Two Aspects of Scientific Creativity [DRAFT]

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It is widely acknowledged that creativity plays a role in the development of science. But both creativity and its role is poorly understood. Is creativity necessary for scientific progress? I argue from broadly Kuhnian perspective that though it is incorrect to regard creativity (in any mysterious, or non-rational sense) as a prerequisite to science, science by its very nature commonly *involves* creativity. Further, by considering two distinct but related aspects of creativity's role in science, I hope to shed some light on what creativity *is*.

1. INTRODUCTION

> . . . there is no such thing as a logical method of having new ideas, or a logical reconstruction of this process. My view may be expressed by saying that every discovery contains "an irrational element", or "a creative intuition". . . . (Karl Popper 1959, 32)

A popular vision of scientific progress accords a key role to creativity. In this vision, the lone, heroic scientist faced with either a theoretical vacuum or plenum of confusion experiences a flash of insight — in a dream or in the bath, perhaps — and sets science moving again. Progress awaits these flashes, these "ah ha!" moments. We revere the creative genius of Copernicus, Newton, Darwin, Einstein and a few others who pushed science forward in such dramatic fashion, partly because we have trouble understanding how they did it. We speak of their "Miracle Year"s with only *tentative* metaphor.

This vision of science — invoking "irrational elements" or "creative intuitions" — thus places significant aspects of science beyond our ken. Creativity is treated as a black box — indeed, it might as well be an *empty* box.[1] We just hope that the scientists can make it work. Collingwood, writing around the same time as Popper, aptly describes a corresponding position in art as the artist "controlled by forces which, though part of himself and specifically part of his mind, are not voluntary and not conscious, but work in some mental cellar unseen and unbidden by the dwellers in the house above" (Collingwood 1938, 126–127).

Fortunately, our ignorance of the sources and nature of creativity need be only one part of the story. Reichenbach's distinction between the context of discovery and the context of justification leaves room for rationality in theory choice, *given some choices* (wherever they come from). The discovery/justification distinction thus encourages an analogy to evolution by natural selection — or, as Lyell might have seen it, to the Hindu mythology of the three aspects of God: creative, sustaining, and destroying. In biology, mutation provides the unconstrained, irrational raw material through which nature methodically sifts. Selection rationally sifts

[1] Though work on the psychological and cognitive aspects of creativity has been popular since the late 1950s, it is only relatively recently that what we'd regard as significant progress is being made. For a survey of this work, I recommend Sawyer (2006).

through the irrational phenotypic product of mutation. In theory choice, empirical adequacy is the great destroyer and the only avenue we have for understanding rational scientific progress.

Scientific creativity — *whatever* it is — thus seems a necessary feature of science. At the height of the Cold War, this thought much concerned psychologists, educators, and politicians. If creativity is necessary for scientific success, how might we *foster it*. Three conferences at the University of Utah in 1955, 1957, and 1959 were directed toward the "Identification of Creative Scientific Talent" and its development. One Thomas Kuhn was on the program of the third conference (Kuhn 1959) then in the midst of writing a certain (1962) book that would leave a definite mark on the history and philosophy of science.[2] In his essay, Kuhn expressed some reticence at the generally enthusiastic tone of the conference, noting (apparently against the grain) that "it is often better to do one's best with the tools at hand than to pause for contemplation of divergent approaches" (Kuhn 1977, 225). This, of course, is the "essential tension":

> To do his job the scientists must undertake a complex set of intellectual and manipulative commitments. Yet his claim to fame, if he has the talent and good luck to gain one, may finally rest upon his ability to abandon this net of commitments in favor of another of his own invention. Very often the successful scientists must simultaneously display the characteristics of the traditionalist and of the iconoclast. (227)

Kuhn's model of science offers an understanding of what creativity amounts to that is worth investigating: creativity as iconoclasm, breaking the constraints of a popular paradigm. But ironically, his comments recall Popper: scientific progress requires a balance between creativity and conformity, but ultimately it *does* require creativity.

