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Professor Joshua Lederberg
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Dear Professor Lederberg,

The kind remarks and interesting suggestions about my Annual Review of Psychology article (1997, 48) titled, "Creative Hypothesis Generating in Psychology: Some Useful Heuristics"in your May 30 letter and accompanying material were much appreciated. It may seem poor evidence of this that I took so long to reply so I should explain that I just received the letter, having spent the months of June and July working and playing at the London School of Economics. The person who was looking after my mail back here at the store did not forward your letter to me; I have not asked her why, but I suspect her frugal habits inhibited her springing for the international postage for a letter with a dozen or more pages of attachments. Actually, I found those attachments quite interesting so I thank you for taking the trouble of sending them to me. I shall try to respond to some or all of the points you raised, going from the nitty-gritty to the more general.

Heuristic J-30, using metatheories as thought evokers. You wonder whether there are other metatheories of comparable scope, provocativeness, and explanatory power to the set of notions that constitute the evolutionary adaptivity metatheory. Granted, evolutionary theory is a biggie, channeling and energizing our thinking in disciplines from biology to sociology as well as our informal explanations of the world about us. Still, I think there are some similar grand notions in other fields of human thought. For example, atomic theory (with its electrons, protons, periodic table, etc.) has proved immensely provocative in chemistry, molecular biology, and physics, so dominating the thinking of professionals that they use it in their sleep, as in the story of Kékule whose preoccupation with carbon tetravalence may have caused his serpent dream about the benzene ring. I suppose very popular and successive metatheories like evolutionary and atomic theory inevitably stifle creativity at the edges. By analogy, it is generally a Good Thing to use the "hill climbing" heuristic in many artificial intelligence programs (I think including DENDRAL) in that it assures that one will get to a fairly high peak. However, it only gets one to the highest nearby peak and interferes with finding much higher, but further off peaks. Evolution and evolutionary theory must somehow correct for this stifling of more wide-ranging search, as by a countervailing heuristic or even by building in an error process that prevents our thought from always climbing the nearest hill. However, I suspect that artificial intelligence workers have an aesthetic aversion to building "errors" into their babies. Yet creativity-provocative heuristics may inevitably stifle creativity unless at least a small component of randomness and even error is built in. Evolution (and evolutionary theory) to work must be, not only blind, but aggressively stupid.

You suggest that other disciplines may have comparably grand notions to evolution as metatheories that provoke and direct creative thinking. Perhaps economics so uses cost-utility theory. Currently, the "rational choice" theory is growing in dominance as a metatheory in political science. In my own field of psychology reinforcement theory (a.k.a. behavioral theory, learning theory, S-R theory, etc.), that the organism tends to act in any type of situation as he or she has been positively reinforced for acting in the past, was a dominant

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metatheory in the middle half of the twentieth century. Perhaps psychology reinforcement theory is to ontongeny what biological evolutionary theory is to phylogeny. I suppose for the past quarter century in psychology the information-processing cognitive metaphor, owing much to the development and use of the computer, is the dominant metatheory in Establishment psychology. There was a time also, before it became fashionable to beat up on Freud, for psychoanalytic theory (with its unconscious needs, psychosexual development, defense mechanisms, etc.) to be a metatheory by which psychologists (and their patients) thought and lived (except when on vacation in August).

I should not be so parochial as to think of metatheories as operating creatively only in sciences. The Judeo-Christian-Islamic world view (with Adam's fall, the covenant, etc.) furnished a metatheory that guided every aspect of thought and life in many times and places (not excluding our own, with its popular fundamentalisms). The rococo extravagances of full-blown astrology was shown by Frances Yates (1966) in her The art of memory to have powerfully shaped Renaissance thinking for better or worse.

