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THE CONNECTION BETWEEN POSTFORMAL THOUGHT AND MAJOR SCIENTIFIC INNOVATIONS

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We distinguish normal human creativity from originality and innovation, using the orders of hierarchical complexity. These account for why major scientific innovators are rare. The four postformal orders of hierarchical complexity are presented in terms of scientific tasks performed at each stage. Historical scientific innovations at the highest orders are empirically scored. Einstein's general theory of relativity and Darwin's evolution scores at the Cross-paradigmatic stage. Scoring of innovators' personality traits indicate that Metasystematic stage 12 is a minimum requirement. Global needs to produce more scientific innovators require institutional changes of the Metasystematic order of hierarchical complexity.

KEYWORDS: Creativity, Cross-paradigmatic, innovation, Metasystematic, Paradigmatic, personality traits, postformal, scientific.

The focus of this article is on postformal creativity and the forms it has taken in science. The purpose is to illustrate why postformal thought is a requisite for genuine creativity. Originality, creativity, and innovation are common concepts. Demonstrations of them are claimed far and wide for many endeavors on a quite regular basis. *Originality* is producing newness that may only be new to oneself or may not have long-term utility. One simply may have a great deal of variability in behavior. *Creativity* is typically used to refer to the act of producing new ideas, approaches, or actions. These actions, to rise above originality, must ultimately make a difference in some social sphere. *Innovation* is the process of applying such creative ideas in some specific context. The task we have set for this article is to discriminate truly creative work from other kinds of originality and innovation. We invoke the Model of Hierarchical Complexity to explain these distinctions. At each stage of performance, the new task successfully accomplished *may be* original and novel for the individual or group successfully completing the task.

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Originality, in that sense, has a narrow scope, because it is performer-bound to that instance. It is not necessarily novel to others or even socially relevant in the present or in the future. Every day, individuals or groups somewhere discover they can perform a new task or come up with a new solution to a problem. These are new for them and genuinely novel at that individual or group level. However, the accomplishments or ideas may very well be "old news" to many others. Thus, it is valuable to note that increases in hierarchical complexity, task by task, are by definition creative acts, and they are natural aspects of being a human actively functioning in the world.

Genuinely creative work is qualitatively and quantitatively different from just original work. It involves understanding large "chunks" of current knowledge, building on it, making novel connections, and subsuming current knowledge in the course of creating new knowledge. In other words, it means genuinely transcending existing knowledge and assumptions, and originating understandings previously not known, not conceived, not assumed, and simply not used. Such behavior indicates the scientist has novel insights into complex challenges of some kind. Generally, it requires a new synthesis of systems (performed at the Metasystematic order), or of metasystems (performed at the Paradigmatic order) or of paradigms (performed at the Cross-paradigmatic order). These orders of hierarchical complexity are described later.

These premises apply to any field of endeavor, not science alone. We select science as the broad domain considered in this article, and draw mostly on historically recognized innovations. These are more accessible, because major scientific accomplishments become public knowledge.

Major scientific innovations—especially when they result in new technologies—may significantly improve the quality of life in the societies that benefit from them. Among the historically most important scientific accomplishments to be discussed, the methods, theories, and techniques do not have to be original, only the manner in which they are used. Conceptual scientific innovations may not only translate eventually to new technologies, but on a global scale, they may also radically alter people's assumptions of how the world works. The debunked myths of the earth being flat and the sun revolving around the earth are two such examples of how scientific innovations altered worldviews for then-current and future generations.

This discussion begins with considering why major scientific innovators are rare. Overviews of the four postformal stages follow, with historical examples of innovations made at the Paradigmatic and Cross-paradigmatic stages. In the following section, we consider the personality characteristics of highly innovative people by relating them to stages of hierarchical complexity. Finally, we offer concluding reflections on implications for the future of both the need for, and scarcity of, major innovation in today's world.

