

CREATIVITY: METHOD OR MAGIC?

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Creativity may be a trait, a state or just a process defined by its products. It can be contrasted with certain cognitive activities that are not ordinarily creative, such as problem-solving, deduction, induction, learning, imitation, trial-and-error, heuristics and “abduction”, however, all of these can be done creatively too. There are four kinds of theories, attributing creativity respectively to (1) method, (2) “memory” (innate structure), (3) magic or (4) mutation. These theories variously emphasize the role of an unconscious mind, innate constraints, analogy, aesthetics, anomalies, formal constraints, serendipity, mental analogs, heuristic strategies, improvisatory performance and cumulative collaboration. There is some virtue in each, but the best model is still the one implicit in Pasteur’s dictum: “Chance favors the prepared mind.” And because the exercise and even the definition of creativity requires constraints, it is unlikely that “creativity training” or an emphasis on freedom in education can play a productive role in this preparation.

Keywords: creativity, creativity training, human mind, unconscious mind, method, preparation

What is “creativity”? Is it a stable cognitive *trait* that some people have and others do not? Is it an occasional *state* that people sometimes enter into? Or is it defined completely by its *products*: “creativity is as creativity does”? Whatever it is, how does creativity come about? How do you do it? Are there rules? Will practice help make you creative?

There is probably some truth in all three notions of what creativity is. It is (at least sometimes, and to some extent) a trait, because it is a statistical fact that some individuals exhibit it repeatedly. It may also be correlated with some other traits; some even think it can be predicted by objective psychological tests. But it is also obviously a state, because no one is creative all the time, and some people are highly creative only once in their lives. Sometimes creativity may not even be a special, unique state, but rather a circumstance that is defined by hindsight based on something external, something creative an individual happens to have done.

There are a number of theories about the underlying mechanisms of creativity, theories attributing it to everything from method to madness – none of them very satisfactory. As to inducing creativity – by using heuristic strategies or through “creativity training” – this has had very limited success.

Pasteur’s dictum. Before proceeding to a discussion of mechanisms and methods of **creativity**, we do well to keep in mind Pasteur’s famous dictum, <...le hasard favorise l’esprit prepare> (“chance favors the prepared mind”), because this will turn out to say more about what *can* be said about creativity than the more ambitious or modern notions. Pasteur was speaking, of course, about a very specific kind of creativity, namely, experimental scientific creativity. (The quote actually begins: – “In the experimental fields” or “In the fields of experimentation”, and was in part concerned with the question of whether experimental discoveries – the so-called “serendipitous” ones – are really just lucky accidents.) Pasteur’s insight seems to apply just as aptly to all forms of creativity, however.

One can interpret Pasteur’s dictum as follows: There is a (perhaps very large) element of chance in creativity, but it is most likely to occur if the mind is somehow prepared for it. Context shows that by “preparation” Pasteur did not mean being born with the “creative” trait. He meant that existing knowledge and skills relevant to the creative “leap” first had to be sufficiently mastered before a “bolt from the blue” was likely. Paradoxically, his suggestion is that the only formula for creativity is the most uncreative one imaginable, which is to learn what is already known. Only then are you likely to have enough of the requisite raw materials for an original contribution, and only then would you even be in a position to recognize something worthwhile and original for what it really was.

Some undefined notions have slipped into this story: “originality”, “worthwhileness”, “creative leaps” and “bolts from the blue.” Clearly creativity has something to do with originality and novelty, but it is just as clear that it can’t just be *equivalent* to something new, because so many new things are random, trivial or uninteresting. This too has to do with “preparation.” A cancer cure (to take a mythic example) is unlikely to be discovered by someone who hasn’t done his homework on what is already known about cancer. He may indeed come up with “new” hypotheses no one has ever thought of, but it will be evident to the “prepared” minds of the field when such an untutored hypothesis is simplistic, nonsensical, or a long-abandoned nonstarter (as it is very likely – though not, of course, logically certain – to be).

