CHAPTER

15

The Connection between Postformal Thought, Stage Transition, Persistence, and Ambition and Major Scientific Innovations

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Abstract

We distinguish normal human creativity from the originative nature of genuine 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. Innovators' personality traits are scored, indicating 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, fractal, innovation, metasystematic, paradigmatic, personality traits, postformal, Spherical Standing Wave Structure of Matter in Space, systematic, scientific

The focus of this chapter 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 innovation. Creativity and innovation are common concepts, and demonstrations of them are claimed far and wide for many endeavors on a quite regular basis. The task we have set for this article is to discriminate truly *originative* work from other kinds of creativity. We invoke the Model of Hierarchical Complexity to explain this distinction.

In a general sense, creativity is quite common. It does not take much thought to realize that at each stage of performance, the new task successfully accomplished is creative and novel for the individual or group successfully completing the task. Creativity, 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. 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 *originative* work is qualitatively and quantitatively different. It involves understanding large "chunks" of current knowledge, building on such knowledge, making novel connections for purposeful reasons, 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/or simply not used. Such behavior indicates that the innovator has novel insights into complex challenges of some kind. Generally, it requires a new synthesis of systems (performed at the metasystematic order), of metasystems (performed at the paradigmatic order), or of paradigms (performed at the cross-paradigmatic order). These orders of hierarchical complexity are described below.

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 upon historically recognized innovations. These are more accessible, since major scientific accomplishments become public knowledge.

Major scientific innovations may significantly improve the quality of life in the societies that benefit from them, especially when they result in new technologies. 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 by 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 orders 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 originate major scientific innovations. A major and overriding reason for this is the very low number of people who develop stages of performance at the three most complex orders of hierarchical complexity cited above (Commons & Bresette, 2006; Torbert & Associates, 2004). 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 & Bresette, 2006). The first two factors are discussed further in Commons and Goodheart (2008). 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 complex "chunks" of understandings and received knowledge.

Once a discovery becomes widely known—fot example, that the Earth revolves around the sun—it also becomes commonplace. As a result, the original task difficulty of creating the knowledge is unknowable by any but those who went through the long process of creating it. The originative scientific creativity discussed here must be truly original action. In that sense it needs to be distinguished from much work in science, which involves 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. We argue, however, that there are several levels of difficulty. The first level of difficulty is that there is little or no preexisting 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 for this new behavior. The absence of support 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 & 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 & Richards, 2002).

The Model of Hierarchical Complexity and Postformal Stages

The Model of Hierarchical Complexity allows for the comparison of different behaviors and "performances" resulting from the completion of a large number of tasks, including the task of major scientific innovation. It does so by taking the actions and tasks in which humans engage and putting them into an order based upon how hierarchically complex they are. The order of hierarchical complexity of a task action is obtained by counting the number of coordinations that the action must perform on each lower-order action until one reaches a set of elementary-order actions. *Stage of performance* has the same name and number as the corresponding order of hierarchical complexity of the task it correctly completes.

The formal model shows why the postformal stages cannot be reduced to the formal stage. Formally, one task is more hierarchically complex than another task if it is defined in terms of two or more lower-order task actions. This is the same as a set being formed out of elements. This creates the hierarchy. The action in A, $A = \{a, b\}$, that is, a, b are "lower-order actions" than A and compose set A. But $A \neq \{A,\ldots\}$. A set cannot contain itself. The action A in question must organize lower-order task actions. This means that a higher-order action A cannot be reduced to any of the lower-order actions. In simplest terms, this is a relation on actions. The relations are order relations, $A = (a, b) = \{a, \{b\}\}$—an ordered pair, a coming first, b coming second. This organization is nonarbitrary. This means that there is a match between the model-designated orders and the real-world orders, not $P(a, b)$—not all permutations are allowed. Fifteen orders of hierarchical complexity have been proposed, as shown in Table 15.1. Only the four postformal orders will be described here, as they are the only ones relevant for the major scientific innovations being considered. There are about 100 studies using some version of the Model of Hierarchical Complexity.

Table 15.1 Orders and Stages

Order	Name of Order of Hierarchical Complexity
0	Calculatory
1	Sensory & Motor
2	Circular Sensory-motor
3	Sensory-motor
4	Nominal
5	Sentential
6	Preoperational
7	Primary
8	Concrete
9	Abstract
10	Formal
11	Systematic
12	Metasystematic
13	Paradigmatic
14	Cross-paradigmatic

Postformal Thought and Its Role in Innovation

The four postformal orders of hierarchical complexity are described below 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. New contemporary scientific work complements the historical examples. 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 Commons and Ross (2008), distinct capacities characterize actions, and thus behavior, at the postformal stages. 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 below 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 formal-order 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 ptioritization. These actions generate systems. Views of systems generated have a single "true" unifying structure. The "trueness" 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 two or more 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 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 stage, tasks require that one's actions create new fields out of multiple metasystems. Examples of new paradigms are described, fot example, by Holton (1973) 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 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 ftom 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.

One example of a paradigmatic scientist is the physicist Clark Maxwell (1873). He created the paradigm of electromagnetic fields, the first time that elecrricity and magnetism were able to be conceived in a unified way. He built upon the then-existing metasystems of electricity and magnetism of Faraday (2000), Ohm (1827), Volta (1800), Ampere (1926), and Ørsted (1820). 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 to both questions is no. 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 (1543/1992) 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 helped Isaac Newton (1687/1999) 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 (1637/1954) 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; Holton, 1995) gave rise to modern cosmology when he coordinated the paradigm of non-Euclidean geometry with the paradigm of classical physics to form the field of relativity. He co-invented quantum mechanics. Holton (1995) reports that Einstein had an insistence that the separate laws of physics could be brought together into one set that is true everywhere in the universe. Max Planck (1922) coordinated the paradigm of wave theory (physics of energy) notions from probability (mathematics), forming the field of quantum mechanics, which led to particle physics. Gödel (1931) coordinated epistemology and mathematics into the field of limits on knowing.

