Chapter 12

Illuminating Major Creative Scientific Innovators with Postformal Stages

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The development and improvement of a society and its culture depend on major scientific innovations. Societies with higher rates of major innovation generally provide better quality of life in terms of scientific, technological, and socioeconomic progress. It follows that societies with the largest number of innovations tend to dominate the world's economic scene. For example, in 1998, the 29 OECD (Organisation for Economic Co-operation and Development) countries with only 19% of the world's population spent \$520 billion on research and development and acquired 91% of all patents (Brauer, 2001). The OECD is a group with 30 member countries (Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Korea, Luxembourg, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Spain, Sweden, Switzerland, Turkey, United Kingdom, United States) sharing a commitment to democratic government and the market economy. Of the OECD countries, 21 are listed as high income and 5 are listed as high middle income. But even within these countries, there are only a small number of people who originate innovations.

This chapter offers five major reasons for the shortage of scientific innovators. First, there is a general scarcity in the learning and development of the higher order–complex thinking and action that is required to identify phenomena and create and integrate paradigms. We argue that such higher order thinking and acting are necessary for scientific innovation to take place. Second, cultural conditions do not appropriately support innovation. This makes it unlikely that the relevant learning necessary for developing higher order thinking will take place. Third, the requisite aspects of personality are relatively rare. Fourth, generally education and learning about highly complex material is insufficient. Fifth, there are biological limitations as to the number of people who can easily learn and then engage in higher order–complex thinking. We consider each of these factors in this chapter together with a discussion on the ways current cultural conditions hinder the creative process, thereby limiting genuine scientific contributions.

CREATIVE AND INNOVATIVE SCIENTIFIC CULTURAL CONTRIBUTIONS

From the multiple kinds of adult innovations that could be discussed, this chapter will focus on relatively rare scientific ones that were historically among the most important. Often, in fact, discussions of the basis for creativity focus on artistic, literary, or musical creativity (Funk, 1989). Or they focus on the usual creative output of very good scientists (Simonton, 1984, 1997). Because it is conceivable that creative production in different domains may be different, this chapter focuses only on scientific creativity and only on some of the most major scientific accomplishments. Later work may seek to generalize from this initial basis.

Minimally, scientific creativity must be original action. This is not trivial because most of what people do repeats what has already been done or varies it slightly. Our sense is that there is confusion between these ordinary high-quality contributions and the extremely rare exceptional contributions. We argue that these types of behaviors may have different origins and therefore different explanations. Among scientific accomplishments, the methods, theories, and techniques do not have to be original. We focus on the manner in which they have been used. It is also important to recognize that such creative acts become (or have become) social memes of long standing. In a metaphorical sense, memes are to cultural evolution what genes are to evolutionary biology. Genes are the basic biological units of information that are transmitted from one individual to another in the form of DNA. *Memes* (Cavalli-Sforza & Feldman, 1981; Dawkins, 1976, 1981) are the basic cultural units of information that are transmitted to other people in the form of behavioral patterns. For example, Einstein added the deep connection between energy and mass in the equation $E = mc^2$. This was a new meme to the culture in 1905. In the course of positive adult development, major innovations can become new memes that are extreme examples of generativity (Erickson, 1959, 1978). Some generative acts are not only important to ourselves but useful to society as well. Innovative generative acts can lead to something new in society.

We approach one major aspect of creativity—creative scientific innovation—from the perspective of the model of hierarchical complexity (MHC). The model includes the MHC itself as well as two forms of learning. The first kind of learning is stage change. Individuals learn the new actions at the next stage. The second kind of learning is about phenomena at a given stage. Individuals learn, practice, and perfect behaviors at the given stage. These two forms of learning are inseparable (Ferrari, 2004; Piaget, 1977; Piaget & Garcia, 1984). Miller, Lee, and Commons (submitted to *Journal of Adult Development*) state that being in environments that encourage a great deal of learning at a given stage can be an important condition for development to the next stage.

