Creativity in Science

by James Bonner

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Discussions of creativity frequently revolve around creativity in art or creativity in literature. We all imagine that we know how to recognize a great creative artist—an artist whose work soars out of and above the imagination. I think we should first ask, in discussing creativity in science, whether there is in fact any comparable creativity in this field. Is the scientist creative? The popular picture of a scientist in our culture runs somewhat as follows: A man in a white laboratory coat grinds away in a logical and inexorable fashion (and dully too) for 20 years, and then suddenly produces nylon or a better mousetrap.

The popular picture of the scientist in our culture might then suggest that scientific work does not grip the emotions, that it is coldly logical, that it is not creative as is the work of the artist. I am prepared, however, to show that this is a misconception. There are many grades and degrees of creativity and innovation in science. The discoveries of which we read in popular magazines are indeed most frequently ones based upon the logical repetitive search for some merely useful material—a new elixir that will magically cure chilblains in mice resident in orbiting space vehicles, and so on. But this is not truly science; it is applied science—and it bears the relation to high-level creative science that the articles in popular magazines bear to creative literature.

Scientific creativity lies much deeper than the repetitive search for a better plastic or the trial and error attempt to find a better desmogger for exhaust pipes. Creative science lies, I believe, in the formulation of relations between facts—the genesis of theories which bring together under one roof observations previously separately housed.

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The scientist is confronted by a multitude of facts; he wishes to reduce them to one fact, to formulate a law of nature. This is the urge of a scientist, to find unity in nature. He wishes to find similarities between things not previously recognized as similar. He must create a theory which will unify facts. There are probably many theories which unify a portion of the available facts, but he must imagine one that will unify all. He must reject those theories that he has imagined which will not encompass all facts. It is a hard task. To formulate this theory, to imagine it, is strictly a personal subjective act. It is not done by committees; there is no known and inexorable way to deduce the correct hypothesis in advance; it must first be imagined by some one person.

Think of some of the truly creative figures in science—Darwin, for example. Darwin's creative unifying act was to see relatedness in all creatures, relatedness by evolution. No relatedness between the earth's living things had previously been imagined—merely an almost infinite number of differences.

Or think of Niels Bohr and his atom, imagined strictly ad hoc to relate the thousands and thousands of spectral lines described as miscellaneous facts by physicists for over a hundred years. Each of these new innovations represented a gigantic new concept, personally conceived and brought to test in the same sense that a creative work of art is personally imagined and brought to light.

There is another characteristic of the creative scientific act which may often, although not always, be perceived. This is the fact that it involves discarding what is generally accepted, in pruning away dogma, as a basis for a new and more general unifying concept. Take Darwin again: He had first to discard the accepted fact that each species is individually created by the creator. This is in a sense a unifying concept, and one generally acceptable and accepted in Darwin's time. Before Darwin could proceed to imagine a new and more unifying concept—namely, that species evolve from common ancestors and that creation therefore occurred but once—he had to discard the accepted view. A creative scientist, then, has to have the strength to question what is presently accepted, to turn things topsy-turvy as a part of his creative synthesis.

What I have said about a few major examples of scientific creativity is also true for less spectacular examples. For there is a complete spectrum of creativity, from acts such as those of Darwin and Bohr, down to the man who imagines how to reconcile today's laboratory results with yesterday's different ones. We see creativity in the scientist at work each and every day; some days are merely more creative than others.

Finally, I may note that I assume that the urge to unify, to bring relatedness where none was found before, is a basic urge and drive for the scientific person. I do not know that this is true, but I suspect strongly that it is. I suspect that the desire to unify and understand is a basic part of man's emotional arrangements.

The evolution of a creative scientist

Let us now consider some of the things that may be observed during the process by which a young person emerges as a creative scientist. I will take for my study what happens in the course of graduate education. Each fall we bring into our biology group at Caltech a dozen or so young men and women, all with fresh Bachelor's degrees. These are new graduate students. They have spent four years in college and twelve years in school before college. They are full of facts. They are full of learning. But with rare exceptions they exhibit no evident qualities of the creative scientist. Let us, however, observe them two or three years later. Many of these same young people will be creative scientists. They will be daily formulating and testing new and often highly original concepts. They reveal their work to the world in print and with great assurance. Some will be guiding others along the same path. It is truly a heart-warming process to follow.