Explicating the Transition Step Sequence

Stages of hierarchical complexity explain how development and evolution appear at each specific order. A full and precise explanation of development, however, must be dynamic. One part of making the model more dynamic is a model of what the transition steps are between one stage and the next. The sequence of transition steps, which has the same form between any two orders, accounts for how the stages themselves come about. Recall that an action at a higher order of complexity coordinates two or more actions at the next lower order of complexity, and does so in a nonarbitrary way. This statement tells us only what lower-stage tasks had to be coordinated. It does not describe the specifics of how the lower-order actions would be selected and coordinated. This second part is described by the transition steps that exist in between one order and the next. These steps are shown in Figure 15.1.

Stage transition, as shown in this figure, is directly tied to the notion of order of hierarchical complexity. Stage transition is complete when the next-order task actions have been defined in terms of the lower-order task actions, and these higher-order tasks have organized the lower-order ones in a nonarbitrary way. Stage transition begins with the deconstruction of the equilibrium attained at the stage of performance. At first, this original lower-order action may be simply failure to obtain the expected outcomes and therefore become rejected. Other lower-order actions are tried in their place. For transition to take place, none of these alternative actions will be satisfying either. The next steps of stage transition

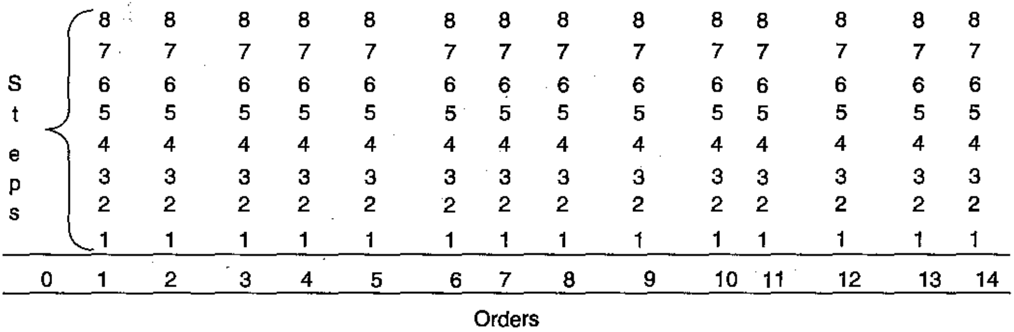


Fig. 15.1 The Ordinal Scales of Orders and Transition Steps. Copyright © 2007–2011 by Sara N. Ross. Reproduced with permission.

result from bringing the lower-order actions in closer and closer temporal proximity to one another until they are close enough to be organized. At first this organization may be arbitrary and not match the real world. That is, they do not address the original perceived failure that led to giving up the earlier strategy. What the organization should be then must be sorted out so that the organization is effective in the world.

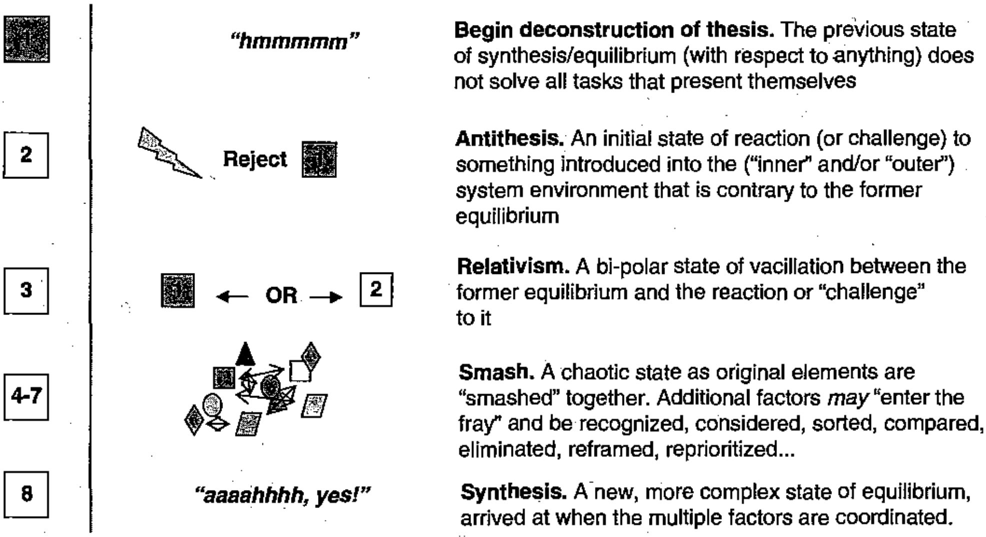
Just as the orders of hierarchical complexity fall on an ordinal scale, so also do the transition steps that individually compose the transition sequence. One way to visualize the relation of the transition step ordinal scale to the orders of hierarchical complexity is as follows: The orders of increasing hierarchical complexity fall on one ordinal scale (i.e., 0, 1, 2, 3, 4… 0.14). The transition steps that lead from one order to another fall on another ordinal scale, which runs from 1 through 8. Figure 15.1 represents the relation of the two ordinal scales, with the step sequence repeated and aligned vertically over the horizontally aligned orders. The unequal spacing in Figure 15.1 is a visual indicator of the ordinality of the scales. The ordinal nature means these are not like degrees of temperature that are on an equally spaced scale. Ordinal scales are simple counts of occurrences, in this case tasks.

The Fractal Nature of the Stages of Hierarchical Complexity

One major implication of this universal, self-similar pattern that shows up in all scales of tasks of any kind is, by definition, that the stages described by the Model of Hierarchical Complexity are fractal, as are the transition steps. That is, the same pattern repeats within each transition sequence; in more complex transition behaviors, fractals of the model's stage sequences also appear within transition sequences (Ross, 2008). A mathematical fractal is based on an equation that undergoes iteration, a form of feedback based on recursion (Briggs, 1992). In the case of hierarchical complexity, a higher-order action always results from the nonarbitrary organization of two or more lower-order actions. And transition always follows the same pattern of rejection of previous action, followed by alternation of behaviors, followed by arbitrary behavioral combinations, and finally by the nonarbitrary organization of behavior at the next higher order of complexity (Figures 15.2 and 15.3).

The following list is an abbreviated description of the eight ordinally scaled transition steps.