Societally important creative tasks seem to be the most complex. This makes learning how to perform such tasks necessary for extremely creative acts of individuals. We will show that less creative tasks are available at lower orders of complexity. Therefore, learning to perform at higher orders of task complexity is central to increasing one's creativity, both for the individual and for the society. The MHC of Commons and Richards (1984a, 1984b; Commons, Trudeau, Stein, Richards, & Krause, 1998) is a system that classifies learning and development in terms of a task-required hierarchical organization of required responses. The model was derived in part from Piaget's (Inhelder & Piaget, 1954, 1958) notion that the higher stage actions coordinate lower stage actions by organizing them into a new, more hierarchically complex pattern. The stage of an action is found by answering the following two questions: (a) What are the organizing actions? And (b) What are the stages of the elements being organized?

HIERARCHICAL COMPLEXITY AND ITS ROLE IN INNOVATION

The Model of Hierarchical Complexity

The MHC (Commons & Richards, 1984a, 1984b; Commons et al., 1998) is universal system that classifies the task-required hierarchical organization of ideal responses. Every task contains a multitude of subtasks (Campbell & Richie, 1983; Overton, 1990).

When the subtasks are completed by the ideal actions in a required order, they complete the task in question. The classification of a task does not depend on the content or context, so it is species, domain, and culture free. Tasks vary in complexity in two ways, either as *horizontal* (involving classical information) or *vertical* (involving hierarchical information). It is not the usual horizontal kind of complexity that makes a difference but a newer kind called hierarchical complexity. Therefore the two forms will be introduced and compared.

Horizontal (Classical Information Theory) Complexity

Classical information theory (Shannon & Weaver, 1949), describes the number of yes-no questions it takes to do a task. For example, if one asked a person across the room whether a penny came up heads when they flipped it, their saying *heads* would transmit one bit of horizontal information. If there were two pennies, one would have to ask at least two questions, one about each penny. Hence, each additional one-bit question would add another bit. Let us say someone had a four-faced top with the faces numbered one, two, three, and four. Instead of spinning it, they tossed it against a backboard as one does with dice in a game. One could ask them whether the face had an even number. If it did, one would then ask if it were a two. Again, there would be two bits. Horizontal complexity, then, is the sum of bits required to complete such tasks.

Vertical (Hierarchical) Complexity

Hierarchical complexity refers to coordination of less complex task actions by more complex ones. Actions at a higher order of hierarchical complexity: (a) are *defined* in terms of actions at the *next lower* order of hierarchical complexity; (b) *organize* and *transform* the lower order actions; (c) produce organizations of lower order actions that are new and *not arbitrary*, and cannot be accomplished by those lower order actions alone. Once these conditions have been met, we say the higher order action *coordinates* the actions of the next lower order. Specifically, the *order of hierarchical complexity* refers to the number of recursive times that the coordinating actions must perform on a set of primary elements. *Recursion* refers to the process by which the output of the lower order actions forms the input of the higher order actions. This "nesting" of two or more lower order tasks within higher order tasks is called *concatenation*. Each new, task-required action in the hierarchy is one order more complex than the task-required actions on which it is built (tasks are always more hierarchically complex than their subtasks).

Formulating the Postformal Orders of Hierarchical Complexity

One of the features of the MHC is that it makes clear that there are stages beyond the stage of formal operations (Commons & Richards, 1984a 1984b). These stages are called *postformal*. Some of the qualities of postformal actions include the following: (a) these actions successfully address problems at which formal actions fail, and (b) they represent complex matters more compactly and systematically. The postformal structures range from multivariate relations to relationships among paradigms. These will be illustrated informally with two examples. Then each of the stages will be defined more formally.

The first example of postformal actions comes from algebra. In contrast to formal operations, which are about relationships between no more than two variables, postformal actions integrate increasingly more complex structures. For example, in formal operations, one may have the distribution of a variable x over the sum of two variables $y + z$, where $x^*(y + z) = (x^*y) + (x^*z)$.