So novelty is not enough. Something creative must also have some *value* relative to what already exists and what is perceived as being needed. (Note that this, and all the foregoing discussion, focuses on what might be called “intellectual” or “technological” or “practical” creativity, whereas there is, of course, another dimension of value that has little to do with practicality and perhaps not much more to do with intellectuality, and that is artistic creativity. Here one of the criteria of

value is aesthetic value, an affective or emotional criterion that will turn out to re-surface unexpectedly even in intellectual creativity. We will return to this below, but, for now, note that intellectual and practical considerations are not the only bases for making value judgments.)

And even being new and valuable does not seem to be enough: The outcome must also be unexpected; there must be a sense that it is surprising. Usually this means that it would not have occurred to most people, who were instead attempting something along the same lines without success precisely because they were following conventional expectations – something the surprising result somehow violates.

And here, with this third and last criterion of “unexpectedness”, we seem to be at odds with Pasteur’s dictum. For what can all that “preparation” do but train our expectations, establish conventions, move in familiar, unsurprising directions? In defining creativity as the production of something that is not only new and valuable, but also unexpected, we seem to have put an insuperable handicap on taking the path of preparation: For whatever direction the preparation actually leads us cannot be unexpected. This does indeed seem paradoxical, but again, a closer look at Pasteur’s dictum resolves the apparent contradiction: The suggestion is not that preparation guarantees creativity. Nothing guarantees creativity. What Pasteur means is that the only way to *maximize the probability* of creativity is preparation. He correctly recognized that the essential element is still chance – the unforeseen, the unexpected – but that this fortuitous factor is most likely under prepared conditions.

Having arrived at three (admittedly vague) criteria for what counts as creative, we could perhaps strengthen the notion by contrasting it with what is *not* creative. We will find, however, that whereas there are many cognitive activities that are ordinarily not in themselves creative, each one is capable of being performed creatively as well, which suggests that creativity is somehow complementary to ordinary cognition.

What is Not Creative?

Problem solving. In general, problem solving is not a creative activity (although Stravinsky thought it was – we will return to his view and his rather different definition of “problem solving”). Problem solving involves applying a known rule or “algorithm” in order to solve problems of an overall type that varies in a minor or predictable way. Although some elements of novelty and decision-making may be involved – it is an undergraduate fallacy, shaped by the unfortunate exigencies of exam-taking, that problem solving can be successfully accomplished by rote – and the pertinent rule or formula may require some insight in or-

der to be understood and applied, conventional applied problem solving is nevertheless a relatively passive and mechanical process. Successfully understanding and applying a rule is just not the same as discovering it. However, as our discussion of analogy below will show, sparks of creativity may be involved even in recognizing that a class of new problems can unexpectedly be solved by an old rule. And even in the context of instruction, gifted students may independently rediscover new applications of algorithms they have been taught for more limited purposes.

Deduction. Deductive reasoning, which is defined as reasoning from general principles to particular cases (as in deducing from the principles that “All Men are Mortal” and “Socrates is a Man” the consequence that “Socrates is Mortal”), is in general not creative. On the other hand, viewed in a certain way, all of mathematics is logical deduction: There are theorems for which it is difficult or impossible to see intuitively whether or not they are true, let alone prove they are true by showing the steps through which they can be deduced from general principles. Hence not *all* deductions are trivial; some may well require formidable creativity to accomplish. In general, it is the size of the deductive gap between the principles and their consequences that determines whether or not deduction requires creativity: “Socrates is Mortal” does not; Fermat’s last theorem does.

Induction. Inductive reasoning, which is defined as “reasoning” from particular cases to general principles, is also, in general, not creative, but it is more problematic, for interesting reasons. For whereas in deductive reasoning, once a theorem’s truth is known and the proof has been constructed, the path from principles to consequences can be traversed relatively mechanically, in inductive reasoning there seems to be no available mechanical path other than trial and error; and this path, in most interesting cases, can be shown to be either random or endless (or both). Hence inductive generalizations that are not trivial (in the way “this apple is round, that apple is round, therefore all apples are round” is trivial) do call for creativity. And even when the general principle is found, there is no “a posteriori” path one can reconstruct using hindsight (as one can do after discovering a deductive proof) so as to lead from the particular to the general – only the other way around.