Research tactics versus strategies. I have two general complaints about current methodology, at least as it is taught and practiced in psychology and the other social and behavioral sciences. Perhaps natural sciences' methodology is less sinning in these two regards. The first complaint is that our methods teaching focuses predominantly on how to test hypotheses and theories, to the almost complete neglect of how to create them; the 1997 Annual Review of Psychology article which you mentioned is intended to point out and help ameliorate this first problem. The second major imbalance in our thinking and teaching about method is that we focus almost entirely on the tactics of the individual experiment, to the almost complete neglect of teaching how to strategically plan multi-experiment programs of research. We deal exhaustively with tactical issues that arise in designing a given experiment (how to manipulate some variable and control others, how to measure effects, analyze relations, etc.).

The focus on tactics to the sacrifice of strategy is pronounced in art and practice, as well as science. During the Great Patriotic War at the Infantry School they taught us officer candidates only tactics, like how to take a defended hill which has two lower hills on either side of it. They taught us not at all about strategy, such as the relevant merits of Eisenhower's plan to keep full-court pressure along the total front versus Montgomery's preference for concentrated attacks and breakthroughs. This was fair enough for officer candidate school, whose graduates were not likely to be called upon to formulate and carry out strategy. However, in science the professional should be more conscious of strategy as well as tactics by explicit mention that there are strategic issues and discussions of how to deal with them. I have elsewhere, in McGuire (1989) "A Perspectivist Approach to the Strategic Planning of Programmatic Scientific Research," sketched out a teaching procedure that I use to sensitize psychology students to the need for, and possibilities of, programmatic research planning in psychology. I shall enclose a reprint of that reference.

Strategically planning a multi-experiment program of research (deciding where to begin, what scope the early experiments should have, what level of complexity, where to go from there, etc.) probably requires use of sets of heuristics, such as those I listed in that 1997 Annual Review article. I suspect that certain subsets of heuristics work synergistically so that the combination is more productive than the sum of the individual heuristics; however, I have not pursued this suspicion in any formal way because it seems a challenge of formidable difficulty. When I have developed exercises to introduce research students to strategic planning of programmatic research, my worksheets have usually incorporated a subset of heuristics. You ask about where such exercises may be found. I shall include with this letter one or two of the worksheets I use.

Artificial intelligence versus cognitive simulation. In the artificial intelligence area where your

DENDRAL approach is situated, I feel that we cognitive psychologists have a special problem in that we are torn between artificial intelligence and computer simulation of cognition more than are people in other fields. You, in developing DENDRAL to identify the structure of organic molecules from mass spectrometric data, had the luxury of carrying out a pure artificial intelligence endeavor, trying to design a computer program that could best achieve this purpose. Similarly, the strict artificial intelligence person developing an unbeatable chess program can concentrate on how to write a program that plays chess with maximum skill. We cognitive psychologists usually tackle these tasks for a different purpose, not designing a program that plays chess as it ought to be played but designing a program that plays chess the way humans (grand masters or masters or whatever) do play chess. We are using simulations to investigate, not how God should have designed us to be optimal chess players, but how He or She did design us to think in chess and other tasks. That is, we are aiming for process simulation rather than product simulation. We are engaged in a sticky business of thinking about thinking, how we poor humans, or some subset of us (novices, grandmasters, or whatever), evolving as we have and growing to maturity as we do, end up playing chess. Because our task is thinking about thinking it may condemn us to some dreadful circularity or confounding; or it may give us some happy hermeneutic insight.

I take it as a working hypothesis that a good artificial intelligence program will differ from a good cognitive simulation program; how chess ought to be played will always differ from how people actually play chess. Behind this hypothesis is the suspicion that the species evolved and the human individual develops in his or her lifeftime to cope with a million and one tasks, including getting rid of CO_2, finding food, etc., among which chess playing did not loom large. To none of these tasks can sufficient resources be devoted to allow perfect performance. Almost inevitably, we will play chess or whatever by heuristics that are quick-and-dirty adaptations of heuristics that serve a hundred and one other purposes, none terribly well. The political psychologist, for example, in predicting election outcomes must be able to swing both ways, producing product simulations and process simulations. I think it does happen that if one devotes effort entirely to a product simulation one can probably predict the election outcomes better than if one tries to do a process simulation, predicting the outcome of voting decisions by identifying the processes that people actually use. Which type of simulation is more useful depends on whether one's purpose is to predict outcomes accurately (product simulation) or to model human decision making authentically (process simulation).