At the first postformal stage, relations between multiple variables form systems of relationships. We next describe two members of two different systems. Each relationship belongs to a different system. At this stage, one can only work within one system at a time. But the truth value is different for the different systems to which they belong even though they look to be of the same form. This is seen in the right-hand distribution law. That law is not true for numbers but is true for propositions and sets.

$$\text{And } x + (y * z) = (x * y) + (x * z) \qquad \text{(Not true for arithmetic)}$$

$$x \cup (y \cap z) = (x \cup y) \cap (x \cup z) \qquad \text{(True for sets)}$$

Continuing our example, at the second postformal stage, one may show that the system of propositional logic and elementary set theory are isomorphic and form a *supersystem.*

$$x \,\&\, (y \text{ or } z) = (x \,\&\, y) \text{ or } (x \,\&\, z) \qquad \text{(Logic)}$$

$$x \cup (y \cap z) = (x \cup y) \cap (x \cup z) \qquad \text{(Sets)}$$

At the third postformal stage, for the predicate calculus just described in part, one comes to see all of these as part of a *paradigm* of mathematical logic and set theory, a field at the basis of mathematics and analytic philosophy.

For a second example, consider causality in relationships. At the formal stage, one person's behavior is seen to cause another's behavior, both empirically and logically. But at the first of the postformal stages, the relationships are seen in a more hierarchically complex fashion. First, a relationship is seen as being at least two-way: One person acts, the other person reacts (causal relation 1), the reaction of the other person affects the first person's future actions (causal relation 2). Those two relations form a system of causal relations (Koplowitz, 1984).

At the second postformal stage, one may consider different systems of relationships, that is, those between friends and enemies, and see to what extent they are comparable in that they conform to the same causal laws. The causal laws that describe such systems of relationships would be a supersystem containing both the laws that are common to friends and enemies and those that are particular. Of course no such supersystems exist yet. At the next stage, we could see that there is no possibility of consistent supersystems. There are too many considerations, and adding them to the supersystem makes the supersystem inconsistent.

Commons (Commons & Richards, 1978; Commons, Richards, & Kuhn, 1982; Commons et al., 1998) showed that the postformal stages were true hard stages in the Kohlberg and Armon (1984) sense, but with some small modification. As Marchand (2001) summarizes, Kohlberg and Armon distinguish "hard" stages (in which development occurs in an invariant and universal sequence (e.g., the Piagetian stages) from "soft" stages. In soft stages, development is conditioned by particular experiences arising from differences in personality, upbringing, social class, periods in one's life, and age. Commons (Commons et al., 1998) used a mathematical system derived from Luce's (e.g., Krantz, Atkinson, Luce, & Suppes, 1974; Krantz, Luce, Suppes, & Tversky, 1971) work on measurement. Each proposed stage was checked with the three main axioms. Again, these assumptions state that any given higher stage action has to be defined in terms of an associated lower one and organize those lower stage actions in a nonarbitrary way.

Commons and Richards's concerns lay with the general specification of any empirical task as opposed to one that is content bound. They deemphasized the reconstruction of the "reality" of a person "at a given stage." Instead, they attempted to develop a general way to specify the organization of tasks in any domain that a person at a given stage in that domain can do. Other attempts to specify what it means to be at a postformal stage can be found throughout the work reviewed here.