I want to suggest that this is almost true. Science *involves* creativity. But we should not think of creativity as a *prerequisite* for scientific progress — as a frame of mind without which science would stagnate, and thus something to be trained or encouraged. Rather, it seems to me that science, in both its normal and revolutionary moments, is creative not because of the fortunate talents which a minority of its individual practitioners bring to the table, but because science by its very nature involves a balance of innovation under constraint and selective breaking of constraints. No doubt, there are psychological prerequisites for successful science — and some of these may also be prerequisites for creativity. But it does not follow that creativity is a prerequisite for successful science.

One difficulty of making my case involves the lack of a commonly accepted definition a creativity. And I do not intend to propose one here. Indeed, when we consider the enormous variety of usages of 'creative', it might strike us as dubious that a single, non-disjunctive, non-circular definition is there to be found. Nevertheless, I

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[2] Papers stemming from all three of these conferences, including Kuhn's, are reprinted in (1963); for discussion of the broader context, see Sawyer (2006, 39–44). I shall cite Kuhn's essay from its reprinting in his (1977).

shall not assume that definition is impossible. I must instead rely on (and query) basic intuitions about creativity's relationship to closely related terms (like 'innovative', 'original', 'novel', 'genius', and so on). These concepts form a tight yet vague and complex interdefinitional network from which there may be no escape. Thus, my goal is to help *clarify* some of these relationships in examining two different aspects of creativity in science. These aspects correspond to certain sorts of constraint breaking and constraint abiding that reflect the social and contextual character of theory-choice. I find myself forced to leave behind the vision of the heroic creative genius. But though admittedly less exciting or inspirational, this revised picture of science offers the hope that, with luck on our side, we mere mortals — "ordinary thinkers" though we may be — might reach what we previously regarded as unattainable heights of scientific insight.

2. Genius

My "hopeful thesis" disputes a common but uninformative understanding of creativity as somehow intimately connected with "genius". The innovative quantum physicist David Bohm questions this connection from a somewhat different angle, suggesting that even *genius* is an insufficient condition for creativity:

> Is creativity then something that is appropriate only to a few people of special talents, who rise to a level that is commonly called 'genius'? Clearly, it is not all a matter of special talent. For there are a tremendous number of highly talented people who remain mediocre. Thus, there must have been a considerable body of scientists who were better at mathematics and knew more physics than Einstein did. The difference was that Einstein had a certain quality of originality. (Bohm 1968, 138)

Recent Einstein scholarship suggests a few other potentially influential differences: for instance, a large proportion of the patents Einstein reviewed during his tenure at the patent office in Bern involved technical questions about how to synchronize clocks across the city (Galison 2003).

But once again, there are reasons for being pessimistic about whether originality and talent are enough. What particular quality of originality does Bohm have in mind? Einstein lore (partly cultivated by Einstein himself) has it that Einstein retained a strong antiauthoritarian streak that perhaps maintained a childlike curiosity in the face of oppressive education. This lore nicely coheres with Bohm's observation that only a few people "in the whole of human history" have achieved the combination of native talent and distinctive originality we recognize as "creative":

> what we learn as children, from parents, teachers, friends and society in general, is to have a conformative, imitative, mechanical state of mind, that does not present the disturbing danger of 'upsetting the apple cart'. And then, most of those who are not satisfied with such conformity fall into the trap of rebelling against it, by projecting an opposing or contrary set of ideals, and trying to conform to these. But evidently, such conformity is also not creative. For reasons that are hard to specify, a few people escape both these kinds of conditioning to mechanical-ness in the operation of the mind. (1968, 144)

For Bohm, creativity flourishes in the narrow space between conformity and unconformity. No wonder we should find so few individuals who manage not to stray into either extreme!

Current research on creativity chalks up the "school-as-creativity-squasher" thesis as a myth (Sawyer 2006, 60). Howard Gardiner (1993, 45) suggests a number of other requirements, including a "childlike quality" combined with sophistication and maturity in a certain domain. Clearly Einstein would never have been able to propose the theories we find creative without first engaging in (and to some degree mastering) the background science against which his originality shines. I shall have more to say about the kind of mastery this represents below. For now, let us pursue the connection between originality and creativity.