In other words, there seems to be no general algorithm or rule for doing inductive reasoning. So whereas most everyday induction is very gradual, trivial and uncreative, the more substantial instances of inductive “reasoning” are probably not reasoning at all, but creativity in action. Note, however, that since the size of the “gap” that separates the conventional from the creative is to some degree arbitrary (and since it is unlikely that our basic cognitive capacities evolved in the service of rare, celebrated events), even “everyday induction” may exhibit bona fide elements of creativity that never achieve celebrity.

Learning. Although, as with all skills, some people will do it better and more impressively than others, learning is, in general, likewise not a creative activity: It is the acquisition of knowledge and skills by instruction and example. By its nature it is not something that can give rise to something new and unexpected, although sometimes there are surprises, with creative students discovering (or, just as important relative to what they already know and don't know: *re*-discovering) things that go significantly beyond the immediate content of what is being taught them.

Imitation. By definition, imitation gives rise to something that is not new; hence it is also in general not a creative activity. And yet it too has been found to be an important precursor of creativity, especially artistic creativity. Those who ultimately become creative innovators often start out as remarkably astute mimics of others. Imitation is also related to other important factors in creativity, such as analogy, metaphor and "mimesis" (a Greek theory that art imitates nature). Invariably the new and valuable resembles the old in some (perhaps unexpected) way.

Trial and error. Almost by definition, trial and error is not creative, involving random sampling rather than inspired choice. Yet the role of chance in creativity must not be forgotten. "Serendipity" refers specifically to surprising, new, valuable outcomes arising purely by chance, and hence potentially out of nothing more than random trial and error. Insights may arise from trying a panorama of individual cases. Nevertheless, random trial-and-error (or "fumble and find") is usually a symptom of a particularly uncreative approach. Yet a prominent exception seems to be the biological evolutionary process (which some have even admirably described as "creative"): Evolution has produced its remarkable results with what, according to the best current theory, is little more than random genetic variation, which is then selectively shaped by its adaptive consequences for survival and reproduction. Similar (usually uncreative) processes are involved in the shaping of behavior by its immediate consequences in trial-and-error ("operant" or "Skinnerian") learning.

Heuristics. Heuristics are usually contrasted with "algorithms" in problem-solving. Solving a problem by an algorithm or failsafe rule is supposed to yield an exact, reliable solution that works for every case. "Solving" it by heuristics – by an unintegrated and incomplete set of suggestive "rules of thumb" that work in some cases, but not in all, and not for fully understood or unified reasons – is just as uncreative as solving it by algorithm. However, many people have noticed that heuristic procedures (such as sampling many special cases by trial-and-error) sometimes lead to insights, sometimes through inductive generalization and analogy with cases in which heuristics succeed, and sometimes because of the stimulus provided by cases in which heuristics (or even algorithms) *fail* (see the discussion of anomalies, below).

Abduction. Peirce has proposed that, besides induction and deduction, there is a third process, called “abduction”, whereby people find the right generalization from considering sample cases even though the probability of finding it is much too low. Since this process is hypothetical, it does not really belong in this list of things we actually do that are (usually) not creative. However, the rest of the hypothesis does refer to a theme that will arise again when we discuss possible mechanisms of creativity. A more recent exponent of Peircean abduction (and one of the most creative thinkers of our age), Noam Chomsky, holds that the reason we succeed so often in finding improbable generalizations is that the solutions are somehow already built into our brains. Hence, according to this view, creativity is a kind of “remembering”, much the way Plato thought learning was remembering [anamnesis] (not conscious remembering in either case, of course). If it is true that the innate patterns of our brain activity play such a crucial role in creativity, then of course no “preparation” is more important than this (evolutionary?) one, and creativity turns out to be in part an instinctive skill.

Thus ends the (partial) list of suggestive cases of what is ordinarily *not* creative activity. I will now discuss briefly the “state versus trait” issue before going on to consider the “creative process” and possible “mechanisms” of creativity.

Creative Trait or Creative State?