1. Reinforcement of thesis decreases
2. Antithesis: Negation or complementation
3. Relativism: Alternation of thesis and antithesis
4. Smash0: Synthesis begins
5. Random hits, false alarms, and misses, low correct rejections (Smash1)
6. More hits, low misses, and correct rejections, excess false alarms (Smash2)
7. Correct rejections and excess misses, low hits and false alarms (Smash3)
8. Synthesis and new thesis: new temporary equilibrium



Begin deconstruction of thesis. The previous state of synthesis/equilibrium (with respect to anything) does not solve all tasks that present themselves

Antithesis. An initial state of reaction (or challenge) to something introduced into the ("inner" and/or "outer") system environment that is contrary to the former equilibrium

Relativism. A bi-polar state of vacillation between the former equilibrium and the reaction or "challenge" to it

Smash. A chaotic state as original elements are "smashed" together. Additional factors *may* "enter the fray" and be recognized, considered, sorted, compared, eliminated, reframed, reprioritized...

Synthesis. A new, more complex state of equilibrium, arrived at when the multiple factors are coordinated.

Fig. 15.2. Anthropomorphized rendition of the transition step sequence. Copyright © 2006–2011 by Sara N. Ross. Reproduced with permission.

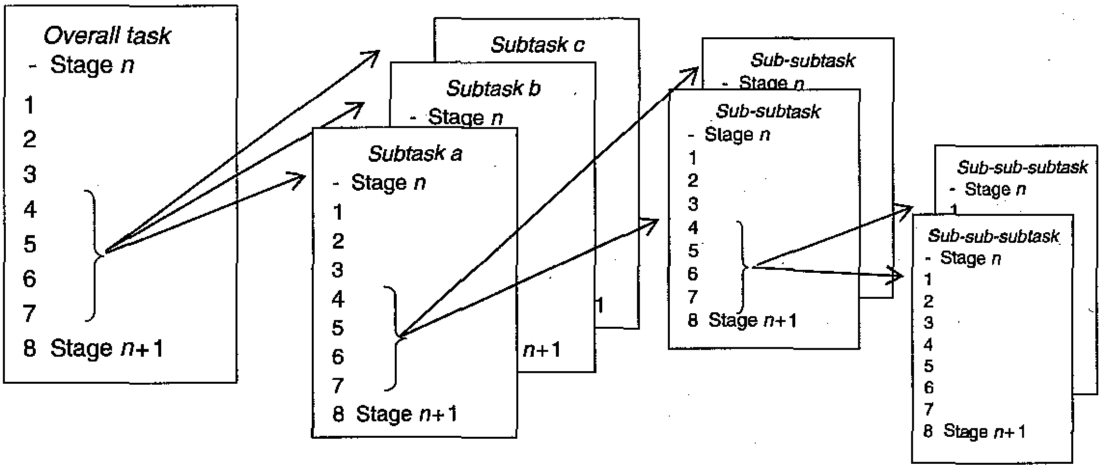


Fig. 15.3. Representation of the fractal nature of transition steps' subtasks. Copyright © 2007–2011 by Sara N. Ross. Reproduced with permission.

Understanding the fractal nature of the orders and of the transition step sequence between each order is important for theoretical, analytical, and practical reasons. This should, for example, make clear that originative action, like lower-order forms of creativity, has to arise in a way that is predictable. It is not due to inspiration or some mysterious process.

Whereas the stages of hierarchical complexity are the axiomatically defined, mathematically specified tasks, the empirically based (and not yet mathematically specified) transition step activity characterizes task-performing complex adaptive systems when they are not operating in a stage-based equilibrium. Humans, for example, spend much of their time in transitions at various scales of activity in their multiple domains of life.

What Drives Stage Transition

Although a description of stage transition is one important part of understanding the dynamics of how higher-stage performances develop, the explanation is still missing information about what might push people through the fractal steps. Each step in transition means that the person has to give up an old way of doing things. People do not like doing that. There may be benefits in the end, but there are also costs. For example, it could be frightening to try new things. In addition, during the transition period itself, individuals may be using strategies that do not always work, leading to lower rates of reinforcement and the resulting emotion of frustration. Note also that the tendency to try new things is something that will differ to some extent from individual to individual. The next few sections will first describe conditions that will make it more likely that people in general would give up current behaviors and move into transition (normative change conditions), and then will describe what would make it more likely that certain individuals in particular will move into transition (individual differences).

Selectionism

First, it is important to understand factors in the environment that lead to certain actions becoming more probable and others becoming less probable in people in general. These are called *normative change conditions*. The part of the behavioral sciences that looks at this is called *selectionism*. Selectionism proceeds at both the evolutionary level and at the individual level.

Selectionism at the individual level operates through learning. Learning can address problems of varying horizontal complexity or vertical hierarchical complexity (Commons & Ross, 2008). Learning that involves successfully addressing a more hierarchically complex task is called stage change. In Quantitative Analysis of Behavior, or modern learning theory, the rules of thumb and proto laws such as Herrnstein's (1970) matching law and Pavlov's (1928) law of conditioned reflexes have been shown to address a number of phenomena, including reflexes and tropisms (a turning movement toward a stimulus), fixed action patterns (a sequence of somewhat reflexive movements), sensitization (acting more sensitively to a stimulus), habituation (becoming used to a stimulus), conditioned reflexes, and operant conditioning (learning from consequences of behavior). Many of the simpler learning models, however, have not been seen as useful in explaining more complex behavior of humans and other species. We argue here and elsewhere (Commons & Richards, 2002) that integration of developmental theories and of learning theories are essential for a comprehensive theory to explain behavior. We therefore suggest here that some operant conditioning (Skinner, 1938) principles that are useful in addressing complex human behavior include melioration (the tendency to change in behavior when the consequences change), matching (responding so that the rate of behaving matches the rate of consequences), maximizing (Rachlin & Laibson, 1997), and behavioral momentum (Nevin, 1992, 1996; Nevin & Grace, 2000).

Of these, the notion of behavioral momentum may be particularly useful for understanding originative creative actions. In the metaphor that best captures the meaning of behavioral momentum, the rate of a behavior in the presence of a cue is analogous to the velocity of a moving body. Resistance to change measures an aspect of behavior that is analogous to the inertial mass of a body. An extension of the metaphor suggests that preference measures an analog to the gravitational mass of that body. The independent functions relating resistance to change and preference to the conditions of reinforcement may be construed as convergent measures of a single construct, analogous to physical mass. That represents the effects of a history of exposure to the signaled conditions of reinforcement. The notion of behavioral momentum unifies the traditionally separate notions of the strength of learning and the value of incentives. Research guided by the momentum metaphor encompasses the effects of reinforcement on response rate, resistance to change, and preference and has implications for clinical interventions, drug addiction, and self-control. It can be used to explain what is usually seen as a character trait—persistence. This will be discussed in the section on individual differences. In addition, its principles can be seen as a modern, quantitative version of Thorndike's (1911) Law of Effect, providing a new perspective on some of the challenges to his postulation of strengthening by reinforcement.