Surely these young people were creative in some respect before they entered graduate school, but it had not made itself manifest in any obvious scientific way. One might conclude that all that has been happening in graduate school is that they have been taught—*trained* is a popular word—to use a new art form, that of science.

Finding a subject

But I think that this would be misleading and that the facts go deeper. During the course of graduate education these students have had but few formal courses. They know some new facts, to be sure, but they are not gaining facts at the rate that they did in their undergraduate years. There is, however, one obvious thing that has happened, and that happens to every scientist who becomes a creative practitioner. Let us watch a new graduate student. He browses around; he looks at many subjects; he talks to many people; and suddenly one day he finds a subject which really sends him, one that grips his emotions for reasons he doesn't understand but doesn't think about. He takes hold of this subject; he wants to find out all about it; he reads about it in the literature; he thinks about it; he dreams about it; he works on it.

I have seen some spectacular examples of this in my years as a guider of graduate students. I have seen young men spend one, two, three years in pedestrian work, routinely carrying out token investigations. And I have seen these same young men suddenly find a new subject which really excited them and then blossom out as creative scientists in a period of months. I believe it is safe to say that, unless the potential scientist finds a subject which really grips his emotions, the scientific creativity of the individual does not come to the fore. This is an essential part of the process of becoming a creative, productive scientist.

But the choosing of an appropriate subject of investigation isn't the only thing that has been happening in graduate school. Graduate school is still conducted by apprenticeship; the newcomer is put in close association with a practicing creative scientist; they talk; they make hypotheses; they think up critical tests of hypotheses; the apprentice is actually watching and participating in the creative work of another. There is obvious transfer here and one can mark this in many scientists. The work of the master-scientist-father can be detected years later in the work and mannerisms of the former apprentice son.

Still another thing happens in graduate school.

Graduate school is a very permissive institution. There are no penalties for questions; everyone does it. There is little structure; the apprentice slowly gets to feel that he can question not only his immediate colleagues, but anyone, professors included. Everyone talks; everyone questions; everyone brings forth new unorthodox ideas. At its best, graduate school is a sort of continuous brainstorming session; new ideas continuously pop out and are batted around. And in this connection there is the matter of reward. In graduate school the apprentice scientist is rewarded for his questioning, for his spontaneity, by the approval of his colleagues, by fellowships, and other symbols of material wealth. He is rewarded, perhaps for the first time, for spontaneous unorthodoxy.

Finally, as the graduate student-apprentice progresses toward becoming a creative scientist he receives responsibility—the responsibility to help others along the same path. This appears to me to be a very maturing experience, a step which helps to free the onetime apprentice from his master, to make him independent. This step involves real change from dependency to adulthood, and the challenge to help another is a catalyst which appears to make the great step easier to take.

These are some of the things which I think can be seen happening in graduate school, things that help to determine whether a student becomes a creative scientist or a pedestrian, repetitive investigator. It occurs to one naturally to ask whether we might take the little knowledge that we have of education for creativity in graduate school and apply it in the earlier stages of the educational process – in the undergraduate college years, for example.

The creative scientific act

Let us now pass to another aspect of scientific creativity and consider the creative scientific act itself. How does a scientist have a creative thought? What does he do when he wants to have a new idea? The facts are simple and they are pretty well agreed upon. The creative act follows a definite sequence of steps, which we can outline as follows:

(1) Define the question. This may in itself be a creative act, since to recognize a question which has not been asked before may take great creativity.

(2) Stuff with facts. Once the question has been defined, the potential scientific creator must have all the information that he can get. He may have to do some experiments; he reads the literature; he gets together all the information that he can imagine bears upon the question at issue.