There is currently considerable debate over whether intelligence is a unitary or a plural trait, i.e., is there one intelligence or are there many? Whatever the truth may be, it is clear that one sort of “preparation” (not Pasteur’s intended one) that a mind aspiring to be creative (intellectually, at least) could profit from would be a high IQ (or IQs, if there are many). Whether IQ itself is an inherited trait or an acquired “state” is too complex an issue to discuss here (it is probably some of both), but note that the unitary/plural issue applies to creativity too. Whether a trait or a state, creativity may be either universal or domain-specific, with individuals exhibiting it with some kinds of problems and not with others. The distinction between intellectual and artistic creativity is itself a case in point (see the discussion of the performing arts, below).

The way IQ tests work is that we pick, in the real world, the human activity or skill (called the “criterion”) that we regard as intelligent (e.g., doing mathematics) and then we design tests that correlate highly with individual differences in this criterion activity, high scores predicting high level performance and low predicting low. This is how IQ tests are validated statistically. Trying to do the same with “creativity tests” immediately raises problems, however, since the criterion “skill” is so rare, diverse and hard to define. So-called “divergent thinking” tests of “creativity” have been constructed without any strong validation. They differ

from the “convergent” tests of intelligence in that they are open-ended, not having a strict correct answer. They are supposed to predict creativity, but the validation problems seem insurmountable, because so much of the definition of “giftedness” and “genius” is post hoc, based on hindsight after rare cases and unique accomplishments. There seems to be a contradiction between the predictiveness of objective tests and the unpredictable element in creativity. However, if there is a (general or problem-specific) trait of “tending to do unpredictable things of value”, then tests could presumably measure its correlates, if there are any.

There is also much confusion and overlap with the measurement of the general and special intellectual skills, and no clear notion about how they may interact in creativity. Life-cycle effects pose problems too: IQ-related skills and knowledge increase with age until adulthood, whereas creativity pops up at different ages and stages, sometimes early (as with mathematicians), sometimes late (as with writers).

In general, the picture we have of creativity based on the objective measurement of individual differences is not very informative, leaving open the very real possibility that, except where it depends heavily on a special (noncreative) intellectual skill, there may be no measurable trait corresponding to creativity at all. We turn now to creativity as a state or process.

Underlying Mechanisms

There are four classes of theories about the underlying mechanisms of creativity. They can be classified (relatively mnemonically) as: (1) *method*, (2) *memory*, (3) *magic* and (4) *mutation*. The “method” view is that there is a formula for creativity (usually this is not claimed so crassly). The “memory” view is that the essential factor is somehow innate. The “magic” view is that mysterious, unconscious, inexplicable forces are involved. And the “mutation” view is that the essential element is chance. Let us now consider several candidate theories in terms of these four categories:

The unconscious mind. Creativity as the working of the “unconscious mind” is in the class of “magic” theories (such as divine inspiration). It offers no real explanation of the creative process, merely attributing it to a mysterious (and very creative) unconscious mind. It is espoused by Hadamard and others in his book on mathematical invention, and is, of course, very much influenced by the Freudian ideas prevailing at the time. The scenario is that for a time one works consciously on a problem, and when one fails, one’s unconscious mind somehow continues and mysteriously accomplishes what the conscious one could not. From the perspective of modern cognitive science this is not very helpful, because *all* cognitive processes are unconscious, and as such, require an *explanation*, not merely an an-

thropomorphic attribution to another, wiser (or more primitive) mind analogous to the conscious one.

The problem of explaining creative and noncreative cognition consists of providing a mechanism for all of our unconscious processing. The only informative aspect of the “unconscious-mind” model is the attention it draws to the incompleteness of the role of conscious, deliberate efforts in the creative process. Note, however, that Pasteur’s dictum had already indicated that preparation was necessary but not sufficient. (Moreover, “conscious, deliberate effort” is not even sufficient to explain such altogether uncreative cognitive activities as remembering a name, recognizing a face or adding two and two.)