THE RARITY OF MAJOR SCIENTIFIC INNOVATORS

Very few people create major scientific breakthroughs. There is one overriding reason for this, which is supported by diverse factors. The overriding reason is the very low number of people who develop stages of performance on tasks at the three most complex orders of hierarchical complexity cited earlier (Commons and Bresette, 2006; Torbert and Associates, 2004). Of these, only a subset is in science. Four related factors support this limitation, particularly when they are confluent: unsupportive cultural conditions, insufficient education to learn and apply complex material, natural biological limitations, and the absence of requisite personality characteristics (Commons and Bresette, 2006). The first two factors are discussed in "Cultural Progress is the Result of Developmental Levels of Support," in this issue. Biological limitations refer to heritability as well as such findings as those reported by Jaques and Cason (1994) of different maturation curves distributed across a population. Requisite personality characteristics are discussed at length by Commons and Bresette (2006). Later in this article, we consider them in terms of hierarchical complexity and their relation to sociocultural support.

A glance at the nature and context of the genuinely creative process helps to make sense of the very low number of people who develop stages of performance at the three most complex orders of hierarchical complexity. In many ways, the genuinely creative act is analogous to the saying "pulling something out of thin air," or the alchemical concept of turning lead into gold. It is not magic, however; rather, it is the work of synthesizing multiple highly abstract—and therefore highly hierarchically complex—"chunks" of understandings and received knowledge.

Once a discovery becomes widely known, for example that the earth revolves around the sun, it also becomes commonplace. The original task-difficulty of creating the knowledge is unknowable by any but those who went through the long process to create it. Minimally, scientific creativity must be original action. This point is essential to distinguish this topic from developing variations on someone else's work. These may be valuable, high-quality contributions, but they are not the rare exceptions that are our focus here. In those rare cases, it may not seem to others, later, that it could have been so difficult to develop them. The first level of difficulty, however, is that there is little or no pre-existing knowledge about how to accomplish or create the new "thing," which may be a provable concept, a process, a formula, etc. The second level of difficulty is the nature of the creative process itself: major scientific innovations are pursued largely in the solitude of one's thoughts and study over often very long periods. Even in research teams, only one member at a time invents, even though the invention might be a joint enterprise in other regards. Even in a cooperative behavior, one person has the behavior first, even if only a millisecond before the other. Together, such factors constitute the absence of support. This raises the stage at which the innovative task has to be done. These ideas are formalized in the idea of different levels of support for task performance (Commons and Richards, 1995). The *difficulty of an action* depends on the level of support in addition to the horizontal information demanded in bits, and the order of hierarchical complexity. Each increase in the level of support reduces the difficulty of doing a task by one stage. Each decrease in the level of support raises the difficulty of doing a task by one stage (Commons and Richards, 2002).

POSTFORMAL THOUGHT AND ITS ROLE IN INNOVATION

The four postformal orders of hierarchical complexity of tasks are described in what follows in terms of scientific contributions. The first two (the Systematic and Metasystematic) are discussed briefly and without historical examples. For the second two (the Paradigmatic and Cross-paradigmatic), historical examples accompany the descriptions. The postformal tasks performed by the scientists given as examples have been empirically scored to illustrate the relationship between the postformal stages and the kind of creativity they demand.

As discussed in articles throughout this issue, distinct proclivities characterize actions, and thus behavior, at the postformal stages. A proclivity is a natural or habitual inclination or tendency, propensity to do something. The creativity of postformal thought begins with two primary capacities. The first is to succeed at addressing problems that cannot be conceived or solved at the Formal stage 10. The second is to think in more compact "chunks" that systematically represent complex matters. As the examples that follow suggest, the nature of these chunks and their content becomes increasingly abstract at each postformal stage, ranging from multivariate relations at the Systematic stage to relationships among paradigms at the Cross-paradigmatic stage.