3. Originality

There is, of course, a weak sense in which scientists are commonly "creative": they *create new* explanations, predictions, theories, models, techniques, processes, substances, and so on. They *add* to the world, even if only to the world of ideas. It was not always allowed that genuine creation was humanly possible. "Aquinas specifically emphasized that what an artist produces is only a 'quasi-creation'; what seems to us a creation is, in fact, no more than a change in the ephemeral form in which a piece of matter is cast. The inherited idea that only God can create was very much alive during the early Renaissance" (Barasch 1985, 186). Creation *ex nihilo* was divine: what the painter did was "invent" — for example, a depiction of a pastoral scene that never in fact existed but all of whose elements did. Even as people grew more comfortable taking of the artist as analogically divine, empiricist philosophers proposed accounts of understanding that had our cognitive faculties as mere mixers or combiners. Galileo's view of nature had him not creating something genuinely new, but instead reading its book. Sympathizers with these lines will thus be resistant to see scientists as *creating* new explanations, rather than discovering them. Discovery may take hard work and ingenuity, but it is not in itself *literally creative*.

So goes a natural, but mistaken, thought. In the first place, as philosophers of science move away from theories of science in which the scientist literally represents nature to model-based accounts of prediction and explanation (see, for example, Giere 1988), resistance to seeing genuine novelty in the products of science ought to wane. Some philosophers are notorious for waxing in the opposite direction. Koestler provocatively suggested that:

> Einstein's space is no closer to reality than Van Gogh's sky. The glory of science is not in the truth 'more absolute' than the truth of Bach or Tolstoy, but in the act of creation itself. The scientist's discoveries impose his own order on chaos, as the composer or painter imposes his — an order that always refers to limited aspects of reality. . . . (Koestler 1964, 252)

But we do not need to accept the full force of Koestler's claim to derive some benefit from it. Scientific models *do* represent selectively and in idealized ways. The openness of these various ways of representing nature (from which aspects we choose to model and how, to what taxonomic divisions suit our particular, contingent goals),

leaves room for creativity to play a role. Little room exists in the "reading nature" approach — at best, Galileo might get to choose an order in which to read the chapters. While this selectivity might not be fully sensitive to nature, other portions of the model no doubt are in ways that an impressionistic painting need not be.

Second, it seems wrong to regard discovery as being not amenable to creativity. Drawing some distinctions will help make this clear. We speak of both *people* and *things* (ideas, theories, methods, processes, artworks, &c.) as creative. In art, for instance, it is common to view both the process of creating an artwork (or the creator) *and* the artwork itself as creative. These can come apart. A creative process might produce an objectively uncreative result. This might occur when the respects in which the process is original or creative does not bear significantly on the originality of the product. A bizarre painter might produce a highly conventional and representational work through highly unconventional means (using, say, small lizards dipped in paint to depict a mundane still life whilst whistling show tunes in a 37-tone scale). Or consider strange Rube Goldberg devices designed to do commonplace things like pouring a cup of tea, or making toast. In similar fashion, scientists might develop intensely creative ways of merely confirming results that most scientists already accept.

Is it likewise possible for a creative product to be produced by a non-creative process? To answer this question, let us again assume that there is *some* connection between creativity and originality and consider a further distinction concerning the originality of the *person*. On the one hand, a person might be original in a strong sense, as being literally the first one to entertain an idea (seriously or otherwise). Call this 'objective originality'. On the other hand, a person might be original in a weaker sense, as being merely uninfluenced by previous ideas. Call this 'subjective originality'.[3] Charles Darwin and Alfred Russell Wallace seem to meet this latter condition, only discovering that their ideas on the species question weren't unique after they were already well developed.

A further kind of example should exercise us in this context: consider creative collaborations like Pablo Picasso and Georges Braque, painters who worked closely together in developing Cubism (see discussion in Gruber 1993, 69). I doubt that we want to say that Braque and Picasso were not creative. But do they not count as original owing to their (more or less) symmetrical association? At this stage, it would be natural to zoom out from these two individuals and consider instead the collaboration itself as the creative entity. The *collaboration* was certainly original and creative. Its originality stems in large part from the fact that Picasso and Braque forged into unknown territory that other painters had not considered or executed. In light of this obvious fact, it seems

[3] We can further imagine a continuum between these extremes in a number of ways, perhaps by considering how "in danger" a person with a subjectively original idea is to discovering that it is not *objectively* original. It is one thing to be Copernicus having never heard of the then forgotten Aristarchus of Samos (who propounded heliocentrism a thousand years before the cracks in the Ptolemaic model began to show); it is another to be an ill-informed physicist in, say, 1919, who manages to independently develop Relativity.

only appropriate to credit both individuals with originality (even if it was only a derivative honor).[4] Notice how this tendency declines as the size of the collaboration increases. Collaborations that include many individuals working collaboratively on a project might similarly be original and creative without a high degree of individual originality amongst the collaborators themselves. If this is right, then it would seem that we ought to include *groups* among *people* and *things* in our domain of possibly creative entities. Thus, creative products might emerge from the hands of *many* uncreative individuals working within an original collaboration.

