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Creativity in Science

Ursula W. Goodenough
Washington University in St Louis, goodenough@wustl.edu

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Abstract

Creativity is a concept far more often associated with art than with science. The creative dimension of scientific inquiry and practice is described and compared with its artistic counterpart; similarities and differences are analyzed.

The Scientific Enterprise

To examine what it means to be creative in science, it is important to begin by developing a shared view of the scientific enterprise, the context in which the scientist is creative. There exists a great deal of confusion and distrust about the scientific enterprise. Some argue that since scientists keep asserting that they are discovering the Truth and then keep changing their minds about what is True, there is no reason to believe anything scientists say. Others argue that all scientific views of nature are just another set of metaphors, and since these metaphors are rather dull compared with the metaphors of literature or music, there is little point in making the effort to understand them.

It is certainly the case that much is still unfathomable about the properties of matter, and that many features of the inanimate world are best described as disordered, but this is simply not the case for the biological world upon which I will focus. Life entails, and indeed necessitates, the creation of order from the inanimate, and this order is highly accessible to human perception. True, we can only describe it in words, and words are metaphors; hence our descriptions are by definition metaphoric. Yet this does not negate the truth of the description, nor the deeper truth of the insight generating the description.

So I will begin by asserting that those of us in the biological sciences are productively involved in finding out how things really are, in explaining an important level of reality. We may change our minds as we deepen our inquiry, but rarely does this mean that our earlier concept of reality was wrong, only that it was incomplete.

Biological scientists, be they engaged in molecular genetics or cancer research or ecology, all work within the same paradigm, that of evolution. Ecosystems, tumors, cells, and genes have all evolved and are all undergoing evolution. Whereas most scientific paradigms tend to restrict the imagination, the paradigm of evolution is completely liberating. An enormous, exhilarating array of solutions has emerged to solve the problem of existence, none of which is deducible a priori. Indeed, if we define creativity as the putting together of things in original ways, then evolution is creativity par excellence.

As most readers are doubtless aware, the past few decades can easily be termed the Golden Age of Biology. There has been an explosion of discoveries, upheavals, and methodologies such that, while it is true that evolution remains our overriding paradigm, most other subparadigms have scarcely enough time to hit the textbooks before they become modified beyond recognition. There is no place, no use these days for established dogmas, and anyone who tries to defend a pet theory runs the risk of looking rather foolish. With this much excitement and ferment, creativity is the name of the game; inapplicable is Kuhn's description of a theorem which hangs around, enjoying years of eminence until it is slowly found to be wearing thin at the edges. It's all edges these days; one is no longer surprised to pick up an issue of the journal Nature and learn of some completely unexpected and clever biological process-unearthed by an equally clever biologist.

All this excitement may sound chaotic, like Wall Street in bullish times, and indeed the media regale us with stories of the dog-eat-dog competition, the lapses into fraud, the suicides, the fights for patents and recognition. All of this exists; there are some manic, power hungry, Donald Trump types out there to be sure. But for most of us they represent aberrations, cautionary tales ofwhat we do not want to become. Most of us are pumped up, turned on, but not bug-eyed.

The big revolutions have occurred in such fields as molecular biology and immunology, yielding a whole new repertoire of ways to ask questions. It is equivalent to imagining that astronomers who know about stars from visual observation are suddenly all given high-powered telescopes. When that happens, when everybody has a telescope, it becomes more important than ever to hear from the gifted observers who have already identified the central problems from visual observation, who know which stars behave oddly and merit a closer look.

In biology it is the same. Twenty-five years ago, biology departments were filled with rancor: Biochemists were splitting off to form their own departments because they thought the people studying cells were fools; the cell people were forming their own departments because they thought the people studying animal behavior were fools. All that has changed. With the new tools, the new telescopes, has come a shared sense of purpose. The scientist down the hall with her odd fruit-fly mutants is suddenly viewed by the molecular biologist as a rich source of interesting research problems; they talk and collaborate and go to fly meetings together.