I think I have witnessed a peculiar trend in psychologists who get interested in artificial intelligence programming. They tend to start off doing cognitive simulation (e.g., trying to answer the question how do chess grand masters think in deciding on their next move). However, there is an esthetic need, as they continue this enterprise, to grow impatient with the limitations of human thought. A result is that the programmer moves to the pure artificial intelligence enterprise as, repelled by the stupidity of actual human chess playing, the programmer becomes obsessed with writing a program for how we should play chess, had we been designed to do this and only this, even though the evolutionary and developmental realities are such that we could never have been designed to play chess optimally. I have experienced myself this drift from trying to simulate actual cognition to trying to do an optimal artificial intelligence program, even while aware of what was happening to me and regretting it. There is the artist in most of us that draws us toward simulating the "should have been" rather than "unfortunately actually is."

DENDRAL. As I understand it, DENDRAL uses the "classical" two-stage approach to creativity, first generating exhaustively possible molecular structures, and secondly selecting or ordering the structures for plausibility. I call this classical because it is the basis of the "brainstorming" technique of enhancing creativity that was advocated by A.F. Osborn (1963) Applied Imagination (3rd edition). I think Osborn was the "O" of the BBD and O advertising agency, who developed the brainstorming technique to increase creativity within the agency and later may have added a consulting division to the agency which taught brainstorming in government

and private organizations. Brainstorming has many components but the most basic one is the isolation of the creative from the critical phase of thinking. Osborn observed that the agency creative people at campaign-producing meetings tended to practice unhealthy self-criticism, discarding ideas because of some perceived shortcomings, before expressing them and giving them a chance to be considered. Many of Osborn's commercial techniques were designed to encourage people to think uncritically, promiscuously, of solutions during a first phase and only later going back over the exhaustive suggestions to evaluate (and elaborate) them.

I have problems with two-stage approaches. (Actually DENDRAL may be a 3-stage approach, dividing the classical stage 2 into two substeps, pruning and confrontation). As regards the first stage, there is a limit to what people can generate exhaustively (though admittedly with the aid of the computer the possibilities have increased exponentially over the past decades). It seems to me that this first, possibility-generating, task must be both reduced and expanded. It must be reduced by using our knowledge (of human cognition, of organic molecules, or whatever) to recognize that some possibilities are more likely than others. To get people (or computers) to retrieve possibilities optimally we must know how the possibilities are stored (or maybe the possibilities are not stored but are stamped out, that is, are present not latently but virtually). Psychologists until recently have accepted the common sense position that cognition precedes affect (i.e., that people first perceive cognitively what the stimulus is, and then decide how much they like it), but now Zajonc (vs. Lazarus) seems to find, on the contrary, that affect tends to precede cognition (i.e., that people can report whether or not they like a stimulus before they can report what it is). Computers may do the common sense thing of first generating and then evaluating alternatives; but pathetically limited humans may have been compelled to develop some crazy way of reversing the two stages, first evaluating an alternative, and then generating it if it passes some elimination-by-aspect sufficing criterion, as in models explored by Simon and Tversky.

The two-stage programs like DENDRAL have also had to build into the selectional stage (whether it comes second or first) deliberate randomness and even errors because, as mentioned above, unless they, like evolution, have at least a small element of not just blindness but of aggressive stupidity, then creative heuristics will inevitably stifle creativity at some edges.

But I have gone on too long in responding to the materials that you sent me on May 30 and on topics where your thinking has probably advanced beyond mine. I probably underrate, for example, the sophistication of DENDRAL.

Sincerely,

William J. McGuire

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