I have obviously left the argument for the claim that unoriginal individuals might collectively instantiate a creative collaboration at an intuitive level at best. I shall attend to it in more detail presently. For now, we need to do more to see whether we should even *bother* returning. One difficulty with the intuitive connection between creativity and originality, whether we are concerned with the individual or the group, concerns the fact that one can easily be original (in both process or product) without clearly being creative.

Consider a depressingly plausible scenario. You spend an inordinate amount of money to attend the debut performance of an unknown jazz musician. Your heart sinks as you discover that this person is a wacko: she plays the upright base with a ham sandwich. After seventy awkward and painful minutes (I'm sorry to say that you mistakenly sat near the front and thus could not sneak out), you turn to your friend and, in an effort to look on the bring side, point out that "at least she was original". Now, was she creative as well? I'm tempted to be liberal and merely divide creativity further into significant and insignificant manifestations. Creativity need not *always* inspire admiration and awe: it can often leave us cold. I can imagine turning back to you and adding further that "she was nothing if not creative in her use of lunchmeat".

Others are not so tempted. Patricia Stokes suggests that "creativity happens when someone does something *new* that is also useful or generative or influential" (Stokes 2006, 1). While offering a simple and plausible way of connecting creativity with originality, this move has the disadvantage of making even individual creativity an extrinsic and possibly retrospective matter. Whether our jazz musician counts as creative depends in part on whether a new genre of "deli jazz" springs forth from her pioneering work. Perhaps some of Stokes' disjuncts are meant to be amenable to synchronic evaluation after all. Perhaps I don't need to wait to see what happens to evaluate a different musician as generative — we might see clearly that, given the tenor of mainstream jazz, his music *will be* deeply influential.[5] Moreover, this evaluation might be insensitive to a surprising (though not necessarily inexplicable) *failure* for the work to be picked up on. How exactly this would work, I do not know.

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[4] This concession might be primarily epistemic, as we might not know in any detail how the collaboration was structured. After all, Picasso might have shared one technique or organizing principle with Braque, who slavishly copied it and vice versa, in alternation.

[5] I felt this way immediately when I first heard the jazz pianist Brad Mehldau.

Unsurprisingly, Bohm is even more draconian in his assessments. Concerning Archimedes' fabled bathtub insight, he writes:

> Such a penetrating insight may lead to important discoveries, and to new inventions of considerable practical importance. Yet, it is not creation. For in creation, one perceives a new fundamental set of similar differences, that constitutes a genuinely new order (and not merely a relationship between two or more orders that are already known). This new order leads hierarchically to a wide range of new kinds of structure. Generally speaking, an isolated penetrating insight connecting up one field with another falls far short of doing all this. (1968, 143)

Whether or not we recognize a need for a certain degree of product significance for creativity or merely prize such products more highly, it seems likely that, especially in the scientific context, only significant products will garner any attention as creative. Have we made anything more simple or have we instead simply introduced a further complication? I have no intention to trying to say anything significant about significance in a short paper like this (for one attempt, see Kitcher 2001, Chapter 6). I'm happy to have time tell. If Stokes and Bohm wish to make assessments of creativity not a potentially retrospective matter, they shall have to do better than this.

4. Constraint Breaking

Creativity as originality is not fully satisfying. Originality seems to come in *several* degrees and clear thresholds or illuminating definitions evade us. You might well complain that I haven't tried very hard. That is because a simpler understanding of originality relevant to our context is closer to hand. Let us consider a simple Kuhnian model of scientific progress.[6] In pre-paradigm science, novelty is easy to come by. Fact-gathering is undirected and relatively superficial (Kuhn 1962, 15). Models that emerge from this poverty of data bespeak an absence of constraint. Though original — new creations —, we encounter no great compulsion to treat them (or their creators) as creative.