I describe this climate of shared beliefs and fermentive change because it is impossible to consider any creative process without an understanding of the medium in which it works. In order to be creative in any endeavor, one needs to know a great deal, if only to know where the problems are, which stars are behaving oddly, which edges in the theories are frayed. In biology this is especially true because everything is changing so fast. Even if one tries to limit oneself to a single odd star, the rest of the accumulating information must be kept in view. All of this requires energy, dedication, persistence, and a keen ability to take new facts and incorporate them into preexisting contexts.

But it also requires more intangible traits, and it is at this point that I shall begin to wander down the more mystical paths of what is involved in being creative. Some scientists just seem to come up with original ideas all the time, while the others, the majority, devote their lives in the main to testing out the ideas generated by the few. We all know who these germinative biologists are; when they come to universities to give seminars, the halls are packed; we award them our honors and prizes. And although there are exceptions, most people are struck by the apparent spontaneity of their achievements. George Wald once said to me of Ruth Hubbard: "When Ruth walks into a lab, things just start to happen."

While it is true that science has its creative stars, just as the art world does, it is equally true that most scientists, like most artists, hit gold now and again. Even more important, all of us are impelled by the *anticipation* of such creative experiences: As one scientist friend put it, we go through life expecting the *real* moment tomorrow. This is to me a stunning and quite thrilling realization: that the hundreds of thousands of scientists and artists in the world have major facets of their existence organized around their expectations of creativity. It becomes most compelling to find out what creativity is all about.

<u>The Creative Process in Science</u>

To begin the inquiry, we can consider how human consciousness is thought to work, how our brains are thought to function. An important notion holds that there are two basic domains of human consciousness -- the first involved with control, analysis, causality, deduction; the second involved with relationship, with the mystical, transcendent, oceanic. Popular wisdom holds that scientists operate in the first domain, that they work through logic, reason, and mathematical formulations; indeed, this belief has contributed to the prejudice that the activities of a scientist are much less interesting than those of an artist, since in the end most of us are more interested these days in feelings than in formulations.

What I hope to do now is to dispel this myth, to convey the mystical dimension of scientific creativity, to convince you of its central importance. Scientists insist that it is essential to live within the system they seek to understand, to become a part of it, to indwell. One develops mental images of a cell, or of the switches turning sets of genes on and off, or of the migration of certain cells in a developing embryo, and these become internal realities. They exist as shapes, not as numbers; they are shapes that relate to each other and with which you form a relationship. You begin to daydream, move about in the system, lose self-consciousness, let your mind go. Barbara McClintock calls it developing "a feeling for the organism"; it can also be a feeling for molecules, for channels letting ions in and out, for hormones binding to their receptors. Or it can get larger, it can become a feeling for an ecosystem, a behavior, a symbiosis.

Now what I am describing may, and should, sound much like the Buddhist ideal of Oneness, the mystic immersion in Nature, the union with the cosmic. Here, though, we come to an important distinction. Whereas the Tibetan monk seeks nothing more than this Oneness, the scientist has a rather different agenda. The scientist wants to understand how it all works. So for the scientist, the immersion is not the end in itself, but rather a means to scientific discovery.

Bronowski makes some interesting observations along these lines. He notes that in civilizations that have expressed themselves in contemplation, such as India or Western Europe during the Middle Ages, neither art nor science has flourished. True, great temples and cathedrals have been constructed, but these have been anonymous, associated with no particular artist, their importance being to serve the worship within them. Science and art, Bronowski argues, involve personal engagement: Immersion is essential, but out of it emerges the inquiry, the search for answers.

Descriptions of this immersed state have been attempted by many scientists. They report that what they experience is the order, the patterns, the unity, and the simplicity of the parts of the system that they understand, and a recognition of the bits and pieces that do not produce a pattern, that lack integration, that await a unifying principle. This engenders what Jacob Bronowski terms the creative state: “the mind is roving in a highly charged, active way, looking for connections, for unseen likenesses” (Bronowski 1960). And then, he offers an important concept: “Given the infinite variety presented by Nature, the creative mind seeks a unity in this variety” (Bronowski 1960).

