold it! The ants probably have a fatty or greasy material on their legs that doesn't break the surface tension of the water when they hold it up. Then the ant broke the surface of the drop with its mouth, and the surface tension collapsed the drop right into his gut. It was *very* interesting to see this whole thing happen!

In my room at Princeton I had a bay window with a U-shaped windowsill. One day some ants came out on the windowsill and wandered around a little bit. I got curious as to how they found things. I wondered, how do they know where to go? Can they tell each other where food is, like bees can? Do they have any sense of geometry?

This is all amateurish; everybody knows the answer, but *I* didn't know the answer, so the first thing I did was to stretch some string across the U of the bay window and hang a piece of folded cardboard with sugar on it from the string. The idea of this was to isolate the sugar from the ants, so they wouldn't find it accidentally. I wanted to have everything under control.

Next I made a lot of little strips of paper and put a fold in them, so I could pick up ants and ferry them from one place to another. I put the folded strips of paper in two places:

Some were by the sugar (hanging from the string), and the others were near the ants in a particular location. I sat there all afternoon, reading and watching, until an ant happened to walk onto one of my little paper ferries. Then I took him over to the sugar. After a few ants had been ferried over to the sugar, one of them accidentally walked onto one of the ferries nearby, and I carried him back.

I wanted to see how long it would take the other ants to get the message to go to the "ferry terminal." It started slowly but rapidly increased until I was going mad ferrying the ants back and forth.

But suddenly, when everything was going strong, I began to deliver the ants from the sugar to a *different* spot. The question now was, does the ant learn to go back to where it just came from, or does it go where it went the time before?

After a while there were practically no ants going to the first place (which would take them to the sugar), whereas there were many ants at the second place, milling around, trying to find the sugar. So I figured out so far that they went where they just came from.

In another experiment, I laid out a lot of glass microscope slides, and got the ants to walk on them, back and forth, to some sugar I put on the windowsill. Then, by replacing an old slide with a new one, or by rearranging the slides, I could demonstrate that the ants had no sense of geometry: they couldn't figure out where something was. If they went to the sugar one way and there was a shorter way back, they would never figure out the short way.

It was also pretty clear from rearranging the glass slides that the ants left some sort of trail. So then came a lot of easy experiments to find out how long it takes a trail to dry up, whether it can be easily wiped off, and so on. I also found out the trail wasn't directional. If I'd pick up an ant on a piece of paper, turn him around and around, and then put him back onto the trail, he wouldn't know that he was going the wrong way until he met another ant. (Later, in Brazil, I noticed some leaf-cutting ants and tried the same experiment on them. They *could* tell, within a few steps, whether they were going toward the food or away from it--presumably from the trail, which might be a series of smells in a pattern: A, B, space, A, B, space, and so on.)

I tried at one point to make the ants go around in a circle, but I didn't have enough patience to set it up. I could see no reason, other than lack of patience, why it couldn't be done.

One thing that made experimenting difficult was that breathing on the ants made them scurry. It must be an instinctive thing against some animal that eats them or disturbs them. I don't know if it was the warmth, the moisture, or the smell of my breath that bothered them, but I always had to hold my breath and kind of look to one side so as not to confuse the experiment while I was ferrying the ants.

One question that I wondered about was why the ant trails look so straight and nice. The ants look as if they know what they're doing, as if they have a good sense of geometry. Yet the experiments that I did to try to demonstrate their sense of geometry didn't work.

Many years later, when I was at Caltech and lived in a little house on Alameda Street, some ants came out around the bathtub. I thought, "This is a great opportunity." I put some sugar on the other end of the bathtub, and sat there the whole afternoon until an ant finally found the sugar. It's only a question of patience.

The moment the ant found the sugar, I picked up a colored pencil that I had ready (I had previously done experiments indicating that the ants don't give a damn about pencil marks--they walk right over them--so I knew I wasn't disturbing anything), and behind where the ant went I drew a line so I could tell where his trail was. The ant wandered a little bit wrong to get back to the hole, so the line was quite wiggly unlike a typical ant trail.

When the next ant to find the sugar began to go back, I marked his trail with another color. (By the way he followed the first ant's return trail back, rather than his own incoming trail. My theory is that when an ant has found some food, he leaves a much stronger trail than when he's just wandering around.)

This second ant was in a great hurry and followed, pretty much, the original trail. But because he was going so fast he would go straight out, as if he were coasting, when the trail was wiggly. Often, as the ant was "coasting," he would find the trail again. Already it was apparent that the second ant's return was slightly straighter. With successive ants the same "improvement" of the trail by hurriedly and carelessly "following" it occurred.

I followed eight or ten ants with my pencil until their trails became a neat line right along the bathtub. It's something like sketching: You draw a lousy line at first; then you go over it a few times and it makes a nice line after a while.

I remember that when I was a kid my father would tell me how wonderful ants are, and how they cooperate. I would watch very carefully three or four ants carrying a little piece of chocolate back to their nest. At first glance it looks like efficient, marvelous, brilliant cooperation. But if you look at it carefully you'll see that it's nothing of the kind: They're all behaving as if the chocolate is held up by something else. They pull at it one way or the other way. An ant may crawl over it while it's being pulled at by the others. It wobbles, it wiggles, the directions are all confused. The chocolate doesn't move in a nice way toward the nest.

The Brazilian leaf-cutting ants, which are otherwise so marvelous, have a very interesting stupidity associated with them that I'm surprised hasn't evolved out. It takes considerable work for the ant to cut the circular arc in order to get a piece of leaf. When the cutting is done, there's a fifty-fifty chance that the ant will pull on the wrong side, letting the piece he just cut fall to the ground. Half the time, the ant will yank and pull and yank and pull on the wrong part of the leaf, until it gives up and starts to cut another piece. There is no attempt to pick up a piece that it, or any other ant, has already cut. So it's quite obvious, if you watch very carefully that it's not a brilliant business of cutting leaves and carrying them away; they go to a leaf, cut an arc, and pick the wrong side half the time while the right piece falls down.

In Princeton the ants found my larder, where I had jelly and bread and stuff, which was quite a distance from the window. A long line of ants marched along the floor across the living room. It was during the time I was doing these experiments on the ants, so I thought to myself, "What can I do to stop them from coming to my larder without killing any ants? No poison; you gotta be humane to the ants!"

What I did was this: In preparation, I put a bit of sugar about six or eight inches from their entry point into the room, that they didn't know about. Then I made those ferry things again, and whenever an ant returning with food walked onto my little ferry I'd carry him over and put him on the sugar. Any ant coming toward the larder that walked onto a ferry I also carried over to the sugar. Eventually the ants found their way from the sugar to their hole, so this new trail was being doubly reinforced, while the old trail was being used less and less. I knew that after half an hour or so the old trail would dry up, and in an hour they were out of my larder. I didn't wash the floor; I didn't do anything but ferry ants.