Innate structure of the mind. The concept already described as “abduction” comes from a “memory” (anamnesis) theory which holds that creativity is somehow guided or constrained by the innate structure of the mind. (It has a counterpart theory of biological evolution, “preformationism”, according to which evolved structure is not shaped by chance and trial-and-error but is already inherent in the structure of matter.) There are two forms that this structural constraint can take. Either it works by eliminating many of the possible false starts we could take by rendering them (literally) unthinkable in the first place, or it somehow guides us in how we select and evaluate the possibilities. Note that this theory at first seems to apply more naturally to intellectual creativity, where there presumably exists a “right” or “wrong”, rather than to artistic creativity; but of course in artistic creativity, where aesthetic (affective and perceptual) criteria prevail, it is easy to see how “right” and “wrong” could depend on our sense organs and emotional structure. (The possible role of aesthetic constraints even in intellectual creativity will be taken up again below.)

The problem with the abduction view is that it seems to attribute too much specific innate structure to the mind (and in this respect it has an element of the magical view). Since language, logic and the mechanical sampling of possible variations by trial and error seem to allow us to conceive of so much, it is hard to see how the first form of abduction – limits on what is conceivable – could have much of a role. The problem of creativity seems to begin once we take the vast array of conceivable alternatives as given: How do we then find the “right” ones? (This is also called the “credit/blame assignment problem” in machine-learning theory.)

The second form of abduction – selective guidance – may be more promising, and will be discussed again below, but for now it should be noted that it is unclear to what extent this “guidance” function – the one involved in hunches, conjectures, intuition, etc. (whatever they are) – is an innate, evolutionary one, arising from the structure of our minds, rather than an effect of experience, preparation, analogy and even chance. The abduction view seems to attribute too much to innate structure without giving any explanation of its nature and origins.

Analogy. Although it is not a complete model for the creative process, the view emphasizing analogical thinking is clearly a case of method. The suggestion is that analogies play an important role in the creative process; that often a new “solution” (or, in the artistic case, a new innovation) will be based on a fruitful and previously unnoticed analogy with an existing solution in another area (Hesse, Black). This depends a good deal on our capacity and inclination to look for, find and appreciate structural, functional and formal similarities. It may well involve a basic cognitive process, related to how our knowledge is represented and manipulated.

There is a more elaborated form of the analogy theory, the “metaphor” theory, that applies not only to poetic creation, but to creativity in general. To the extent that this theory is not itself merely metaphorical, it is informative about the surprising productiveness of the strategy of finding or even imposing similarities by juxtaposing objects, images or ideas and then, in a sense, “reading off” or interpreting the consequences of the juxtaposition (Harnad). This is not a failsafe strategy, however, any more than systematic induction or random trial and error are, for there are many more fruitless and empty analogies than “creative” ones. The options are narrowed, however, by preparation (and perhaps abduction), and, with the aid of chance, analogy – both deliberate and accidental – does play an undeniable role in creativity.

Preparation. At this point, the Pasteur “method” itself, that of preparation, should be mentioned. Creative outcomes tend to be novel recombinations of existing elements, which must hence all be made readily available in advance by preparation. The probability of generating and recognizing a new and valuable outcome depends on a sufficient command of what is already available. *No surer strategy can be recommended to anyone aspiring to make a creative contribution in any domain than to master as thoroughly as possible what is already known in that domain, and to try to extend the framework from within.* This is paradoxical, to be sure. First, by definition, a creative contribution will *not* be with existing methods and from “within.” Second, there is the well-known problem of falling into a mental “set”, which involves perseverating with existing methods by habit, at the expense of trying out or even noticing new ones (as in going back to look for something you’ve lost in the same place over and over) – precisely what an undue emphasis on preparation might be expected to encourage.

Conventional sets are an everpresent danger, and there exists no formula for overcoming them except to bear in mind that mastery does not imply slavishness and that the ultimate goal is to transcend conventions, not to succumb to them: An attitude of admiration and dedication toward the knowledge or skill one is intent on mastering is not incompatible with a spirit of open-mindedness, individuality, and even some scepticism; indeed, an early imitative capacity coupled with an element of rebelliousness may be a predictor of promise in a given domain (al-

though prodigal gifts sometimes come to nothing). Whether creativity is a state or a trait, it is clear that, given the same initial knowledge or skill, some people do succeed in making original contributions whereas others fall into fruitless, perseverative ruts. The only remaining strategy to be recommended is that if progress is not being made after a sufficiently long and serious attempt, one should be prepared to move on (temporarily or even permanently), perhaps in the hope that creativity, like intelligence, is plural, and one will be able to exhibit it in some other area.