The poet Coleridge defined beauty as the “unity of variety.” It is a wonderful definition, incorporating somehow that gasp we experience when we see the face of a beautiful child which somehow distills all children’s faces into a single, unitary perfection, stunning in its inherent simplicity. We feel such a gasp at a superb poem or string quartet. And scientists throughout the ages report the same experience: When they arrive at one of Nature’s truths, they recognize it because it is so very beautiful. Francois Jacob describes the audience at the Institute Pasteur when Watson first presented the structure of the DNA double helix: “For a moment the room remained silent. Then a few points of clarification were raised. But no criticisms. No objections. The structure was of such simplicity, such harmony, such beauty even, and biological advantages flowed from it with such rigor and clarity, that one could not believe it untrue” (Jacob 1988).

The experience of discovering one of Nature’s truths is an experience we can term the eureka moment. The emotional state this evokes is well described by Jacob, whose insight into the mechanism of gene regulation was one of the key eurekas of the century:

> Suddenly a flash. The astonishment of the obvious. Barely had these ideas emerged than I felt invaded by an intense joy, a savage pleasure. A sense of strength as well, of power. As if I had climbed a mountain, attained a summit from which I saw in the distance a vast panorama. I no longer felt mediocre or even mortal. I needed air. I needed to walk. I had gained access to the very essence of things, and this allowed me to feel emancipated from the laws of time, from the chaos of the universe. A triumph over death! (Jacob 1988)

Needless to say, this description could be transposed onto any description of an ecstatic religious experience.

With the attainment of such eureka moments as the goal of scientific inquiry, and immersion in the system as an essential way to achieve this goal, we need now to introduce a third component, that of intuition. Some have called it a good scientific nose. Given the infinite variety, the bits and pieces that do not produce a pattern, the creative scientist gets a hunch. Somehow, as Polanyi puts it, she or he is able to anticipate hidden truth, is guided by a sense of an approaching solution. My experience of it is that I let the cells start to tell me a story, and just as when I am listening closely to a story, I begin to anticipate what is coming next, how it might turn out. The hunch requires familiarity with the story line, with scientific knowledge, but it also entails such ineffable qualities as originality and imagination and courage. Thus, its source can no better be described than the inspiration for a poem.

So, the creative scientist indwells, has intuitive gifts, and has as his or her goal the eureka, the unifying principle, the recognition of something beautiful embedded in Nature. Even after all this is in place, however, the creative moment cannot be predicted or dictated. Many report that they have to let the material mill around, even lie fallow, and then, quite suddenly, it seems to organize itself for them as Jacob has described. All report that there must persist throughout the process a personal obsession, a drive; Michael Polanyi (1966) calls it the creative thrust, fed by the anticipated beauty of the discovery, the excitement of the achievement, and the professional success that will follow. We will return later to the motivation for success. Next we can consider what happens once a scientist shouts “eureka”.

From Insight to Demonstration

As everyone knows, it is not enough for the scientist to have a beautiful idea; it must also be a correct idea, concordant with what Nature has come up with during the course of evolution. Polanyi states it well: “What the scientist pursues is not of his making; his acts stand under the judgment of the hidden reality he seeks to uncover. His vision of the problem, his obsession with it, and his final leap to discovery are all filled from beginning to end with an obligation to an external objective” (Polanyi 1966).

Thus the creative scientist has a second task: to *demonstrate* the validity of the principle. The scientific community demands that the new idea not only have inherent beauty but also be backed up by experiment, by observation, by predicted outcomes. As one scientist remarked, “I *know* how my system works, now I just have to prove it.”