The art analogy is harder to imagine, but I think still supports this inclination. We regard the Cubists as creative not so much for the fact that we had not seen art in that style previously, but because it transgressed against norms — to depict scenes (in various senses) realistically — that characterized much of what we *had* seen. If the murals of Lascaux had been dominated by multi-perspective representations, we might not have regarded them as especially creative, had there been no tradition of single-perspective representation to break with. Ancient Egyptian art is not stylized in its peculiar way because the Egyptians did not understand how to accurately represent perspective, but because accurate representation was not their aim. It aimed *not* to be creative in any strong sense.

[6] I believe that much of what I have to say is compatible with various elaborations by Kuhn and his commentators and, to a reasonable degree, to other accounts of scientific development, though I obviously cannot make the case for these contentions here.

On the Kuhnian model of scientific revolutions, breaking the constraints of previously dominant paradigms necessarily dovetails with the introduction of *new* paradigms (Kuhn 1962, 77). No wonder the idea of creativity as creation should appeal to us. The unification model of explanation (Kitcher 1981) suggests another way in which we might recognize constrain-breaking as behind creativity. According to this account, a collection of propositions (or argument schemas, if you prefer) explains a collection of facts when they *unify* those facts. But unification may be difficult to achieve. Assumptions of separateness — e.g., of the terrestrial and celestial realms — may hinder unification. These hindrances need not be significant. Indeed, they may often amount to little more than a failure to entertain the possibility of seeing a connection. Forging connections may often be as simple as pushing aside the impediment and seeing how far we can apply our explanatory schemas.

Again, however, we encounter puzzling questions. Our questionably-creative lunchmeat-musician can be assimilated to the constraint breaking model with ease. Standard practice in jazz when playing the upright bass is to use one's fingers or a bow to play. Playing the bass with a sandwich is a particular way of transgressing this practice. Is she creative or just crazy? Intentions seem to matter. Perhaps she is approaching her art in an algorithmic way, systematically attempting to break with tradition in various ways, "considering the negative" (Boden 1994, 82). In such a case, we tend to deny that she is in fact creative: she merely *wants* to be and is trying too hard. She overestimates the significance of originality. In art, Stokes notes that "sadly, development is sometimes stymied because a talented individual places too much value on novelty" (2006, 12). In science, such flawed valuations are especially problematic. This point underpinned much of Kuhn's work.

But again, intentions matter. Can we cite any *reasons* for transgressing certain constraints? Why *this* constraint over *that* one? In the case of our quirky jazz musician, we might ask after the aesthetic or symbolic significance of the ham sandwich (does it have something to do with the song choice of "Goodbye Pork Pie Hat"?) or even of the significance of the algorithm that initiated the particular series of possibly random bass-playing implements. In science, focusing on some constraints over others as subject to pressure or revision might reflect different levels of commitment (Kuhn 1977, 234). This may still leave plenty of a paradigm's components on a par with nothing to choose among them. We just have to start somewhere.

Choices to attack one constraint over another need not be rational; but this clearly does not make them *irrational* or otherwise mysterious. The heroic model confines their non-rationality to the black box of inexplicable creative intuitions. The chemist August Kekulé famously claimed that the ring structure of benzene occurred to him in a reverie which he described variously as involving dancing atoms or auto-cannibalistic snakes (Gruber 1981). If Kekulé was not trying out hallucinatory ideas at random, then must not there be some subconscious, fundamentally creative source of new ideas?

It is not clear what to say about such reports. There is some reason to be skeptical of historical reports of discoveries, even by the scientists themselves (for a discussion of Kekulé in particular, see Schaffer 1994, 23–29).