Postformal Orders of Complexity

We assert that highly creative innovations require postformal thought. This is in contrast to Feldman, Csikszentmihalyi, and Gardner (1994), who instead of focusing on the relationship between stage and creativity focus on intelligence (e.g., multiple intelligences) and creativity. As far as we know, there is no empirical research relating creativity to postformal stages (but see Sinnott, 1981). Therefore, to illustrate the relationship between postformal stages and creativity, we have empirically scored the postformal tasks that certain outstanding, postformal-stage scientists successfully complete. Four postformal orders of hierarchical complexity have been proposed (Commons & Richards, 1984a, 1984b; Commons et al., 1998), beginning with systematic thinking and developing through metasystematic to paradigmatic and cross-paradigmatic thinking. The four postformal orders, according to the MHC, are briefly defined in table 12.1.There is a growing consensus that these are the postformal stages as shown in table 12.2.See the references listed in table 12.2 for citations empirically supporting the exact sequence proposed (for a review, see Marchand, 2001). The columns represent the major adult developmental stages. The rows list the researchers and some key publications for the names and numbers of the stages.

Systematic Stage

This stage was introduced by Herb Koplowitz (while we were working on a chapter of his at Dare Institute, Koplowitz suggested that metasystems and general systems must operate on systems; personal communication, 1982; Koplowitz, 1984). Kohlberg (1990)

TABLE 12.1. Postformal Stages, as described in the General Model of Hierarchical Complexity

	What Is Done	*How This Is Done*	*The End Result*
11 Systematic operations	Constructs multivariate systems and matrices	Coordinates more than one variable as input	Events and ideas can be situated in a larger context; systems are formed out of formal-operational relations
12 Metasystematic operations	Constructs multisystems and metasystems out of disparate systems	Compares and analyzes systems in a systematic way; reflects on systems; creates metasystems of systems	Metasystems are formed out of multiple systems
13 Paradigmatic operation	Fits metasystems together to form new paradigms	Synthesizes metasystems	Paradigms are formed out of multiple metasystems
14 Cross-paradigmatic operation	Fits paradigms together to form new fields	Forms new fields by crossing paradigms	Fields are formed out of multiple paradigms

referred to this stage as consolidated formal operations and only much later saw his moral stage 4 as being the same. Fischer (1980) listed it as the third level in the fourth tier. At the systematic order, ideal task completers discriminate the frameworks for relationships between variables within an integrated system of tendencies and relationships. The objects of the systematic actions are formal operational relationships between variables. The actions include determining possible multivariate causes and outcomes that may be determined by many causes, the building of matrix representations of information in the form of tables or matrices, 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. 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. Behavior of events is seen as governed by multivariate causality. Our estimates are that only 20% of the U.S. population now functions at the systematic stage. That estimate is based on data that about 20% of the population are employed in professions requiring systematic stage action (Commons et al., 1995). These professions require graduate degrees. Hence, the percentage of graduate students and professionals are good examples. For example, in the Plano, Texas, 2000 census (*Plano's Population Characteristics*, 2000), 17.6% of the population had graduate or professional degrees, whereas in Geneva, New York (*Geneva's Population Characteristics*, 2000), this figure was 19.5%.

We know how to train individuals to perform at this stage. We send them to graduate and professional schools. They learn how to think in a multivariate manner from the explicit instruction they are given. They may in some unusual cases learn how to combine multiple causal relations in an original way.

Metasystematic Stage

At the metasystematic order, ideal task completers act on systems; that is, systems that are the objects of metasystematic actions. The systems in turn are made up of formal operational relationships. Metasystematic actions analyze, compare, contrast, transform, and synthesize systems. The products of metasystematic actions are metasystems or supersystems. For example, consider treating systems of causal relations as the objects. 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. 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.

As an example, 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 order of hierarchal complexity to produce