At different stages of development, we suggest that different kinds of reinforcement contingencies may be effective, a point only introduced here but not discussed in depth (for a more extensive discussion, see Commons & Hsieh, 2003). Briefly, to give one example, one can consider three different types of explanations of how value affects behavior. The most traditional theory, rational expectation theory (Muth, 1961), predicts that utility will be maximized. Such theories predict that a choice with the highest expected utility (Bernoulli, 1738; von Neumann & Morgenstern, 1944), which is measured by multiplying rate or probability of reinforcement times the value, is always chosen. This kind of calculation of value is operative at systematic stage 11 because it is multivariate. Such a multivariate calculation can be proposed by certain theorists, but it is not always clear that animals or humans use this kind of heuristic in their everyday problem solving. Another explanation of how value is related to behavior, the matching law states that organisms allocate their choices in a proportion that matches the relative reinforcement obtained on these choices (Herrnstein, 1961; Rachlin & Laibson, 1997; Williams, 1988). The matching law has been shown to be valid in a variety of task paradigms and across species (e.g., pigeons, rats, monkeys, humans) (Anderson, Velkey, & Woolverton, 2002; de Villiers & Herrnstein, 1976; Gallistel, 1994; Williams, 1988). This suggests that this model applies across a range of stages starting as soon as operant conditioning appears at stage 2, circular sensory-motor. Even so, it is a relatively static model, and because it looks for an overall rate of reinforcement, for example, across a session, it does not always explain behavior. A third model, called the melioration model (Vaughan, 1976, 1981) suggests that matching in concurrent schedules occurs because the subjects equalize the local reinforcement rates (reinforcers received for each alternative divided by the time allocated to each alternative). This is operative from circular sensory-motor stage 2 on. Some of these ideas will be further developed in the discussion of individual differences or traits that follows.

Hierarchical Complexity and Traits of Innovators: An Individual Differences Account

Highly innovative people occur with statistical rarity (Cook-Greuter & Miller, 2000). There are a number of reasons for this. One is that, as we have argued above, truly innovative work requires solving problems of postformal orders of hierarchical complexity. A second reason that is at least equally important is that such people have an unusual set of traits. "Traits" refer to behavioral tendencies that manifest in a stable fashion over time. They may be inherited or learned to varying degrees (Bouchard, Lykken, McGue, Segal, & Tellegen, 1990). The traits that innovative scientists have are very important because such scientists must move through transition and reach a new synthesis of postformal concepts. They may say they aim to a) discover an answer to a problem they are motivated to solve; b) identify a final yet-missing chunk of an analysis that is important to complete; or c) acquire a new understanding to an open question they have been curious about, for which existing answers leave out elements they know must be coordinated. The reason it can take a long time to form a synthesis at the next stage is that the elements that need to be successfully coordinated if synthesis is to be accomplished are already complexly constructed elements, such as metasystems and supersystems of metasystems (paradigms). A "supersystem of metasystems" may be defined as the multiple metasystems coordinated to a certain point within a transition, prior to arriving at a paradigmatic synthesis. Colloquially, in order to "plan" to tackle such difficult problems, we would say that such scientists have a high degree of ambition. In order to continue to work on such problems in the face of difficulty and for long periods of time, we might say that such scientists exhibit persistence, or openness to challenge. Below, we lay out a more systematic account of what ambition and persistence might consist of.

Commons & Bresette (2006) previously discussed traits that commonly appear in highly creative people who demonstrate postformal reasoning in their chosen scientific domain. Here, we elaborate on that account in several ways. First, we present a model that interrelates some of the traits and also explains, in terms of modern learning theories, how they might influence behavior. Second, we relate the traits more explicitly to the orders of hierarchical complexity.

A Model of Scientific Ambition and Persistence

One way to look at what differentiates major innovators in science from others is to look at what controls their choices. As stated above, such scientists make the choice to begin pursuing difficult problems (ambition) and also persist at working at them in the face of obstacles. Commons-Miller et al. (2010) proposed a model for choice that includes three variables, and their associated parameters, emphasized here. The first variable is reinforcement; its associated parameter is sensitivity to reinforcement. The second variable is delay, along with its associated parameter, sensitivity to delay, and finally, there is risk and sensitivity to risk (i.e., change in delay). This model will be used here to explain ambition.

Reinforcement and Sensitivity to Reinforcement

Consider that reinforcement is a single accession from a long sequence of reinforcements. There is a possibility that all reinforcers satiate. Food, water, tastes do. Does money do so? Gates, Buffett, and others seem to behave as if they think so.

A_m = the total value of all the reinforcers delivered until total satiation has occurred.

Each instance of a reinforcer, *m*, occurs in what may be a very long sequence of events. For creative scientists, it may be an event every few years.

ΔA_m = the change in overall value of reinforcers delivered with no delay when the position in a sequence of reinforcers is ignored until satiation occurs. In equation 1, this is the perceived reinforcing value of event *m*.

$$A_m = \Sigma \Delta A_m \qquad (1)$$

The term *diminishing returns* is the way economists talk about the fact that the value of reinforcement decreases as the number of delivered reinforcers increases. Each time a reinforcer is delivered as *m* increases, it reduces the value of ΔA_m by a discrete amount. Mathematically this is:

m = the m^{th} delivered reinforcer in a sequence of reinforcing events.

$\Delta A_1, > \Delta A_2, > \Delta A_3 \ldots\ldots > 0$

The total value, A_m, is the total value of all the reinforcers delivered with no delay until total satiation has occurred and ΔA_i decreases in value to 0.

The strength of ΔA_m not only varies with where in a sequence of reinforcing events it occurs, but on a number of other factors: The animal under consideration, its preferences for food, water, mates, prey, companions, tastes, etc. In humans, ΔA_i also varies with personal interests, culture and genes.