And perhaps there is *nothing* to say except that such episodes appear to be rather rare.[7] It is well known that even widely acknowledged creative scientists such as Newton, Darwin, and Edison emphasized their *hard work* as key ingredients of their success.[8] Such reports lend credibility to Kuhn's description of what happens in times of scientific crisis:

> Though now aware that [the scientist's working paradigm] cannot be quite right, he will push the rules of normal science harder than ever to see, in the area of difficulty, just where and how far they can be made to work. Simultaneously he will seek for ways of magnifying the breakdown, of making it more striking and perhaps also more suggestive than it had been when displayed in experiments the outcome of which was thought to be known in advance. And in the latter effort, more than in any other part of the post-paradigm development of science, he will look almost like our most prevalent image of the scientist period you will, in the first place, often seem a man searching at random, trying experiments just to see what will happen, looking for an effect whose nature he cannot quite guess. (Kuhn 1962, 87)

While not the sort of total freedom that characterizes pre-paradigm science, crisis loosens certain constraints of normal science. It invites *considering* breaking them. Their ultimate transgression may be prompted by firmer features of the paradigm in crisis. But as Kuhn admits,

> more often no such structure is consciously seen in advance. Instead, the new paradigm, or one sufficient to permit later articulation, emerges all at once, sometimes in the middle of the night, in the mind of a man deeply immersed in crisis. What the nature of that final stage is — how an individual invents (or finds he has invented) a new way of giving order to data now all assembled — must here remain inscrutable and may be permanently so. (Kuhn 1962, 89–90)

Of course, that we do not know the source of our inventions does not imply that we never will. The hunt continues. But even if *some* springs of invention *do* remain forever inscrutable, we should not despair of partaking in the kind of collective creativity constitutive of scientific revolutions, methodically trying to break out of an imploding paradigm. After all, we might get lucky and be prepared enough for our luck to pay off. However such breakthroughs occur, on the Kuhnian model, constraints *will* be broken and new paradigms will replace the old. And the novelties which arise, assuming they achieve some degree of success, will be significant (at least for a time). We have, then, the makings of at least a creative product. It seems to me that there is a more neglected,

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[7] I am also tempted to say that — at least in the context of ordinary life — they are quite common. Why did I choose to have Cheerios rather than Grape Nuts for breakfast this morning? I have no idea. The choice seemed to come out of nowhere! Such situations are common, but do not suggest a mysterious, irrational "faculty of decision making".

[8] When asked from whence his ideas came, Newton is reputed to have quipped: "From thinking on them continually." Darwin considered what he called "fool's experiments", ideas he had no particular reason to accept or consider, but did anyway (Simonton 1993, 180–181). And Edison (most famous for his "one percent inspiration, ninety-nine percent perspiration" equation for genius), described his strategy thusly: "I have the right principle and am on the right track, but time, hard work in some good luck are necessary, too. First up is an intuition, and comes with a burst, and difficulties arise — this thing gives out and them that — 'Bugs' — as such little faults and difficulties are called — show themselves in months of intense watching, study and labor a requisite for commercial success — or failure — is reached" (Freidel and Israel 1987, 28–29 quoted in Schaffer 1994)

more pedestrian but thus *more comprehensible* sort of creativity that is part and parcel to normal science and in fact affords the somewhat rare revolutionary opportunities. To this we now turn.

5. Constraint Abiding

I have suggested above that creativity (and plausibly originality) requires a background network of constraints and commitments. Boden appears to agree: "The more clearly we can identify [a conceptual space], the more confidently we can identify and ask questions about the creativity involved in negotiating it" (Boden 1994, 94). On the Kuhnian model, moreover, the practice of normal science is what allows for crises that permit constraint breaking to emerge in the first place.[9] Normal science is often thought of as encouraging — even *mandating* — conformity or "convergent thinking" (Kuhn 1977, 226): "Education in the natural sciences . . . remains a dogmatic initiation in a pre-established tradition that the student is not equipped to evaluate" (229).

I think that this view of normal science obscures the workings of a multifaceted aspect of creativity. First, we have what could be termed "permission discovery". Recall that a central role of normal science is the articulation of a paradigm (Kuhn 1962, §4). This may be by the discovery of novel facts, extensions of the predictive and explanatory power of the paradigm, or even (on the basis of these) the discernment of novel constraints or their absence. I have a hard time not seeing Ptolemy's articulations of the Aristotelian paradigm of celestial motion as creative. Their creativity inheres partly in their clever abiding by the constraint of the perfect sphere as the basic geometrical component of a legitimate model of the universe. What Ptolemy found is that he could live with this constraint — even in the face of more accurate data that pressed harder on that constraint — when the circles were combined in famously baroque ways. The system's predictive ability (such as it was) under Aristotle's geometrical constraints betokened the *absence* (or slackness) of certain norms for simplicity or obvious physical interpretability. As it turned out, of course, Ptolemy's successors looked at this situation with a *horror vacui*. The general lesson here is that sometimes cleaving to a paradigm's constraints *comprehensively* takes a lot of effort and reveals considerable ingenuity (Kuhn, after all, regarded puzzle-solving as a *test* of ingenuity) but also results in articulations of novel (or previously tacit) constraints or permissions.