The well-known observation that mathematicians tend to make their creative discoveries when they are very young may be due to the “set” effect: It may be at the point of culmination of one’s “preparation” in this most elegant and technical problem area – when one is freshly arriving at the threshold of mastery (sometimes called mathematical maturity) – that one is in the best position to make a creative contribution in mathematics; then one can spend a lifetime exploring the implications of those virginal insights. After longer exposure, unproductive sets form and are difficult to break out of. It may be that if they had changed areas or had first come to mathematics at a later age, the same precocious individuals would have displayed a “later” creativity. It is undeniable, however, that (just as in athletics) there are life-cycle – and trait – effects in creativity irrespective of the timing or field of one’s preparation. The insights and skills of historians and writers, for example, tend to mature later in life, perhaps because they depend on more prolonged and less concentrated “preparation”, or because verbal skills mature later.

But despite the everpresent danger of falling victim to uncreative sets, if there is one creative “method”, then “Pasteurization” is it, with the creative “trait” perhaps amounting to no more than a rare form of resistance or immunity to contagion from convention despite extensive exposure.

Intuitive and aesthetic factors. Theories that appeal to “intuition” and “aesthetics” as guides for creativity are, as already mentioned, in the “memory” category. Apart from what has already been said, it is instructive to reflect on Bertrand Russell’s anecdote (based on a story he heard from William James¹) about the man who, when he sniffed nitrous oxide (laughing gas) knew the secret of the universe, but when it wore off, would always forget it. One time he resolved that he would write it down while under the influence. When the effects subsided, he rushed to see what he had written. It was: “The smell of petroleum pervades throughout.” What Russell took this anecdote to suggest was that intuition can be a *false* guide too. If one is directed only by one’s intuitive or aesthetic sense of profundity, then one may be led to attribute cosmic significance to nonsense. So Russell suggested that, whereas it may be well and good to allow oneself to be influenced by aesthetic considerations (what mathematicians have called “beauty”, “elegance”, etc.), one must keep in mind that these subjective intuitions must an-

swer to objective tests subsequently (in the case of mathematics, rigorous provability), and that one must not get carried away by one's subjective "epiphanies."

It must be added, however, in favor of intuition, and perhaps abduction, that in mathematics there appears to be a "trait", one that only a very few highly gifted mathematicians have, of being able to repeatedly make intuitive conjectures that turn out subsequently to be proven right. Some even go so far as to say that this ability to intuit what is true is the real genius in mathematics, not the ability to produce rigorous proofs. Of course, the two go together, with no better guide in constructing proofs than an intuitive sense of what will turn out to be true and what false. In any case, the role of pre-verbal, perceptual and aesthetic intuitions should not be under-rated in creativity. Note also that aesthetics need not be innate. Some "tastes" may be acquired from preparation, analogy with other areas of experience, or even chance.

Anomaly. Another "recipe" for creativity, the preparation/anomaly-driven model, is a method based on the observation that creative insights are often provoked by encountering an anomaly or failure of existing solutions. It is not clear whether this variable is truly causal or just situational (i.e., where there is to be a creative solution, there must first be a problem), but what must ultimately provoke a creative solution is evidently some sort of failure of noncreative ones. Sometimes just the discovery that a faithful rule unexpectedly fails to work in certain kinds of cases sets one in the right direction. The result, if successful, is a revision of an entire framework so as to accommodate the anomaly and at the same time subsume prior solutions as special cases. John Kemeny used to say: "If I encounter something new, I first try to fit it into my system; if I cannot, I try to reject it [as wrong or irrelevant]; if that fails, then I try to revise my system to fit *it*." (And, in a slightly magical variant of his own, Russell adds: "If all else fails, I consign it to my unconscious until something pops up.")