The index, *i*, refers to what event is serving as a reinforcer, i.e., food, water, scientific accomplishment. The parameter, ΔA_i, should reflect the factor loadings on the Holland scale (Holland, 1985; Holland & Gottfredson, 1992), with investigative (or *I*) being the one to predict scientific and mathematical interest the most. This means that outcomes in the areas related to *I* are the most reinforcing for those with high interest in *I*. For example, the search for answers to scientific questions is extremely reinforcing and would be an important factor in the behavior we call ambition.

There are a number of factors that are probably related to high interest in investigative pursuits:

1. High investigative interest may be heritable to some degree.
2. Cultural values for answering questions as opposed to acquiring existing knowledge—Discovering is an active process. One difference between scholar and innovative researcher is that discovering is more active. Some cultures may make being active and asking questions extremely reinforcing, while others may make taking direction and following authority more reinforcing.
3. Identification with certain models over others can strengthen the A_i of *I—Investigative*. Who does one see oneself as like? Reading about people is an early and important source of models with which to identify. People can use such models to form ambition and get a mission.

Delay and Sensitivity to Delay

The effect of delay on reinforcement value as reflected in performance was modeled early on by Chung and Herrnstein (1967) and Fantino, Abarca and Dunn (1987):

The value of a reinforcement instance, ΔA_i, with respect to changes in the time from the instance of the reinforcer to the choice, Δt_i. Now if the ratio of the differences, value, ΔA_i with respect to time, Δd_i, is taken, one gets the Commons/Mazur additive noise model (Commons, Woodford & Duchney, 1982; Mazur, 1987) shown immediately below. This is a slightly revised version of Commons/Mazur, V is replaced by ΔV because A_i has been replaced by ΔA_i in equation 2.

$$\Delta V = \Delta A_i / (1 + k_1 d) = \text{Discounted value of a reinforcer } i \qquad (2)$$

$d = \Delta t - 1$ delay equals change in time minus 1.

$\Delta t =$ Change in time. Note that for $t = 1$, reinforcement is not delayed i.e., $d = 0$.

$j =$ is an index of which difference equation it is. $j = 1$ value; $j = 2$ is delay, $j = 3$ is risk

$k_2 =$ is for sensitivity to delay

Consider the case of $\Delta A_i /(1+ k_2 d)$ with $d = 0$, no delay

This makes $1+ k_2 d = 1$, then $\Delta V_i = \Delta A_i$

In contrast, taking the long view, means being relatively insensitive to delay. It should be reflected in a small value for k_2, the delay parameter. To successfully address high order of complexity scientific tasks, one has to have long-term goals that allow for a large delay of reinforcement. Most discoveries take multiple years to achieve.

There are a number of possible factors explaining why certain people can delay immediate reinforcement and others cannot.

1. Developmental: Children are not good at delaying.
2. Cultural: Most very innovative scientific projects take a long time. Different cultures may differ in the extent to which they value patience.
3. Social class: This may be seen, for example, in people who go to college instead of going straight to work. They delay their earnings and engender debt but end up making more in the long run.

Risk and Sensitivity to Change in Delay

Major innovative scientists should also be somewhat insensitive to risk, making it possible to attack very difficult problems that no one else is doing and other problems that no one else even sees. Here risk is represented by how sensitive an individual is to a change in delay, usually increases in delay. This is the quantification of Vaughan's (1976, 1981; Herrnstein & Vaughan, 1980) melioration concept (also see Herrnstein & Prelec, 1991). This is represented by taking the differences with respect to changes in time in the ***second*** difference equation, Commons/Mazur equation 2:

This would be

$$\Delta(\Delta A_i / \Delta d)\Delta d = \Delta(\Delta A_i / (1 + k_3 d))/\Delta d \qquad (3)$$

$k_3 =$ is sensitivity to risk, the change in value with respect to change in delay.

Openness to Challenge

There are two other characteristics of highly innovative scientists that can be related to this overall model. One is openness to challenge. Those who are more open to challenge perceive a higher overall value to successfully addressing difficult problems, everything else being equal, than those who are less open to it. In social or personality psychology, this is often referred to as optimism.

Persistence and Behavioral Momentum

Another important characteristic of innovative scientists who do achieve things is persistence. Persistence has been defined as the ambition to solve problems, and tolerance of ambiguity (Howe, 2001, 2004). Here, persistence is related to the overall model because it results from a combination of tolerance for delay and tolerance for changes in delay. In other words, even in the face of a task that starts out taking a very long time, and that probably gets longer as one works on it, some individuals continue to work on the task.

A recent model that explains behavior of this kind is Nevin's (1992) model of behavioral momentum, which was previously mentioned. Behavioral momentum should be caused by lots of free reinforcement. This makes one resistant to extinction. For example, scientists who receive big unrestricted grants or are independently wealthy should be more creative and persistent. Scientists with nothing should also be more creative because they have nothing to lose. Scientists who have a lot of free time will also show more persistence since the delays will appear relatively less important to them than to others who have very limited time.

The capacity to tolerate ambiguity on a sustained basis first becomes possible at systematic stage 11. This goes beyond what Nevin has found with pigeons with behavioral momentum. The ambiguity is of a different order of hierarchical complexity and addresses abstract relationships found in systems. 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 over 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.

Additional Traits That May Influence Originative Creativity

Another additional factor in originative creativity may be decentration. This can mean not only being able and willing to move away from one's own point of view but, more broadly, to be able to switch easily between multiple perspectives on an issue. As a result, when doing the work, it is less about oneself and more about the process and the discovery. In order to carry out this kind of work, one has to be able to visualize more than three dimensions. After three dimensions, one runs out of simple representational space in the brain. One has to think in n-space. One can imagine more axes at right angles. This may require a larger occipital lobe than normal, just in back of the central sulcus, and possibly a large forward part of forebrain. Ability to imagine things that do not exist in one's senses is very necessary. For example, Copernicus looked at the data differently than Ptolemy (2000) did, Ptolemy had preconception based on church dogma. Also, Holton (1995) reports that Einstein had a great ability to visualize interactions in nature, which he used in his characteristic "thought experiments." Einstein was neither the first nor the last scientist to use these free, useful experiments, but he had unequaled ability to interpret them.