A second facet of this aspect of creativity within constraint takes advantage of the various degrees of freedom constraints provide. Jazz represents a familiar example of creativity operating within constraint. Most jazz musicians own what are commonly known as "fake books": compendiums of the chord structures of a collection of standards (occasionally coupled with melodies, rhythms, general notes on how the songs are to be played, and

[9] Perhaps this is what Boden has in mind with this somewhat cryptic remark: "Many creative ideas, however, are surprising in a deeper way. They concern novel ideas that not only *did not* happen before, but that . . . *could not* have happened before" (Boden 1994, 76).

so on). Improvisation occurs within this structure: the musician chooses the particular chord voicings[10] — perhaps augmenting the prescribed structure in ways that still clearly count as an instance of the song described — and improvises the rest. Apparently at the other end of this spectrum lies the transcription: *every note* of a particular recording of an improvisation set down on paper. It is the definition of conformity. But this is misleading. While transcriptions clearly present *more* constraint than mere chord structures, they leave open room nonetheless. In his characteristically sensitive and subtle preface to the authorized transcription of the famous "Köln Concert", Keith Jarrett warns the reader of the pitfalls of transcription:

> While this edition is as close as possible to the music on the record, there are many places where notes are correct, but time is not, because on the recording I am playing *completely out of* metronomic time. There are also places where we had to choose between alternate *in*accuracies. Also, we decided that notation would actually work *against* accuracy, since none of the notation methods of which we were aware were correct for much of the piece. It would almost need notation *on every note* to be accurate. . . . There is much more going on on the recording, but this "going on" does not always translate into notes on paper. Many notes are *inferred by the rhythmic sense*; others depend on the harmonics or attack of the previous note (or notes). So, writing down *all* the notes would give *more* of a false view of the sense of [a section of Part IIa] than selecting *some* notes. And yet, even this selection cannot reveal the real sense of this section *as an improvisation*, where listening is what determines the music's strength. (Jarrett 1975)

The development of scientific models resembles Jarrett's description to a surprising degree. Confirming certain models or putting them to use in offering explanations or making predictions yet leaves investigators a wide range of ways in which to do this. Experimentalist cleave to certain cherished facts or methodologies in imagining clever ways of teasing secrets out of nature. Where do these good ideas come from? Our discussion above applies: we don't know — maybe from nowhere. But they only get the chance to *count* as clever or creative against the background of a paradigm's constraint.

The development of a paradigm of course puts us in a position to discover anomalies that may not have been initially apparent. A final aspect of constraint abidance ultimately leads to the paradigm's demise. This occurs when a new constraint is introduced into a paradigm and followed at the expense of others. The composer, Arnold Schoenberg adopted interesting "new constraints to structure his music making: using every note in the chromatic scale, for instance" (Boden 1994, 81) which necessitated the transgression of preexisting constraints (e.g., that a musical piece should be in a single key). Or in the case of Cubism, "precluding a privileged viewpoint (the barrier) precipitated the multiplication of viewpoints within a single pictorial pace (the breakthrough), allowing the artists to point more things about their subjects (what they knew) than a single vantage point (what they saw) permitted" (Stokes 2006, 7–8). Such episodes can of course be conceived as simultaneous constraint abiding and constraint breaking. Thus my two aspects of creativity shade into one another. Perhaps the most

[10] As Boden (1994, 92) points out, "chords", e.g., in a fakebook, are actually *classes of chords*; "chord voicings" are instances of members of these classes.

well-known and studied episode of scientific creativity — the development of relativity — appears to take precisely this form. Einstein asked what physics would have to look like (what constraints would need to be relinquished) if we took the speed of light as a constant in *any* circumstance.

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