(3) Wait. The scientist may mull the facts over; he may worry; but in principle what he has to do now is wait.

(4) A solution pops out. Perhaps many solutions pop out. Often solutions emerge to consciousness when one is half asleep, or perhaps during a daydream. They may occur when one is talking with others, or they may happen during full but solitary consciousness. The principal point is that creative solutions occur at quite arbitrary and unpredictable times.

(5) Assess the solution. The scientist must now ask himself whether his new creative idea is a useful one or not: Is it good or bad? Does it actually unify everything that is present to be unified?

Steps 1, 2, and 5 above are conscious steps; they are logical. Steps 3 and 4 are not conscious; something is taking place in the preconscious, and here is the nub of the problem of scientific creativity. There are ways to get at what is happening during the waiting period, and at the time the solution pops out. Suggestions as to what is happening are contributed by the study of free association and by the many modifications of the free association process that have been applied to the study of creativity; as for example, in brainstorming, in the psychoanalytic session, the Rorschach and Thematic Apperception tests of psychologists, and in observations of creative people who talk.

The nub of the problem

All of these observations suggest that one and the same individual produces many new arrangements, new constellations, new unorthodox concepts from the same information. They suggest that what is happening during the preconscious interval before a creative solution to a problem emerges is that the facts which have previously been stuffed in to the conscious are taken to the preconscious and there jumbled and rearranged in all possible ways. From time to time one of these rearrangements emerges to consciousness – with greater frequency when certain strictures are removed, as in half sleep or in the brainstorming situation.

We are now in a position to make a formal model of the creative process. We can formulate this model as follows: The scientist who wishes to make a creative solution to a problem must first have a problem and must further possess information on the problem. Next, he must have an objective. The objective is to produce a new symmetry from the component parts of this information. Next, the information is taken into a device, the preconscious of the individual, and there subjected to random rearrangement and recombination. Finally, our unconscious machinery permits the filtered release to consciousness of selected rearrangements.

The key question concerning the nature of the creative act and the creativity of individuals seems to me to lie, if the above model is correct, in what determines which rearrangements come to consciousness. Obviously, the filter process does us a good turn if it serves the objective of only releasing rearrangements that possess some new symmetry, and discards at once all rearrangements that are nonsense and which have no symmetry. But, nonetheless, the filter process is quite evidently a highly untrustworthy instrument; it is wholly subject, because it is unconscious, to unconscious control and to the accompanying opportunities for distortion. The filter process can, for example, quite unbidden, *prohibit from coming* to consciousness creative rearrangements that threaten the security of the individual, that run counter to general opinion, that run counter to long forgotten prohibitions learned in childhood, and so on.

The filtering act would certainly appear to be the most vulnerable, the most unsatisfactory, and the least accessible of the components of creativity. However, I think that we may conclude that, insofar as this part of the creative process is concerned, creativity and spontaneity are closely allied, or perhaps identical. We may conclude, too, that to the extent that we preserve and nurture spontaneous behavior, we minimize *the restricting influences of the filter process* on creativity.

Some case histories

Let us now stand back and look at some selected examples of scientists at work. My examples cover the spectrum from high to very low creativity, but they are selected in a special way. In the first place, they are fictitious, but if they really existed they would all be hard-working, industrious, intelligent and meritorious people, and people who have contributed significantly to science – although with very different degrees of productivity.

My first example is a bubbling, loquacious man of broad interests; he understands any and all subjects, and he can take any problem and contribute really new solutions to it. He is verbal. In conversation on any of a wide variety of matters he will take the subject, grind away inexorably and logically for awhile, and then suddenly he will shift gears and take off in fantasy, producing one new unorthodox concept after another, reassorting all of the facts of the situation into new arrangements, mostly nonuseful.