Attention Deficit Hyperactivity Disorder (ADHD) (Cramond, 1995) may contribute in some instances to originative creativity, even though the condition may coexist with any stage of performance. Its characteristic of rapidly changing thought content and use of less content-bound analogies that can result in making disparate connections that more methodical thought processes may take longer to develop. Its energetic thought may also in some way either slow down or facilitate the tasks of decentering attention. It may also raise the rate of associating complex chunks of information that must be coordinated at the metasystematic, paradigmatic, and cross-paradigmatic stages.

Another behavior also sometimes associated with ADHD is a relative independence from feedback from others. The contribution that this can make to originative creativity is clear. All too often, the most innovative scientists are going against, or at least beyond, existing ways of explaining things.

A third additional factor that seems important is a 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 begin only at formal stage 10. The ability to make logical linear connections among variables can be stimulating and can 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 curiosity and particular attention to novelty. Curiosity about novel observations can lead to making systematic stage 11 connections as one attempts to figure new challenges out. 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 metasystem(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.

Recognizing and promoting novelty in problem solving is a fourth trait. As discussed earlier, every task newly accomplished with any content at any next order 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.

Finally, a number of other characteristics, including withstanding social conformist influences (Roe, 1952), field independence (Minhas & Kaur, 1983), internal locus of control (Ross, 1977), taking risks, and being able to withstand rejection (Smith, Carlsson, & Sandstrom, 1985), have also been related to highly originative creativity. 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 fields. 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 chapter indicates that most of the traits found in creative innovators require postformal thought. To find many of the personality characteristics (also see Shavinina & 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 & 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 innovation 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 reframing what progress means, what stakes are involved, and how humanity will face its challenges. Scientific innovation will certainly have a role in this new era, though it is difficult for us to imagine 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 capacities described here, without keeping the ranks of the supported grievously low by thinning them with competition? It requires only metasystematic stage 12 tasks to answer that question and execute its implementation.

References

Ampère, A. (1826). *Memoir on the mathematical theory of electrodynamic phenomena, uniquely deduced from experience.* France.

Anderson, K. G., Velkey, A., & Woolverton, W. L. (2002). The generalized matching law as a predictor of choice between cocaine and food in rhesus monkeys. *Psychopharmacology, 163*, 319–326.

Bernoulli, D. (1954, January1738). Exposition of a new theory on the measurement of risk (Dr. Louise Sommer, Trans.). *Econometrica, 22*(1), 22–36. DOI: 10.2307/1909829.

Bouchard, T., Lykken, D., McGue, M., Segal, N, & Tellegen, A. (1990). Sources of human psychological differences: The Minnesota study of twins reared apart. *Science, 250*(4978), 223–226.

Briggs, J. (1992). *Fractals: The patterns of chaos* (p. 148). London: Thames and Hudson.

Chung, S. H., & Herrnstein, R. J. (1967). Choice and delay of reinforcement. *Journal of the Experimental Analysis of Behavior, 10*(1), 67–74.

Commons, M. L. (1973). *Decision rules and isosensitivity curves for the discrimination of reinforcement density using a choice procedure.* New York, NY: Department of Psychology, Faculty of Pure Science, Columbia University.

Commons, M. L. (1978). *How time between reinforcement opportunities in reinforcement schedule samples affects their discriminability and perceived value.* Paper presented at the First Harvard Symposium on Quantitative Analyses of Behavior: Schedules as Discriminative Stimuli, Harvard University, Cambridge.

Commons, M. L. (1979). Decision rules and signal detectability in a reinforcement density discrimination. *Journal of the Experimental Analysis of Behavior, 32*, 67–74.

Commons, M. L. (1981). How reinforcement density is discriminated and scaled. In M. L. Commons & J. A. Nevin (Eds.), *Quantitative analyses of behavior: Vol. 1. Discriminative properties of reinforcement schedules* (pp. 51–85). Cambridge, MA: Ballinger.

Commons, M. L., & Bresette, L. M. (2006). Illuminating major creative scientific innovators with postformal stages. In C. Hoare (Ed.), *The handbook of adult development and learning* (pp. 255–280). New York: Oxford University Press.

Commons, M. L., & Ducheny, J. R. (1979, June). *The relationship between perceived density of reinforcement in a schedule sample and its reinforcement value.* Paper presented at the Second Harvard Symposium on Quantitative Analyses of Behavior: Matching and Maximizing Accounts, Harvard University, Cambridge.

Commons, M. L., & Goodheart, E. A. (2008). Cultural progress is the result of developmental level of support. *World Futures, 64*, 406–415.

Commons, M. L., & Hsieh, M. T. (2003, May). *A quantitative behavioral developmental analysis of reinforcement contingency efficacy.* Paper presented at the Society for Quantitative Analysis of Behavior, 25th Annual Symposium, San Francisco, California.

Commons, M. L., & Richards, F. A. (1995). Behavior analytic approach to dialectics of stage performance and stage change. *Behavioral Development, 5*(2), 7–9.

Commons, M. L., & Richards, F. A. (2002). Organizing components into combinations: How stage transition works. *Journal of Adult Development, 9*(3), 159–177.

Commons, M. L., & Ross, S. N. (2008). What postformal thought is, and why it matters. *World Futures: Journal of General Evolution, 65*(1–3), 321–329.

Commons, M. L., Woodford, M., & Ducheny, J. R. (1982). The relationship between perceived density of reinforcement in a schedule sample and its reinforcing value. In M. L. Commons, R. J. Herrnstein & H. Rachlin (Eds.), *Quantitative analyses of behavior: Vol. 2. Matching and maximizing accounts* (pp. 25–78). Cambridge, MA: Ballinger. 1979, Harvard.

Commons, M. L., Woodford, M., & Trudeau, E. J. (1991). How each reinforcer contributes to value: "Noise" must reduce reinforcer value hyperbolically. In M. L. Commons, M. C. Davison, & J. A. Nevin (Eds.), *Signal detection: Vol. 11. Quantitative analyses of behavior* (pp. 139–168). Hillsdale, NJ: Lawrence Erlbaum Associates. 1987, Harvard.

Commons-Miller, N. K., Commons, M. L., Francis Gane-McCalla, R., Pekker, A., & Woodford, M. (2010, March). Understanding value and time in static and changing schedules of reinforcement. Paper presented at the International Conference on Comparative Cognition, Melbourne, FL.