Having said this much, we can develop a more typical view of how the creative process works in science. Rarely does the scientist move from indwelling to intuition to the ultimate eureka in a single smooth motion. What usually happens is that while nosing around in a problem, the scientist gets a hunch, and immediately the thinking shifts from inductive to deductive. How can I test this hunch? How can I find out whether it is valid? What would be a clever approach, an incisive experiment? This switch from meditative to deductive, from holistic to reductionist, from right-brain to left-brain, is crucial, since the implications of the hunch must be dissected into clear elements if they are to be tested and verified. All too often we read research proposals wherein the investigator has identified an interesting problem and presents a plausible notion as to how the system might work but is then incapable of generating or articulating a clear set of deductions that follow from this notion.

It is useful to illustrate the interplay between inductive and deductive creativity by example. Let us say I have a hunch that *A* ---> *B*, and I deduce that if this is the case, a particular cell should behave in a particular way with a particular stimulus. I then go into the lab and do the experiment. If the prediction is borne out and the hunch is supported, I am encouraged that I may be on the right track. But let’s say the cell does something completely different. What I try to do is watch carefully what *does* happen and, I hope, derive from this observation a new hunch, such as “Aha, perhaps *A* doesn’t go to *B*; maybe it goes to *C* instead. If that’s true, then the following experiment should yield the following outcome. ” And the next day, I’m back in the lab doing the next experiment.

Hunches and their deductions are essential to science because they provide the frame, the paradigm, for making the observations. I stated in my example that “I try to watch carefully what *does* happen.” In fact, if you think about it, the process of watching entails looking *for* something: You only pay attention if you have an expectation. So my expectation that a particular cell will behave in a particular way allows me to watch, to dissect out a few relevant facts from the hundreds of things the cell is doing. And it is as

I notice that the cell is behaving differently from my expectation that I notice what is happening instead; without the hunch, I would be unlikely to see anything at all.

Now how does all this compare with art? When I first approached this question, I thought that things were very different with art. I thought that once the artist shouted “eureka” and began to synthesize bits and pieces into a poem or a painting, the resultant work had an inherent validity. I thought it could be judged “good” or “bad” but never “right” or “wrong,” that there was no equivalent to Mother Nature out there with the true answers.

As I have thrashed this through with artist friends, however, I realize that things are not all that different. Artists, I now realize, also have an obligation to an external objective, namely, the receptivity of other humans. We call something art when its effect is to move people, to deepen their understanding of who they are, to bring to them an aesthetic experience. The criteria here are obviously far more difficult to pin down: The work may move some people and not others; it may resonate with the concerns of the nineteenth century but have little to say to the twentieth; and so on. In the end, though, the importance of the art is most directly measured by its timelessness and universality: It is because Shakespeare speaks to all peoples in all centuries that we call him great.

Not only does art have to answer to an external objective, it also operates in much the same way as science in terms of its execution. My artist friends tell me that while of course they start out with some ideas, these ideas simply provide the means for initiating the project, for focusing in on some of its key elements. It is as they start putting the ideas to paper or canvas or the dance floor -- that is, as the hunches are transmuted into deductions -- that the interplay begins: Good approaches are incorporated, while poor approaches generate new ideas by the very way in which they fail. So as it becomes obvious that to put a square shape in a corner of the canvas would imbalance the whole, so does it become clear that a round shape would be the next thing to try.

We spoke earlier of the role of intuition in developing novel ideas. Intuition clearly operates again at this level of interplay between idea and execution. The creative artist somehow recognizes that the square is wrong; the creative scientist somehow notices that the cell is behaving in a way that suggests *C* rather than *B*. And as before, a critical means to achieve this state is to indwell. The observant scientist, the one who picks out the useful information, is the scientist who is living in the system, has an affinity for the cell, so that the occurrence of the event we call *C* elicits the reflexive “Aha.”

The actual creative process, then, is much more like a conversation than like the soliloquy we described earlier. All the features of pure intuition are at play, but in addition the scientist keeps in touch, keeps asking “Is this how it works?”, keeps flipping from hunch to experiment to hunch. And because Mother Nature is infamous for keeping her secrets hidden, one has to be clever indeed in devising ways to get clear yes or no answers, and to cull useful information out of the numerous no’s that are encountered.