TABLE 12.2 Comparative Table of Concorded Theories of Formal Stage

Researchers	*Abstract*	*Formal*	*Systematic*	*Metasystematic*	*Paradigmatic*	*Cross-Paradigmatic*	*Transcendental*
Bowman (1996); Commons & Richards (1984a, 1984b); Commons (1991); Commons & Rodriguez (1993); Commons & Wolfsont (2002); Rodriguez (1989)	9 (= 4a)	10 (= 4b)	11 (= 5a)	12 (= 5b)	13 (= 6a)	14 (= 6b)	
Sonnert & Commons (1994)	group	bureaucratic	institutional	universal	dialogical		
Inhelder & Piaget (1958)	formal III-A	formal III-B	postformal	polyvalent logic; systems of systems			
Fischer (1980); Fischer, Hand, & Russell (1984)	7	8	9	10			
Sternberg (1984)		first-order relational reasoning		second-order relational reasoning			
Kohlberg (1981)	3 mutuality	3/4	4 social system	5 prior rights/ social contract 6 universal ethical principles			
Benack (1984)	4	5	6	7			
Pascual-Leone (1984)	late concrete	formal and late concrete	predialectical	dialectical			transcenddental
Armon (1984)	3 affective mutuality	3/4	4 individuality	5 autonomy	6 universal categories		
Powell (1984)	early formal	formal	stage 4a/interactive empathy	category operations			
Labouvie-Vief (1984)		intrasystematic	intersystematic	autonomous			
Arlin (1984)	3a low formal (problem solving)	3b high formal	4a postformal (problem finding)	4b relativism of thought 4c overgeneralization, 4d displacement of concepts	4e late postformal (dialectical)		

Sinnott (1984)		formal	relativistic/relativize systems, metalevel rules	unified theory: interpretation of contradictory levels			
Basseches (1984)	phase 1b: formal early foundations	phase 2 intermediate dialectical schemes	phase 3:2 out of 3 clusters of advanced dialectical schemes	4. advanced dialectical thinking			
Koplowitz (1984)		formal	systems	general systems		unitary concepts	
Perry (1970); see West (2004)	dualistic	multiplicative	relativistic	committed			
King & Kitchener (2002)	4	5	6	7			
Torbert (1994)	diplomat	technician	achiever	ironist			
Kegan (1994)	3: inter-personal	3/4	4: institutional	5			
Loevinger (1998)[a]	conformist-conscientious	conscientious	individualistic	autonomous integrated			
Cook-Greuter (1990)	3/4	4	4/5	5	5/6		6
Gray (1999, June, personal comm.)	early formal	formal	systematic	metasystematic			
Bond (1999, June, personal communication)	early formal	formal	systematic	metasystematic			
Dawson (2002a, 2002b)	9	10	11	12	13	14	
Kallio (1995); Kallio & Helkama (1991)	formal 1	formal 2	formal 3 generalized formal	postformal			
Dometriou (1990); Demetriou & Efklides (1985)							
Broughton (1977, 1984)	3: person versus inner self	4. dualist or positivist; cynical, mechanistic	5. inner observer differentiated from ego	6. mind and body experiences of an integrated self			

[a] Loevinger table of contents as modified by Commons (present volume).

truly creative innovations. By definition of the metasystematic stage, it means that such persons have to coordinate at least two multivariate systems. Although both the systematic and the metasystematic stage can be found to characterize the work of most scientists, we find that true adult creativity depends on an adequate performance on other related tasks. This is because the solution to tasks the society deems creative quite often requires a new synthesis of systems of thought (the metasystematic stage) or even a new paradigm (the paradigmatic order) or a field (the cross-paradigmatic order).

Paradigmatic Stage

At the paradigmatic stage, actions create new fields out of multiple metasystems. Examples of new paradigms are described by Holton (1973/1988) and 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 from recognition of a poorly understood phenomenon. The actions in paradigmatic thought form new paradigms from metasystems. 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. This suggests that learning in one realm can be generalized to others.

Examples of paradigmatic order thinkers are perhaps best drawn from the history of science. For example, nineteenth-century physicist Clark Maxwell (1873) constructed the paradigm of electromagnetic fields from the existing metasystems of electricity and magnetism of Faraday (1839/2000), Ohm, (1927), Volta (1800/1999), Ampere (1826/1958), and ;tOrsted (1820). Maxwell's equations for fields and waves showed that electricity and magnetism could be united, thus forming the new paradigm. The wave fields can be easily seen as the rings that form when a rock is dropped in the water or a magnet is placed under paper that holds iron filings. This paradigm made it possible for Einstein to use notions of curved space to describe space-time to replace Euclidean geometry. The waves were bent by the mass of objects so that the rings no longer fit in a flat plane. From there, modern particle theory has been able to add two more forces to the electromagnetic forces giving us the standard electromagnetic weak force.