Cook-Greuter, S. R., & Miller, M. E. (2000). Introduction: Creativity in adulthood: Personal maturity and openness to extraordinary sources of inspiration. In M. E. Miller & S. R. Cook-Greuter (Eds.), *Creativity, spirituality, and transcendence: Paths to integrity and wisdom in the mature self* (pp. xv–xxxiv). Stamford, CT: Ablex.

Copernicus, N. (1992/1543). *De revolutionibus orbium coelestium* [On the revolutions of the heavenly spheres] (Edward Rosen, Trans. and Commentary). Baltimore, MD: Johns Hopkins University Press.

Cramond, B. (1995). *The coincidence of attention deficit hyperactivity disorder and creativity* (RBDM 9508). Storrs, CT: The National Research Center on the Gifted and Talented, University of Connecticut.

Darwin, C. (1855). *On the origin of the species.* London: Murray.

Darwin, C. (1877). A biographical sketch of an infant. *Mind, 2*, 285–294.

de Villiers, P. A., & Herrnstein, R. J. (1976). Toward a law of response strength. *Psychological Bulletin, 83*, 1131–1153.

Descartes, R. (1637/1954). *The geometry of Rene Descartes: with a facsimile of the first edition* (D. E. Smith & M. L. Latham, Trans.). New York, NY: Dover Publications.

Dunn, R., & Fantino, E. (1982). Choice and the relative immediacy of reinforcement. *Journal of the Experimental Analysis of Behavior, 38*(3), 321–326.

Einstein, A. (1950). *The meaning of relativity.* Princeton, New Jersey: Princeton University Press.

Fantino, E. J., Abarca, N., & Dunn, R. M. (1987). The delay-reduction hypothesis: Extensions to foraging and three-alternative choice. In M. L. Commons, J. E. Mazur, J. A. Nevin, & H. Rachlin (Eds.), *Quantitative analyses of behavior: Vol. 5. The effect of delay and of intervening events on reinforcement value* (pp. 309–328). Hillsdale, NJ: Lawrence Erlbaum Associates.

Faraday, M. (2000/1839, 1844, 1855). *Experimental researches in electricity (3 Volumes).* Santa Fe: Green Lion Press.

Gallistel C. R. (1994). Foraging for brain stimulation: Toward a neurobiology of computation. *Cognition, 50,* 151–170.

Gödel, K. (1931/1977). Some metamathematical results on completeness and consistency; On formal undefinable propositions of Principal Mathematica and related systems I; On completeness and consistency. In J. Heijehoort (Ed.), *From Frege to Gödel: A source book in mathematical logic 1879–1931* (pp. 592-617). Cambridge: Harvard University Press. (Original works published 1930, 1931, 1931, respectively.)

Grace, R. C., & McLean, A. P. (In press). Integrated versus segregated accounting and the magnitude effect in temporal discounting. *Psychonomic Bulletin and Review.*

Herrnstein, R. (1982). Melioration as behavioral dynamism. In M. L. Commons, R. J. Herrnstein, & H. Rachlin (Eds.), *Quantitative analyses of behavior: Vol 2. Matching and maximizing accounts* (pp. 433–458). Cambridge, MA: Ballinger Publishing Co.

Herrnstein, R. J., & Prelec, D. (1991). Melioration: A theory of distributed choice. *The Journal of Economic Perspectives, 5*(3), 137–156.

Herrnstein, R. J. (1961). Relative and absolute strength of response as a function of frequency of reinforcement. *Journal of the Experimental Analysis of Behavior, 4,* 267–272.

Herrnstein, R. J. (1970). On the law of effect. *Journal of the Experimental Analysis of Behavior, 13,* 243–266.

Herrnstein, R. J., & Vaughan, W., Jr. (1980). Melioration and behavioral allocation. In J. E. R. Staddon (Ed.), *Limits to action* (pp. 143–176). New York: Academic Press.

Holland, J. L, & Gottfredson, G. D. (1992). Studies of the hexagonal model: An evaluation (or, the perils of stalking the perfect hexagon). *Journal of Vocational Behavior 40*(2), 158–170.

Holland, J. L. (1985). *Making vocational choices: A theory of vocational personalities and work environments.* Englewood Cliffs, NJ: Prentice Hall.

Holton, G. (1973, 1988). *Thematic origins of scientific thought: Kepler to Einstein.* Cambridge, MA: Harvard University Press.

Holton, G. (1995*). Einstein, history and other passions.* Reading MA: Addison-Wesley.

Howe, M. J. A. (2001). *Genius explained.* Cambridge, Great Britain: Cambridge University Press.

Howe, M. J. A. (2004). Some insights of geniuses into the cause of exceptional achievement. In L. V. Shavinina & M. Ferrari (Eds.), *Beyond knowledge: Extracognitive aspects of developing high ability* (pp. 105-118). Mahwah, NJ: Lawrence Erlbaum Associates.

Jaques, E., and Cason, K. 1994. *Human capability: A study of individual potential and its application.* Falls Church, VA: Cason Hall and Co., Publishers.

Kuhn, T. S. (1970). *The structure of scientific revolutions.* Chicago: University of Chicago Press.

Leibniz, G. W. (1768). *Opera Omnia.* L. Deutens (Ed.). Geneva: Deutens.

Leibniz, G. W. (1875). *Die Philosophische Schriften.* Berlin: Gerhardt.

Maxwell, J. C. (1873). *A treatise on electricity and magnetism.* Oxford: Clarendon Press.

Mazur, J. E. (1981). Optimization theory fails to predict performance of pigeons in a two-response situation. *Science, 13,* 823–825.

Mazur, J. E. (1984). Tests of an equivalence rule for fixed and variable reinforcer delays. *Journal of Experimental Psychology: Animal Behavior Processes, 10,* 426–436.

Mazur, J. E. (1987). An adjusting procedure for studying delayed reinforcement. In M. L. Commons, J. E. Mazur, J. A Nevin, & H. Rachlin, H. (Eds.), *Quantitative analyses of behavior: Vol. 5. Effect of delay and intervening events on value* (pp. 55–73). Hillsdale, NJ: Lawrence Erlbaum Associates.

Mazur, J. E. (2001). Hyperbolic value addition and general models of animal choice. *Psychological Review, 108,* 96–112.