The Importance of Dialogue

The metaphor of conversation has an important extension. Not only do scientists keep up running dialogues with Mother Nature, and with the published literature, and with their own mental faculties; they also talk nonstop to one another. Whenever I get a new hunch, or think of an experiment to test a hunch, I more often than not think of someone I can try it out on. It may be someone in my lab, or in my department, or at another university. “I’ve got this idea,” I might say. “Do you think if I did the following experiment and got the predicted result, it would support the idea?” The response may be positive, but often it is not. I might hear: “Oh, I think Fred tried that once and it didn’t work. Why don’t you give him a call.” Or, “There’s an article in last week’s *Nature* saying that that reagent doesn’t do what we all thought.” Or, “You’d need the following control and that would be tricky to set up.” This is marvelous. And we all do it. We go to meetings and sit around thrashing things out. Indeed, several scientists I know are adamant in claiming that they had never had a new idea *except* in conversation, that they require the challenge and the stimulus of human engagement to think creatively.

Again, we can compare this to the arts. While artists of course talk nonstop with one another about the *products* of their creativity, they usually forge the work alone. They might call up a friend and say, “I have this idea. Do you think it would work in yellow? In F-sharp minor?” and the friend might venture, “Have you considered ochre? C-major?” But in the end the artist must first give the work an existence, after which its validity can be discussed and tested. In contrast, the scientist is engaged in ferreting out what already exists; hence, judgment calls can be offered dogmatically, and at any stage in the process.

This brings us to the matter of scientific judgment. While Mother Nature is our final arbiter of merit, she does not review our papers; other scientists do. It is other scientists who judge whether an idea is beautiful enough to be true and whether the experiments indicate that this truth is embedded in biological reality. There is much misunderstanding about this process. Our cultural tradition includes accounts of the hostility visited upon the likes of Copernicus and Darwin by such authorities as the Church, and there has developed the popular notion that any new scientific ideas are greeted with negativity, that the creative scientist is typically judged as a deviant.

I do not think this is true in present times. To be sure, any scientist who proposes a far-out idea, one that represents a real discontinuity with accepted paradigms, is expected to accompany that idea with a particularly persuasive set of observations. Well known are cases of scientists who go about espousing an idea that may well have an intrinsic appeal but for which compelling evidence is lacking; such people, as one friend put it, have “the trappings of creativity without the substance,” and they are asked to go home and come up with some persuasive deductive data.

Overall, in fact, the process of scientific scrutiny seems to me to work remarkably well, and indeed I agree with Bronowski that the scientific community is, in the best sense of that difficult word, a democratic community. We challenge one another; we raise objections; we repeat each other’s experiments; and in the end, sooner or later, the judgment that emerges is a vindication of valid notions and a rejection of invalid ones.

Importantly, this exercise is ultimately carried out with consideration and respect. As Polanyi puts it: “Each exchange of mutual criticism is something of a tussle, and may even be a mortal struggle, but new standards of plausibility and of scientific interest are thereby initiated and eventually established, so that while science is steadily reshaped, its coherence is maintained. Each scientist is subject to criticism by all others but is also encouraged by their appreciation of him” (Polanyi 1966). Or Bronowski: “You cannot carry out the activity of science if you do not have a society where you recognize the fallibility of others’ achievements, yet you also do them honor because it is their achievement; it is a society rich in dissent and yet rich in tolerance and rich in honor”

(Bronowski 1960).

Other Skills

Thus far, then, we have considered the inductive and deductive approaches that are critical to scientific creativity. Is this all it takes, or are there other important talents?