Cross-Paradigmatic Stage

The fourth postformal order is the cross-paradigmatic stage. The objects of cross-paradigmatic actions are paradigms. Cross-paradigmatic actions integrate paradigms into a new field or profoundly transform an old one. A field contains more than one paradigm and cannot be reduced to a single one. One might ask whether all interdisciplinary studies are therefore cross-paradigmatic. Is psychobiology cross-paradigmatic? The answer to both questions is "no." Such interdisciplinary studies might create new paradigms, such as psychophysics, but not new fields.

This fourth order has not been examined in much detail here because there are so very few people who successfully 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. All that can be done at this time is to identify and analyze historical examples.

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, which in turn led to a scientific revolution that spread throughout the world and totally altered our understanding of humans' place in the cosmos. It directly led to what many would now call true empirical science with its mathematical exposition. This in turn paved the way for 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, which consisted of disjointed physical laws.

René Descartes (1637/1954) first created the paradigm of analysis and used it to coordinate the paradigms of geometry, proof theory, algebra, and teleology. He thereby created the field of analytical geometry and analytic proofs. Charles Darwin (1855,

1877) coordinated paleontology, geology, biology, and ecology to form the field of evolution, which, in turn, paved the way for chaos theory, evolutionary biology, and evolutionary psychology. Darwin (1855) noted that finches had diverged into a wide variety of birds. If they had not been isolated in the closed environment of the Galápagos Islands, these finches would have represented a wide number of species, as was the case of mainland birds. Many people had been exposed to just such novel situations but made nothing of it. Although Darwin discovered this phenomenon in the early 1800s, it was not until many years later that he made any sense of it when he devised his theory of evolution. Darwin saw that evolutionary forces had transformed the birds differently. But although his specific observations of finches did not have much impact on the direction of science, his evolutionary theory did. Darwin created a good deal out of three new interrelated paradigms: paleontology, evolutionary biology, and ethology.

Darwin's theory constituted a radical innovation in the science of his time for three reasons. First, he presented evolutionary evidence establishing the fact that human thought and action are continuous with animal thought and action. Second, he proposed an explanation for human evolution that was not teleological, that is, one that did not claim an ultimate purpose. Finally, Darwin's theory brought together four distinct prior paradigms, those of biology, ecology, animal behavior, and geology.

Albert Einstein (1950) coordinated the paradigm of non-Euclidean geometry with the paradigms of classical physics to form the field of relativity. This gave rise to modern cosmology. He also coinvented quantum mechanics. Max Planck (1922) coordinated the paradigm of wave theory (energy with probability) forming the field of quantum mechanics. This has led to modern particle physics. Last, Gödel (1931/1977), coordinated epistemology and mathematics into the field of limits on knowing. Along with Darwin, Einstein, and Planck, he founded modern science and epistemology.

Innovators functioning at each of the four stages do tasks of different hierarchical complexity that do not overlap with one another. The rarity of people functioning at these higher stages is reflected in the higher rate of pay they receive. The increased pay and freedom to direct their own activity probably function as an incentive to learn the next stage of behaviors. Persons functioning at each stage do the different tasks using skills that are increasingly rare. The end results are entirely different for society. The results of innovation become much more important at the paradigmatic and cross-paradigmatic stages. The results change the world culture and our very view of the world. In fact, so few people exist at the cross-paradigmatic stage that societies have no formal mechanisms to encourage such activity as far as we know. Yet that change influences the course of civilization. For example, Copernicus changed our view of our place in the universe, making the Earth just another planet revolving around the sun. Darwin changed our view of human origins and place within the world of animals to make us one more animal. Copernicus altered the course of modern physics and astronomy, and Darwin's contribution led a vast array of academic disciplines including modern genetically based medicine, evolutionary biology, paleontology, and behavioral psychology.