Systematic Stage

At the Systematic order, tasks require that one can discriminate the system or framework in which relationships between at least two variables are apparent. This means to recognize and describe an integrated system of tendencies and relationships. The objects of these systematic actions are Formal stage 10 relationships between variables. The greater the number of such relationships that are considered and coordinated, the more complex the resulting system of understanding is. Systematic actions include determining possible multivariate causes—outcomes that may be determined by many causes. This often requires building matrix representations of information and the multidimensional ordering of possibilities, including the acts of preference and prioritization. These actions generate systems. Views of systems generated have a single, true unifying structure. The "true-ness" results from having successfully coordinated all the variables brought into the analyses. However, this does not mean that all possibly correct or necessary other variables were included. It merely means that the system holds true with respect to the factors considered. Other systems of explanation, or even other sets of data collected by adherents of other explanatory systems, tend to be rejected. At this order, science is seen as an interlocking set of relationships, with the truth of each relationship in interaction with embedded, testable relationships. Most standard science operates at this order. Researchers carry out variations of previous experiments. They may in some unusual cases learn how to combine multiple causal relations in an original way.

Metasystematic Stage

At the Metasystematic order, tasks require that one can act on systems constructed as above; that is, systems are the objects of metasystematic actions. Metasystematic actions analyze, compare, contrast, transform, and synthesize systems. By definition of the Metasystematic stage, this means that actions have to coordinate at least two multivariate systems. The products of metasystematic actions are metasystems or supersystems. Instead of analyzing and comparing relationships among variables, as is done at the Systematic stage, systems created at the Systematic stage are treated as higher-level variables to manipulate. These higher-level variables are systems of causal relations. This allows one to compare and contrast systems in terms of their properties. The focus is placed on the similarities and differences in each system's form, as well as on constituent causal relations and actors within them. For example, philosophers, mathematicians, scientists, and critics examine the logical consistency of sets of rules or propositions in their respective disciplines. Doctrinal lines are replaced by a more formal understanding of assumptions and methods used by investigators. We suggest that almost all professors at top research universities function at this stage in their line of work. We posit that a person must function in the area of innovation at least at the Metasystematic stage of hierarchal complexity to produce truly creative innovations.

Paradigmatic Stage

At the Paradigmatic order, tasks require that one's actions create new fields out of multiple metasystems. Examples of new paradigms are described by Holton (1988) and by Kuhn (1970). The objects of paradigmatic acts are metasystems. When there are metasystems that are incomplete, and adding to them would create inconsistencies, quite often a new paradigm is developed. Usually, the paradigm develops out of a recognition of a poorly understood phenomenon.

Paradigmatic actions often affect fields of knowledge that appear unrelated to the original field of the thinkers. To coordinate the metasystems, people reasoning at the Paradigmatic order must see the relationship between very large and often disparate bodies of knowledge. Paradigmatic action requires a tremendous degree of decentration. One has to transcend tradition and recognize one's actions as distinct and possibly troubling to those in one's environment. But at the same time, one has to understand that the laws of nature operate both on oneself and on one's environment—a unity. This suggests that learning in one realm can be generalized to others. This capacity to abstract from one set of metasystems and generalize across disparate domains to conceive a new paradigm is one way to describe how decentration functions at the paradigmatic stage of performance.

example of a paradigmatic scientist is the physicist Clark Maxwell (1873). He created the paradigm of electromagnetic fields, the first time that electricity and magnetism were able to be conceived in a unified way. He built on the then-existing metasystems of electricity and magnetism of Faraday (2000), Ohm (1827), Volta (1999), Ampere (1826), and Ørsted (see Larsen, 1920 on Ørsted). His equations for fields and waves demonstrated the uniting of electrical and magnetic energy, a new paradigm.

Cross-Paradigmatic Stage

At the Cross-paradigmatic order, tasks require that one can operate on existing paradigms. Actions at the Cross-paradigmatic stage integrate paradigms into a new field or profoundly transform an old one. In this definition, a field contains more than one paradigm, irreducible to a single paradigm. One might ask whether all interdisciplinary studies are therefore cross-paradigmatic. Is psychobiology cross-paradigmatic? The answer is that neither is cross-paradigmatic. New paradigms, such as psychophysics, may be created out of such interdisciplinary studies, but they are not new fields as defined here. This fourth order of postformal thought has not had the benefit of much examination because so few people are able to perform tasks of this order of hierarchical complexity. It may also take a certain amount of time and perspective to realize that behavior or findings are cross-paradigmatic.