Two immediately come to mind. The first is skill at scientific metaphor, at translating knowledge into language. Even if a theory is true and the experiments are valid, they may long elude acceptance if they are incoherently presented. Conversely, scientists gifted in rhetoric may convince the community of the validity of incorrect claims by the sheer brilliance of their verbal presentation. In both cases the derailment is ultimately temporary: The opaque-but-true science will eventually be represented more lucidly, often through the ministrations of a sympathetic colleague, and the brilliant-but-false science will not in the end survive. Still, the lag may be a long one, long enough to profoundly discourage the incoherent creator and elevate to fame the incorrect orator.

Skill at scientific metaphor has a second bonus, namely, that one becomes a good teacher of science. Teaching, of course, can be a wonderfully creative activity. Indeed, I am not so sure I understand anything about science until after I have taught it, until after I have put it into words, provided the context, the story line, the analogies. Some scientists simply do not have a clue as to how to do this, and to my mind they are most bereft.

The second talent of utmost importance is technical facility. It is a talent that I can speak of with particular envy since I lack it completely: While I understand cells almost implicitly, I have no feeling whatsoever for a vacuum pump. I contrast this with my scientist/husband John Heuser, who astounded me early in our courtship by his encounter with a chain saw at my summer home, a saw that had long before been diagnosed as inoperable by several repair shops. John sat on the front porch and, with no diagrams whatsoever, took the saw entirely apart, cleaned off every piece with an oily rag, put it all back together, pulled the cord, and up it started. As I stared in disbelief, I saw a small pile of nuts and bolts remaining on the floor. “What are those?” I asked. “Oh,” he answered with disinterest,“those didn’t seem to be necessary for anything.” It goes without saying that such skills are enormously useful in getting experiments to work and in designing new ways to ask questions.

Since most scientists have varying endowments of different talents, most choose to work in teams wherein complementary skills can be combined. The structure of these teams varies widely: In some, the professor sits in an office and suggests experiments for the younger scientists to carry out; in others, such as mine, I do the kinds of experiments I do best and others do the kinds of experiments they do best, and that I would do poorly. I do not want to suggest that these teams always work well; there are numerous opportunities for personality conflicts, jealousy, undercutting, and the like. But at their best, these teams work with marvelous synergism, and would delight any designer of utopian communities. There is a palpable sense of shared creativity. Each person is unquestionably autonomous -- we are not constructing a Gothic cathedral -- yet our personal engagements are woven together to generate the final new glimpse of the truth.

A friend who recently returned from a sabbatical in Japan offers some interesting perspectives on this point. The Japanese tradition, he notes, is not only rooted in Buddhist anonymity, but is also still strongly influenced by both its feudal system of hierarchy and a sense that decisions should flow from consensus. Hence the personal engagement declared by Bronowski to be essential for creativity has been a rare commodity in Japan, and Japanese biological science has in the main been characterized as derivative and confirmatory rather than pathbreaking. In the labs where this is changing, my friend reports, there are typically one or several scientists who have trained for a time in the West. They instill in the group the sense that it is a good thing to question, to criticize, to go off on one's own, to be nonconformist, and as this starts to happen, there emerges that fermentive process known as innovation.

Acknowledgment of Creativity

I have come up with these perspectives on scientific creativity from my own experience and from forays into the writings of science philosophers. In addition, I have approached the topic as an anthropologist might. During the past year, when out to dinner with a seminar speaker or drinking beer with a group of scientists at a conference, I would explain my Star Island mission, take out a paper and pen, and say "What *is* scientific creativity anyway?" The question invariably generated great interest and a rich array of responses, most of which were strongly concordant with my own deductions and with those of the philosophers.

Particularly wonderful was the response of Dan Hanson, a scientist in my department. He and his wife were sitting with me one chilly evening in front of a fire, a good bottle of wine infusing our sense of well-being, when I floated out my question. Dan stared into the fire for about thirty seconds and then said: "Creativity in science is like coaxing a secret out of an older kid and then telling it to a younger kid."