McCarthy, D. C., & White, K. G. (1987). Behavioral models of delayed detection and their application to the study of memory. In M. L. Commons, J. E. Mazur, J. A Nevin, & H. Rachlin, H. (Eds.), *Quantitative analyses of behavior: Vol. 5. The effect of delay and of intervening events on reinforcement value* (pp. 29–34). Hillsdale, NJ: Lawrence Erlbaum Associates.

Minhas, L. S., & Kaur, F. (1983). A study of field dependent/independent cognitive styles in relation to novelty and meaning contexts of creativity. *Personality Study and Group Behavior, 3*(1), 20–34.

Muth, J. F. (1961) Rational expectations and the theory of price movements. In *The new classical macroeconomics* (Volume 1, 1992, pp. 3–23). International Library of Critical Writings in Economics, vol. 19. Aldershot, UK: Elgar.

Myerson, J., & Green, L. (1995). Discounting of delayed rewards: Models of individual choice. *Journal of the Experimental Analysis of Behavior, 64,* 263–276.

Nevin, J. A. (1992). An integrative model for the study of behavioral momentum. *Journal of the Experimental Analysis of Behavior, 57,* 301–316.

Nevin, J. A. (1996). The momentum of compliance. *Journal of Applied Behavior Analysis, 29,* 535–547.

Nevin, J. A., & Grace, R. C. (2000). Behavioral momentum and the Law of Effect. *Behavioral and Brain Sciences, 23,* 73–130.

Newton, I. (1687/1999). The Principia: Mathematical principles of natural philosophy. I. Bernard Cohen and Anne Whitman (Eds.), assisted by Julia Budenz (Trans.). Berkeley: University of California Press.

Ohm, G. S. (1827). *Die galvanische Kette, mathematisch bearbeitet* von Dr. G. S. Ohm. Mit einem Figurenblatte. Berlin: Bei T.H. Riemann.

Ørsted, H. C. (1820). *The discovery of electromagnetism, made in the year 1820 by H. C. Ørsted.* Copenhagen: Published for the Oersted Committee at the expense of the State by Absalon Larsen, 1920 (Copenhagen: H.H. Thieles bogtrykkeri).

Pavlov, I. P. (1928). *Lectures on conditioned reflexes.* New York: Liveright Publishing Corp.

Pear, J. J., Rector, B. L., & Legris, A. (1982). Towards analyzing the continuity of behavior. In M. L. Commons, R. J. Herrnstein, & H. Rachlin (Eds.), *Quantitative analyses of* *behavior: Vol. 2. Matching and maximizing accounts* (pp. 3–24). Cambridge, MA: Ballinger.

Planck, M. (1922). *The origin and development of the quantum theory* (H. T. Clarke and L. Silberstein, Tran.). Nobel Prize address delivered before the Royal Swedish Academy of Sciences at Stockholm, 2 June, 1920. Oxford: Clarendon Press.

Ptolemy (2000). *Harmonics* (Jon Solomon, Trans. and Commentary). Mnemosyne, Bibliotheca Classica Batava, Supplementum, 0169–8958, 203. Leiden and Boston: Brill Publishers.

Rachlin, H., & Laibson, D. I. (Eds.) (1997). *The matching law: Papers in psychology and economics.* Cambridge, MA: Harvard University Press.

Rachlin, H. (2006). Notes on discounting. *Journal of the Experimental Analysis of Behavior, 85,* 425–435.

Raiffa, H. (1968). *Decision analysis: Introductory lectures on choices under uncertainty.* Reading, MA: Addison-Wesley.

Raiffa, H., & Schlaifer, R. O. (1961). *Applied statistical decision theory.* Boston: Division of Research, The Harvard Business School.

Roe, A. (1952). *The making of a scientist.* New York: Dodd Mead.Ross, B. L. (1977). *Interrelationships of five cognitive constructs: Moral development, locus of control, creativity, field independence, and intelligence in a sample of 167 community college students.* Unpublished Dissertation, University of Southern California.

Ross, S. N. (2008). Fractal transition steps to fractal stages: The dynamics of evolution II. *World Futures: The Journal of General Evolution,* 64(5–7), 361–374.

Schoenfeld, W. N., & Cole, B. K. (1972). *Stimulus schedules.* New York: Harper & Row.

Schoenfeld, W. N., & Cumming, W. W. (1960). Studies in a temporal classification of reinforcement schedules: Summary and projection. *Proceedings of the National Academy of Sciences USA 46*(5), 753–758.

Shavinina, L. V., & Ferrari, M. (2004). *Beyond knowledge: Extracognitive aspects of developing high ability.* Mahwah, NJ: Lawrence Erlbaum Associates.

Skinner, B. F. (1938). *The behavior of organisms: An experimental analysis.* New York: Appleton-Century-Crofts.

Smith, G. J., Carlsson, I., & Sandstrom, S. (1985). Artists and artistic creativity elucidated by psychological experiments. *Psychological Research Bulletin, 25,* 9–10.

Stubbs, D. A., Pliskoff, S. S., & Reid, H. M. (1977). Concurrent schedules: A quantitative relation between changeover behavior and its consequences. *Journal of the Experimental Analysis of Behavior, 27,* 85–96.

Thorndike, E. L. (1911). *Animal intelligence.* New York: Macmillan.

Torbert, B., & Associates. (2004). *Action inquiry: The secret of timely and transforming leadership.* San Francisco: Berrett-Koehler.

Vaughan, W., Jr. (1976). *Optimization and reinforcement.* Unpublished doctoral thesis, Harvard University.

Vaughan, W., Jr. (1981). Melioration, matching, and maximization. *Journal of the Experimental Analysis of Behavior, 36*(2), 141–149.

Volta, A. G. A. A. (1800/1999). *On the electricity excited by the mere contact of conducting substances of different kinds.* London: Royal Society Philosophical Magazine. Bicentenary ed. in French, English, German, and Italian of letter to Sir Joseph Banks of the 20th of March 1800.

von Neumann, J., & Morgenstern, O. (1944). *Theory of games and economic behavior.* Princeton, NJ. Princeton University Press.

Williams, B. A. (1988). Reinforcement, choice, and response strength. In R. C. Atkinson, R. J. Herrnstein, G. Lindzey, & R. D. Luce (Eds.), *Stevens' handbook of experimental psychology* (2nd ed., pp. 167–244). New York: Wiley.