Copernicus (1992) coordinated geometry of ellipses that represented the geometric paradigm and the sun-centered perspectives. This coordination formed the new field of celestial mechanics, and led to what some call true empirical science with its mathematical exposition. That assisted Isaac Newton (1999) to coordinate mathematics and physics forming the new field of classic mathematical physics. The field was formed out of the new mathematical paradigm of the calculus (independent of Leibniz, 1768, 1875) and the paradigm of physics.

René Descartes (1954) created the paradigm of analysis and used it to coordinate the paradigms of geometry, proof theory, algebra, and teleology, resulting in the field of analytical geometry and analytic proofs. Charles Darwin (1855, 1877) coordinated geology, biology, and ecology to form the field of evolution, later paving the way for chaos theory, evolutionary biology, and evolutionary psychology. Albert Einstein (1950) gave rise to modern cosmology when he coordinated the paradigm of non-Euclidian geometry with the paradigms of classical physics to form the field of relativity. He co-invented quantum mechanics. Max Planck (1922) coordinated the paradigm of wave theory (notions of energy) with probability theory. He had to create a new probability theory, forming the field of quantum mechanics, which led to particle physics. Gödel (1977) coordinated epistemology and mathematics into the field of limits on knowing.

HIERARCHICAL COMPLEXITY AND TRAITS OF INNOVATORS

Highly innovative people occur with statistical rarity (Cook-Greuter and Miller, 2000). Such people have an unusual set of traits. *Traits* refers to tendencies that manifest in a stable fashion over time. They may be inherited or learned to varying degrees (Bouchard, Lykken, McGue, Segal, and Tellegen, 1990). Commons and Bresette (2006) reviewed and discussed traits that commonly appear in highly creative people who demonstrate postformal reasoning in their chosen scientific domain. To contribute additional interpretation to the traits, here we condense them in clusters to notate how such characteristics would likely show up in sustained fashion in task performances at different orders of hierarchical complexity.

Attention Deficit Disorder (ADD) (Cramond, 1995). The condition ADD may coexist with any stage of performance. Its characteristic of rapidly changing thought-content can result in making disparate connections that more methodical thought processes may take longer to develop. Its energetic thought may in some way either slow down or facilitate the tasks of decentering attention and associating complex "chunks" that must be coordinated at the Metasystematic, Paradigmatic, and Cross-paradigmatic stages.

High level of curiosity and attention to novelty. Children often demonstrate curiosity and notice new things as part of normal development. Outward signs of sustaining these traits likely begins only at Formal stage 10. The ability to make logical linear connections among variables can be stimulating and be its own attractor for pursuing more such thought, innovative strategies, and entrepreneurial enterprises. These tend to differ in *content matter* and *context,* yet are a common *kind* of creative contribution, because Formal stage 10 performances are prevalent in people who have had formal education. For Formal stage 10 task-performers to not rest on their laurels in the illusion of "having it all figured out" possibly requires the higher attentional energy of these traits. Curiosity about novel observations can lead to making Systematic stage 11 connections as one attempts to figure out new challenges. At the Systematic stage, investigating idiosyncrasies, outliers, and other exceptions can lead one to investigate beyond the boundaries of a familiar system, and into Metasystematic tasks. Task-performers at the Metasystematic stage 12 may apply their curiosity to casting broad nets to seek out information about the disparate systems related to the metaystem(s) they are developing. Likewise, Paradigmatic task-performers may do the same with respect to the metasystems they are coordinating toward a new synthesis, in addition to internally building the chunks that will fall into place. We speculate that Cross-paradigmatic tasks may require relatively more of the internal chunk-accumulating processes toward syntheses of existing paradigms than gathering external information about them.

Novelty in problem-solving. As discussed earlier, every task newly accomplished at any next stage of hierarchical complexity is novel to the one who performs the task. Thus, novelty is a context-dependent concept. When applied to scientific innovation, the scientific methods common to empiricism at Formal stage 10 would not constitute novelty in problem-solving because they operate on well-known abstract-stage variables. Systematic Stage 11 innovations may result in new schemes, but tasks at this stage do not generally work with enough systems of relations to generate novel findings. Genuine novelty becomes more likely at Metasystematic stage 12 and higher, because the problems tackled are increasingly complex and mostly previously undefined by others.