As far as I am concerned, this pretty much says it all and can serve to summarize what we have been describing. The older kid is, of course, Mother Nature, and coaxing secrets from her represents the activity of the scientist. But the metaphor goes much further. The protagonist, maybe a child in third grade, is capable of intimating the wonder, the mystery, the magic of that secret possessed by the sixth grader. His curiosity generates a hunger, an overwhelming need to know. To get the secret, he has to form a close relationship with her, and devise clever schemes to get her to tell. Possession of the secret, the eureka, infuses the child with a sense of richness, of importance, of euphoria. And then, even better, he gets to tell the secret to a second grader, to someone who does not yet know it, whose admiration of his possession may be quite as delicious as the secret itself.

The gratification in telling the younger kid brings us to the question we glossed over earlier: How much are scientists motivated by ambition, by the desire for applause and admiration from their peers and the world at large?

I would answer that all of us are motivated both by our ambitions and our ideals; the ambitions push, the ideals pull. The ratio varies in each of us, and this is no less true of scientists: Some scientists are highly motivated by the anticipation of the applause, whether or not they admit it; others can more readily identify with the extraordinary case of Barbara McClintock, whose total immersion in her science received virtually no acclaim until she was awarded the Nobel Prize at the age of eighty. That we all have elements of both poles is the point, and it does not seem to me that we should care very much *why* a person is motivated to be creative; the creativity will come out in proportion to the strength of the motivation, and what is important to cherish is the creativity per se.

Another way of looking at the desire for applause is that the applause represents an acknowledgment that one has indeed been creative. The importance of receiving such acknowledgment is no better seen than in the preoccupation of scientists with the matter of priority. Most of the feuds in science revolve around disputes over priority, over who got there first, who *really* had the idea, the implication being that the other person was *not* the creative one, was derivative or even guilty of *stealing* the idea.

Here I can tell a personal story. For ten years I collaborated with a biochemist named Steven Adair. We shared a lab, did everything together, talked nonstop, and were best of friends. And then, after years of work, a lot of things quickly came together, resulting in major advances in our understanding of the cells we were studying. Our initial euphoria gave way to a growing tension between us as it became clear that each of us thought that the other was trying to take credit for the insights, was trying to claim priority. Fortunately, in our case, we caught it in time and were able to acknowledge that the only reason that any of it had happened was because we had worked together, indwelled together, combined our talents. To celebrate this, we wrote a paper narrating the course of our discoveries, flipped a coin to determine whether it would be authored as Adair and Goodenough or Goodenough and Adair, and then drank together two bottles of champagne.

<u>Appreciating Scientific Understandings</u>

I would like to conclude by considering an important adjunct to the creative process, namely the *appreciation* of creativity. Most people do not experience eureka moments firsthand, and even the creative paragons report only a few world-class eurekas per lifetime. In the main, then, most of us experience creativity largely by reliving the creative process of others, at experiencing what Arthur Koestler (1940) calls a “re-creative echo.” This is not a passive process. It is in many ways the same kind of activity as the act of creation itself, involving the same impulses, the same intuition, the same concentration, and the same infusion of pleasure. Most of us have experienced it often in our appreciation of art: We are swept away by a dance performance, thrilled by a symphony, moved to tears by a poem. Yet things are very different with scientific creativity: Whereas I can pick up an issue of *Nature* and be swept away by five or six articles, this is probably not true of most people. One could argue that the *Nature* articles are written in inaccessible language, but even when gifted science writers take great pains to explain a brilliant scientific discovery, few seem to be listening and far fewer retain what they have heard. Whence this dichotomy, made infamous by C. P. Snow, between science and the humanities?

