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The Search for Solutions

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In the dialogue between the possible and the actual, the search for solutions, what qualities of mind are required? Not long ago, I asked that of Joshua Lederberg, who is a geneticist and who got his share of a Nobel Prize for discovering the fact that some bacteria mate, passing copies of their DNA—their genes—from one to the other, and for following out the consequences of that discovery. We were in Lederberg's office at Stanford University; he was putting books and file folders into cardboard boxes, because in a few days he was moving to New York to take up the presidency of the Rockefeller University.

"I don't think there is one logic for science and another logic for the commonsense world," Lederberg said. "If there were, we would be in real trouble. I think there is a somewhat more systematic use of formal reasoning—well, it is more formal than everyday language and less formal than the mathematical type of reasoning. I'd say that the ability to discover analogies, the ability to generalize, the ability to strip to the essential attributes of some actor in the process—the ability to imagine oneself *inside* of a biological or other situation—these are some of the pretty obvious talents."

I mentioned the other sort of stripping away, that which creates the models of the mathematical physicist, the universe abstracted to a page or two of equations.

"Well, *we* are not ready to write equations, for the most part, and we still rely on mechanical and chemical or other physical models," Lederberg said.

What were such models about?

"When I think of a DNA molecule, I have a model of it looking like a rope," Lederberg said. "And I know, for example, if I pull at the two ends of a DNA molecule, it will break somewhere. Then I have to jump to a different level and say, 'Well, I know the structure isn't quite like that.' And I will try to look a bit more analytically at the

question, 'Can I predict where the DNA molecule will break, if I hold the two ends, knowing that it isn't quite like a rope—in the following particular ways?'

"I think that that ability to move from one level of analogical reasoning to another, and not get stuck in the analogy at inappropriate times, is terribly important." Lederberg blew the dust off a book, put the book into a box. "You had better be able to do it. You have to be able to fantasize in rather crude ways—but then be able to shift from one frame of reference to another. That, I think, is more rare than you might suppose.

"Then there's a skill at combinatorial arrangements that comes up over and over again. Constantly, in planning experiments—trying to think if there are different ways in which a system might be put together—one has to have the skill to do a systematic, fairly rapid first scanning of the possibilities, of a given territory. And then the ability to know whether or not that's worth pursuing."

Was that in part a matter of trial and error?

"There are still enormous amounts of trial and error," Lederberg said. "Even after one has thunk through all the possible arrangements, one's still usually left with a few dozen—or a few hundred—testable alternatives. Which you then have to try and work through in a somewhat more systematic way. You may just come upon a blank wall. And then it helps, to make more discoveries, just to fiddle. You make more discoveries in the course of simply putting a couple of things together, in ways where you think you know how they are going to behave: but if the system is complicated, and you are not sure, then every now and then you get a discrepancy. Then you need the ability to spot a discrepancy quickly—that is, to know when you have got a finding that doesn't fit the model you thought you had. But many people are just not that explicit about what their premises were.

"That is one of the most important functions of experimental finesse. The person who is simply careless in experiments either ends up being a scoundrel, if he believes in his results and insists on them; or, much more usually, he is so mistrustful of the isolated finding that he will attribute it to an instrumental failing or to an error in technique. If you don't have the confidence that when you do an experiment you do it correctly, then when you get an aberration you're likely to say, 'Well, a speck of dust fell in,' and then ignore the result. Or else spend endless time reexamining what were, in fact, artifacts."

I said that there appeared to be a feedback between fact and idea—or rather, an upward spiraling between model and evidence.

"You go back and forth from observation to theory," Lederberg said. "You don't know what to look for without a theory; and you can't check the theory without looking at the fact; and the fact is only meaningful in the light of some theoretical construction."

Medawar had written of that back-and-forth movement of the mind, I said.

"I believe that that movement back and forth occurs thousands, even millions of times in the course of a single investigation," Lederberg said.