As he works on a problem, he takes the facts and rearranges them audibly, as it were. We can imagine that we see the preconscious reassortment process at work. Among the many rearrangements produced by this man, he selects consciously with great care and logical skepticism. He discards all but a few. The few that remain are subject to exhaustive testing in every possible way. He is a man of no self-delusion, and his creative ideas, when they are finally passed on to the world at large, are always (thus far) correct. *He is a man with no great measure of personal* investment in his ideas; an idea is not right merely because it is his own. If logic shows that it is wrong or nonuseful, he throws it away; he couldn't care less about it. This man possesses to a high degree the characteristics of a creative, productive person.

My second example is also a man who is bubbling, spontaneous, loquacious and whimsical. He, too, takes a problem and grinds away on it audibly. Here again we imagine that we see and hear the rearranging, reshuffling process at work, the rearrangements coming out as successive fantasies. He is much less rigorous than the preceding individual in the final selection and assessment of his many new and fanciful ideas, and many have proved to be incomplete or even wrong. But his contributions have been tremendous. He, too, has the ability to throw away his own ideas when they are shown by others to be erroneous. Even his mistakes have been useful for the progress of science.

My third example is a quiet man, a lone worker, who does, however, produce creative and quite new ideas. These have reshaped the world of science. But he holds with equal tenacity ideas which appear to be merely capriciously unorthodox. He is a man with *tremendous personal investment in his creative notions*, right or wrong. A questioner of any idea, no matter whether good or bad, becomes at once a personal enemy. This man exemplifies the trait, common to us all, of feeling that his views must be correct because he wants so much to have them be.

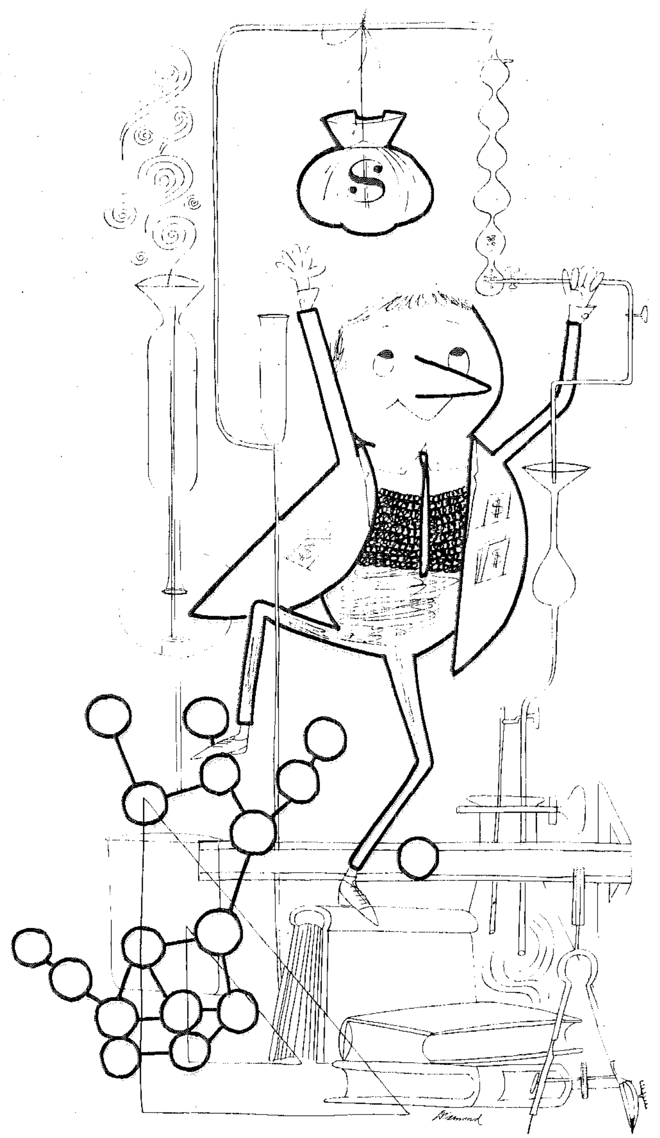
My fourth example is another loquacious bubbler who spouts out a continuous succession of new ideas. But he has, unfortunately, essentially no ability to distinguish logically good new concepts from bad notions. In following up the bad with the good he wastes his effort and, as a result, his scientific impact has been much smaller than it should properly have been.