Hierarchical Complexity and Level of Support

To understand why innovation is so difficult and requires people who can successfully address the most hierarchically complex tasks, we have to realize that when the innovation was carried out there was almost no previous knowledge as to how to approach the task. Using hindsight, the tasks of innovators do not seem as difficult. The difference is that we live in a world that surrounds us with past knowledge and has created a context in which the discoveries make sense. Our understanding of these discoveries, one might say, is supported by this knowledge and the teaching of that knowledge. The original discoveries, however, took place without any of this support. This raises the stage at which these tasks had to be done. These ideas are formalized in the idea, described below, 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 level of support represents the degree of independence of the performing person's action and thinking from environmental control provided by others in the situation (Vygotsky, 1962, 1966, 1978). We define six levels of support: *Manipulation* (–3 level), which is literally being moved through each step of how to solve a problem; *transfer of stimulus control* (–2 level) is being told each step; *pervasive imitation* (–1 level) is being shown, which includes delayed imitation or observational learning (Gewirtz, 1969). The imitated action may be written, depicted, or otherwise reproduced. Fischer and Lazerson (1984) call this form of control the optimal level. *Direct* (0 level) is being given no help or support in problem solving or hacking (without support). Fischer and Lazerson (1984) call this the functional level. Most of Piaget's work was at this level. *Problem finding* (+1 level) is in addition to not getting help. One must discover a task to answer a known question. Persons may be given an issue, and they are asked to give examples of a problem that reflects that issue. Arlin (1975, 1977, 1984) introduced postformal complexity (systematic order) by requiring the construction of a formal operational problem without aid or definition. Finding a given problem increases complexity demand by one order of complexity over solving a posed problem with no assistance. *Question finding* (+2 level) is in addition to not getting help. Here, one must discover the question, not just the problem, to address a known issue. With a known phenomenon, people find a problem and an instance in which to solve that problem. One has to discriminate the phenomenon clearly enough to create and solve a problem based on that discrimination. *Phenomenon finding* (+3 level) offers no direct stimulus control. There can be no direct stimulus control without a description of the phenomenon, unrecognized up until the discovery. Also, discovering the new phenomenon is necessary for there to be a reinforcement history with that phenomenon.

There is little support for major innovations in culture because there is no history of the necessary hierarchical complex task accomplishments or actions surrounding the task. Nor is there a history of reinforcement that would induce the subject to detect new phenomena. Creating an advance requires two more levels of complexity. This is roughly paradigmatic complexity. Absorbing or assimilating an advance created by someone else requires formal operational complexity.

The Stage of an Inventor and the Stage of a Culture Differ

Individual and cultural developments have a straightforward relationship to one another, as we have argued elsewhere (Commons-Miller, in press). The stage of cultural development is limited by the highest stage of performance of at least one member. But it is always lower in stage than that of that person's performance. In a particular population or culture, stage will be normally distributed, with most of the population performing on most tasks central to that culture at one stage and with fewer individuals at both lower and higher stages. Our best estimate from Dawson's (2002a, 2002b) data on stages of moral development is that each stage is spaced one standard deviation apart. Next we discuss reasons for our assertion that stages within populations work this way.