I can suggest two answers. The first, offered by Koestler, is that art is a form of communication that *aims* at the sharing of experience, at *eliciting* the re-creative echo, whereas science has no such mission. The second answer, the more obvious one, is that the experience being communicated by art resonates with our collective human experience, our sensory perceptions, and our emotions, so that while many of us undergo training to heighten such faculties, we all start out inhabiting these worlds; we already indwell. To indwell effectively with cells and molecules, on the other hand, requires not only training, not only Biology 1 and Chemistry 1, but also, I would argue, affinity, and an immersion, and a dialogue with the bits and pieces encountered. Or, as

Koestler frames it, the nonscientist is at best capable of comprehending the solution, the discovery; he or she cannot experience the problem, the process of arriving at the discovery, and hence the re-creative echo. The solutions themselves, Koestler argues, are of little interest: “If you cut off the creative impulse, then you reduce the great scientific adventure to a dusty heap of theorems” (Koestler 1940).

So, can anything be done, or are we stuck with this dichotomy? I rather think we are stuck with it. To indwell in science you really have to live it, become a part of it; that is, you have to become a scientist. I have close nonscientist friends who read *Scientific American* with great interest and are familiar with many of the concepts, but their ability to share my work experience or the broader implications of science remains quite limited. Indeed, scientists themselves are stuck with these limitations: I experience no re-creative echoes with the discoveries in astrophysics or computer sciences; at best I keep up with the punch lines. I don’t think there is any inherent reason to be concerned about this impasse. Still, I wish it were possible for all nonscientists to inhabit our world, if only for a day; it is a most pleasurable place to be.

It is pleasurable not only intellectually, but actively in the *doing*. Not yet mentioned, but mentioned often by fellow scientists, is how much *fun* it is to be a scientist. One of my favorite stories comes from a biologist at Duke who was out collecting sand dollars off the shore of North Carolina. He was thigh-deep in warm water, the sky was a brilliant blue, the air was soft and enfolding, and he suddenly turned to his companion and said, “Christ, do you realize I’m being *paid* to do this?” When I am puttering around in my lab, pouring cells into test tubes, weighing stuff out on balances, and watching what happens, I really get the sense that I am playing, in the best sense of that word. In fact, playing is probably as apt a metaphor for the process of scientific creativity, and indeed for creativity in general, as any we have developed thus far. To play as a kid is to daydream, to imagine, to be curious, to be learning, to be relaxed and ready to laugh, to be open and suggestible, to be doing what you want to do (as opposed to work, which is doing what your *mother* wants you to do).

A travesty, of course, is that we scientists get to play all day long for fine salaries, whereas most artists must also hold down a work-type job and can engage in creative play only on their own time, and for far less money. If I have a utopian vision, it is that scientists and artists, and our enunciators the teachers, should join together and demand that we be paid equivalent salaries for full-time play, that we are held as equivalently important members of society. Since creativity, more than any other trait that I can think of, cuts across all lines -- class, race, gender, nationality -- this utopian occurrence could have far-ranging consequences indeed.

Those of us who think about religion have found valuable the concept of myth: humans need myths to infuse their lives with purpose and transcendence, and these myths have until recently usually included some sort of god or gods. Once Darwinism exploded much of our biblical myth, there has been an urgent search by Western philosophers for myths that better resonate with our understanding of who we are. I would like to conclude by quoting where Bronowski comes out on this. He writes:

> What has really happened is that for the myth of creation, scientists and artists have substituted the myth of creativity. This gives us the sense that it is human beings who are peculiarly the creators. Of course I do not think that this is a myth; but it is the nature of myth that those who hold it do not believe it to

> be a myth. Certainly science and art have enabled us to see human life and the place of humanity in rather special ways. Human beings are seen to have the capacity for self-fulfillment, the ability to fulfill the human part of the creative potential. If we have to call something a myth, I am proud to call that a myth. (Bronowski 1960).

References

Bronowski, Jacob. 1960. "On Art and Science." In *The Common Sense of Science*. New York: Vintage Books.

Jacob, Francois. 1988. *The Statue Within*. New York: Basic Books.

Koestler, Arthur. 1940. *Insight and Outlook: An Inquiry into the Common Foundations of Science, Art, and Social Ethics.* New York: Macmillan

Polanyi, Michael. 1966. *The Tacit Dimension*. Garden City, NY: Doubleday.
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