My next example is a quiet person of tremendous erudition, full of facts, a creative poser of good questions. He poses a question, he gets the facts and then more facts, but the creative rearrangement of these facts into a unified picture does not come. Repeatedly now this has happened. Time and again the facts so laboriously gathered have been unified by others. How frustrating!

My final example is of a hard-working, knowledgeable person, an able experimenter, but with neither the ability to pose new questions nor to solve creatively a problem posed by others. Always a follower, his work is repetitive and tends toward the determination of further significant figures in important constants. He is a useful person, a technician, but not creative. He comes close, perhaps, to the common picture of a scientist in our culture.

Perturbations of the creative process

Let us now turn to some of the troubles implicit in these case histories which beset the creative scientist, and indeed the creative worker generally. We will disregard such obvious matters as the fact that many scientists work under restrictive surroundings for mere money. More pressing are the aspects summarized by Lawrence Kubie in his book, *The Neurotic Distortion of the Creative Process*, and in two articles



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in the *American Scientist* (Oct. '53 and Jan. '54).

The first has to do with the goals of the individual scientist. What is the scientist unconsciously trying to achieve by scientific work? I have already pointed out that I assume it to be a human urge and desire to make order, to unify, to simplify, to understand. To a scientist for whom this is the goal, a creative solution to a problem is its own reward. But we know that creative solutions to problems can stand for many other things. To one scientist they may unconsciously stand for material success, to another they may mean acclaim. Or, a creative solution to a scientific problem may represent in symbolic form a way to seek affection, and so on, endlessly.

These are distorted goals. Perhaps one of the commonest symbolic meanings of creative success for the scientist is that of acceptance and adulation. To such a scientist, science represents a route to such success and adulation. Papers submitted to journals represent stepping stones to fame rather than a sharing of creative discovery. And scientists in whom this distorted goal stands high are not highly creative. Such a person has a monkey on his shoulders distorting his creative effort by distorting its goal.

Then there is the matter of problem selection. I have mentioned that a student goes along browsing through the fields of science and all of a sudden finds a subject, a problem, which engrosses him. Obviously this choice has some background, some meaning, just as does career selection in the first place. Perhaps always, the problem selected has its intellectual challenge, but many problems do. Quite probably there are unconscious factors at work in problem selection. The problem has some symbolic meaning. In fact, a great deal of jesting about this matter goes on in biology—how geneticists are people justifying to themselves their own guilty interest in sex, etc., and since this is made as a joke there is probably truth in it.

Creative unorthodoxy

I would note here too the problems associated with the fact that creative thoughts are often held by others to be antisocial, or at least dangerously anti-status-quo, and the sanction which is thereby implied for safe, acceptable, but repetitive work. I think that we can all sense that submissiveness, obedience, acceptance of authority, as the child learns and feels it, can very well have a much wider meaning and significance in later life in relation to creativity. The creative scientist must of necessity allow unorthodox thoughts to come to consciousness. Submissiveness and acceptance of authority is the antithesis of this. And so we should know and understand how to rear children and produce adults in whom creative unorthodoxy has not been dampened by demands for obedience.

These are just a few of the many ways in which unconscious drives can and do prevent or dampen the creative process. And the moral, it seems to me, is twofold: first, that we need much more knowledge of the creative process and the factors that affect it, and wider acceptance of this knowledge. We need to use this knowledge to improve child-rearing procedures, to improve educational processes, and to foster creativity in adults. Just consider college educational procedures with their learning by repetition, their dependence on authority, and the competition between students for grades that depend on acceptance of these procedures. How much more wisdom could we convey in the undergraduate years if we just knew how to use the student's own creative drive in the learning process itself!

The second conclusion, and my final one, is that the creativity of the scientist is beset by many traps and hidden dangers. He needs self-insight and self-awareness to avoid these dangers, and to maximize and free his creativity to keep it turned to the solution of real problems.