Despite the role of anomaly as a stimulus (and logical precondition) for creativity, however, it is hardly a reliable method, as countless noncreative (and unsuccessful) encounters with anomalies must testify. Anomalies may serve to break sets, but they may also create them, in the form of repeated unsuccessful attempts at resolution. Yet it is undeniable that the history of theory building in science can be described as anomaly-driven revision and subsumption.²

Constraints. Another "method" is suggested by Stravinsky's views on the creative role of "constraints" in what he called "problem solving."³ Stravinsky explained why he continued to compose tonal music after most composers had abandoned the tonal system by saying that "You cannot create against a yielding medium." He needed the tonal system as a constraint within which he could exercise creativity.

Stravinsky's view may well be a variant on the "preparation" theme, for if "anything goes" (because of insufficient preparation), nothing creative can happen. This is why Stravinsky saw all creativity as problem solving. He felt that a creative medium could not be infinitely yielding, infinitely "free." It had to resist in some way (perhaps by giving rise to anomalies, problems) in order to allow creativity to be exercised or even defined. For most of his life Stravinsky personally preferred the classical tonal system as a constraint, working to create innovations *within* it; others, such as the twelve-tone composers, rejected tonality, replacing it by *another* system of constraints (possibly, some believe, abductively "unnatural" ones, which suggests that even in the arts constraints cannot be entirely arbitrary). But Stravinsky's point was that there can be no creativity without problems, no problems without constraints, no constraints without preparation. Rules may be made to be creatively broken, but they must be mastered before they can be modified or abandoned, and there must always be new ones to take their place.

There may be a lesson here for advocates of "touchie-feelie" creative freedom (in preference to "pasteurization") in early education. The strategy probably represents yet another form of ineffectual and perhaps even counterproductive "creativity training." Although ultimately desirable and even necessary for creativity, freedom (the absence of constraint) also makes creativity logically impossible in advance of preparation. Moreover, freedom may have more to do with what you are than what you do, training hence being better addressed to first showing you how to follow rules rather than how to flout them. Perhaps studying the true examples of creative freedom – and their real-time historical course – would be more helpful and stimulating than inculcating fabled freedoms in a yielding medium of wishful thinking: The creativity of future generations is more likely to be maximized by inspired than by indulgent pedagogy.⁴

Serendipity. The class of theories that might be called the "cerebral serendipity" school (to which Einstein and Poincaré belonged) are mutation theories, emphasizing the crucial role of chance in creativity. Pasteur of course believed this too. The scenario is one of gathering together the elements and constraints out of which a creative solution is (hoped) to arise, and then consigning the rest to the (unconscious) "combinatory play" of chance, with intuition perhaps helping to suggest which combinations might be fruitful. This view provides an important clarification of the role of preparation, for without preparation, the essential elements out of which a fortuitous combination could arise would simply be absent, unrecognized or unappreciated.

Mental analogs. There are some speculative "mental analog" models, belonging to the memory class, that suggest that sometimes the structure of a problem and its solution may have analog counterparts in the mind. Mental "catastrophes" and "phase transitions" arising from mental models actually encoded in the brain and governed by mathematical catastrophe theory or fractal theory have been sug-

gested, among others. These are still too speculative to be considered, but something of this sort could in principle mediate abductive solutions, and even acquired ones.

Heuristic strategies. Another class of methods arises from suggestions (e.g., Polya's) to engage deliberately in heuristics – doing random or mechanical trial-and-error sampling, trying out analogies and inductive conjectures, etc. – as discussed earlier. These strategies might better be described as the heuristic phase of preparation. They can clearly guarantee nothing, although they may increase the likelihood of a stroke of luck in an otherwise prepared mind.

Improvisation and performance. A special case combining the heuristic, aesthetic and analogic “methods” is suggested by the performing arts, which exhibit “real-time”, “on-line” creativity while executing, interpreting and, especially, improvising upon the formal codes created by composers and playwrights. Musical scores and theatrical scripts, together with training in the performing arts, constitute the constraints and the preparation, whereas the performance itself, if it is not merely mechanical but innovative and expressive, is the creative “act.”