Persistence (Howe, 2001, 2004), ambition to solve problems, and tolerance of ambiguity. The capacity to tolerate ambiguity on a sustained basis first becomes possible at Systematic stage 11. This is because the Formal stage 10 preference for definitive bottom lines is superseded by discovering more complex multivariate relations that vary by context. Ambiguity is a necessary part of the creative process if for no other reason than it takes time for information and understandings to fall into place. Ambition to solve problems for their own sake, rather than for renown, becomes possible only at the Systematic stage 11, although it is more common at Metasystematic stage 12 and higher. This is attributable to the ability to invest time in working on complex problems that, if solved, have social or scientific utility. There is likely a connection between that utility and the characteristic persistence of innovators to realize their objectives.

Withstand social conformist influences (Roe, 1952), *field independence* (Minhas and Kaur, 1983), *internal locus of control* (Ross, 1977), *take risks, and be able to withstand rejection* (Smith, Carlsson, and Sandstrom, 1985). All of these traits reflect task performances first possible at Metasystematic stage 12. From the perspective of hierarchical complexity, these traits indicate one task. Generically, the task is to coordinate the following multiple systems: (a) the self; (b) social, cultural, and/or institutional norms; (c) others' perspectives; and (d) methodologies and boundaries characteristic of one's "home" field(s). As findings and circumstances shift over time, this metasystem may be reformulated and a new one coordinated to take into account such changes. This meta task would be, we expect, the necessary platform to produce a major scientific innovation.

This presentation indicates that most of the traits found in creative innovators require postformal thought. To find many of the personality characteristics (also see Shavinina and Ferrari, 2004) in one individual is considered rare, yet most may have to be present in genuine innovators. We suggest that these traits regularly underlie such persons' inventive endeavors, even when superficially a person may appear to be dedicating attention to other endeavors. They also may manifest in varying degrees of intensity at different times of life, different stages of developing innovations, and in response to different environmental circumstances. We stress that such traits should not be viewed as causes of behavior. They are better understood as intermediate results that happen to correlate with behavior. In so correlating, they thus risk being viewed, erroneously, as causal explanations (Commons and Bresette, 2006).

Instead, we posit that task performances at Metasystematic stage 12, Paradigmatic stage 13, and/or Cross-paradigmatic stage 14 are causal explanations for major scientific innovators' contributions. These require complexity in the area of the work as well as commensurate complexity in coordinating relevant social systems, including oneself. When these two dimensions work together, the likelihood of a major scientific innovation is enhanced.

CONCLUSION AND IMPLICATIONS FOR THE FUTURE

This article began and ended with discussions that explained the hierarchical complexity perspective on why major scientific innovators are rare. Between those bookends, science-oriented descriptions of the four postformal orders of hierarchical complexity were offered, accompanied by examples of significant innovators. Personality traits associated with highly creative people were analyzed in terms of the hierarchical complexity required for them to manifest in the enduring way that seems necessary to make innovations possible. It is evident that the results of creativity become much more important at the Paradigmatic and Cross-paradigmatic stages. New scientific paradigms change the world culture, our views of how the world works, and thus the course of civilization.

We turn now to reflection on implications for the future of both the need for, and scarcity of, major innovation in today's world. We write this at the beginning of a new era when the human species, for the first time in its history, recognizes that life as it has known it on any of the continents is unlikely to continue as before.

We have apparently exited the era of assuming that quality of life could only get better, and that "progress" would spread to and benefit all corners of the globe. Now is a time for re-framing what progress means, what stakes are involved, and how humanity will face its challenges. Scientific creativity will certainly have a role in this new era, although it is difficult to specify what those new contributions should or could be.

What must our societal institutions begin to do now to identify and actively support scientists who demonstrate the proclivities described here? How can they provide support and protect the thinning of the number of very high stage scientists by lower-stage peer review and other such mechanisms? It requires only Metasystematic stage 12 tasks to answer these questions and execute their implementation.

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