There are many misunderstandings of performance as somehow being derivative or second-rate creativity. This is incorrect. Every creative medium has its own constraints, its own “givens”. And they all leave room for originality and for innovation – in short, for genius. The performing arts may in fact be especially revealing about creativity because they “externalize it”, so to speak, making it happen before your very eyes. The lessons one learns from it are familiar ones: Much preparation and craft, considerable imitation of the past, an aesthetic sense guiding one's taste in innovation, and the ability and inclination to do something worthwhile, convincing and new with the raw material. Before the “creative” and “performing” arts were separated, one might have watched with one's own eyes while a performing poet-minstrel, in the thrall of an inspired moment – guided by his muse – elaborated an inherited (prepared) tale in a new and inspired way during an improvisatory performance.

Complementarity. Finally, among methods, one must mention the role of collaborative, cumulative and complementary efforts in the combinatory play among many different minds (perhaps differentially “favored” with intellectual and creative gifts) in maximizing the likelihood of a creative, joint outcome. The performing arts already suggest that creativity is not a static, and perhaps not even an individual process. There is complementary specialization in all creative domains: composer/performer, actor/director, experimentalist/theoretician, intuitive conjecturer/rigorous theorem-prover. And then there is the most fundamental complementary relation of all: the relation of the present to the past. One's preparation invariably takes the form of the creative products of one's predecessors. They have furnished the constraints on the otherwise yielding medium in which one can then try one's own chances at making a creative contribution.

Conclusions

Creativity is a phenomenon with both external and internal constraints. The external ones concern the historical state of the problem domain and the role of the unpredictable. The internal ones concern how prepared and how “favored” (endowed) a mind is. Although there are some heuristic methods that one can attempt (such as trial-and-error induction and analogy), the best strategy one can adopt to maximize the likelihood of creativity is to maximize preparation. Maximization is not the same as a guarantee, however; although it is not magical, creativity will always remain mysterious because of the essential rule of unexpectedness and unpredictability in its defining conditions. Preparation can only provide a favorable setting for chance, not a certain one. Moreover, it is unlikely that chance or freedom – i.e., an independent propensity for the fortuitous – can be tutored. Apart from problem-specific preparation and open-mindedness, one’s only remaining strategy is to be prepared, given one’s mental, physical and experiential resources, to move on (temporarily or permanently) to other potential creative problem domains if a sufficiently dedicated and patient effort ends in unproductive, perseverative loops: Finding one’s creative calling (if it exists) may itself call for some (prepared) trial-and-error sampling, guided, perhaps, by the native or acquired dictates of one’s aesthetic judgment, but ever dependent for success on the vagaries of chance.

Suggested Readings: Black, *Models and Metaphors*; Hadamard, *The Psychology of Invention in the Mathematical Field*; Harnad, *Metaphor and Mental Duality*; Hesse, *Models and Analogies in Science*; Stravinsky, *The Poetics of Music*; Polya, *How To Solve It*.

Notes

- ¹ <http://www.emory.edu/EDUCATION/mfp/jnitrous.html> and <http://www.theatlantic.com/issues/96may/nitrous/nitrous.htm>
- ² New “paradigms”, though they may involve startlingly bold innovations, must still be commensurable with the past, at least in the sense of subsuming it as a special case (e.g., the flat-earth theory, which will always remain *approximately* true); this shows that theory building is actually a cumulative and perhaps never-ending series of closer and closer approximations converging on the “truth.”
- ³ It must be borne in mind that Stravinsky’s suggestion may be peculiar to artistic creativity, where the constraints can be provided from within, so to speak, unlike in science and mathematics, where they come from without: from external reality and from the formal world of logical and mathematical consistency.
- ⁴ Readers wishing to form their own judgments about some of the adult creativity training methods that exist may want to read a book or attend a seminar on “brainstorming”, “synectics”, “lateral thinking” or some other soundalike. Or you may sample the offerings of any organiza-

tion that also specializes in weekends on “rebirthing” and “making miracles work for you.” Do not be confused by the fact that the adjective “creative” will tend to be freely appended to most of the available offerings, irrespective of their specific benefits.