In related work, scoring actions and problem solving of animals, we have reported that at least some chimpanzees perform at the concrete operational stage. This is seen, for example, on some social perspective-taking problems (Commons & Miller, 2004). We can assume that because some chimpanzees perform at the concrete stage, some of our common ancestors would have likewise performed at the concrete stage. Commons and Miller (2004) argued that there was a progression in top performance of the ancestors to *Homo sapiens* through the abstract, formal, and systematic stages. That is, with some of the new hominid species, leading eventually to *Homo sapiens*, some of those species had at least a single individual who could solve problems at one higher stage than the species that they eventually replaced. The requirement for speciation is for only one such member who then passes on his or her genes. Specifically, at some time after the first Cro-Magnon *Homo sapiens*, we have argued (Commons & Bresette, 2000) that the population would have been large enough, based on probability alone, that there could have been an individual who behaved at the paradigmatic stage in at least one domain.

Only one member at a time invents, even though the invention might be a joint enterprise in other respects. Even in a cooperative behavior, one person has the behavior first, even if only a millisecond before the other. Yet inventing behavior depends on others' past inventions. Inventions can only build on the last inventions and may be limited to advancing just one or two stages beyond those inventions, which are always postformal. Individuals may be limited to one or two stages above the stage of invention in a culture. The general stage we assign to cultures can be so much lower than the stage attained by the most developed individuals in that culture working in science at the time. Even though individuals might act at the highest stages—for example, cross-paradigmatic—societal development tends to lag behind individual development because at each stage of cultural development the development of the cultural innovators outpaces that of their contemporaries, at least within their domain of innovation. For a culture to progress, there must be a supply of innovators who work with minimal support from their culture. For example, Marie Curie did not have an academic position until her husband died and she took over his professorship at the Sorbonne University. The size of this supply of paradigmatic and cross-paradigmatic thinkers seems to be the largest bottleneck in cultural development.

Truly Creative Acts Change Culture

To be truly creative, an act has to reach and influence a large enough group within the world that it survives in the culture and has influence. Sometimes potentially creative acts are not communicated, either because the society is not proficient enough to receive them or simply because the acts themselves are not transmitted at all or are inefficiently transmitted. For successful transmission and dissemination of innovation to take place, the culture must be ready to absorb the discovery. Being ready to absorb a discovery is partly a characteristic of cultures. A demand for the innovation also has to exist so that innovation pays off. Cultural transmission, however, ultimately relies on the ideas being adopted by individuals. Discoveries and findings need to be spread to other individuals by infection of memes (Best, 1997; Commons, Krause, Fayer, & Meaney, 1993; Moritz, 1995; Trivers, 1985). The transmission of memes usually requires that the uninitiated individuals receive some degree of support to learn the new memes. Formal and informal education is one of the means by which memes are acquired; such mechanisms provide implicit and explicit support for learning (Cavalli-Sforza, Feldman, Chen, & Dornbusch, 1982). Formal education promotes the learning of new ideas through means such as direct instruction. Informal education promotes learning by providing opportunities for individuals to observe the behavior of those who have a greater degree of competence. Either form of learning opportunity would be necessary, because most people cannot possibly understand an innovation on their own. They do not reason at a high enough stage. Increasing support through teaching and training ensures that they come to understand and possibly use a higher stage behavior (Fischer, Hand, & Russell, 1984), including a discovery. Including such opportunities for learning allows individuals who would not on their own reach a somewhat higher stage than their own to do so. It is also important to recognize that providing the opportunity to learn one innovation, such as computer programming, may put one into a context or an educational system that transmits other memes as well. The larger set of infecting memes becomes part of the participants' resulting behavior. In short, the rate of transmission of memes depends on increasing contagion through these various means—education, training, and communicating results—so that potential innovators come into contact with the most advanced forms of the present culture.

Finally, it follows as well that it would be useful for the innovator to be some form of teacher for the new memes to be acquired by others. One incentive to having many graduate students is that some might follow-up and build on one's own work. In current society, it is necessary to publish, present, and promote much innovative work because otherwise it gets lost in the huge number of publications. It may also help to get material into textbooks and reviews.

The difficulty in spreading memes, as just defined, has dramatically slowed the process of discovery. We speculate that many discoveries have to be made repeatedly before they take hold. People have to engage in activities that require the new cultural information. In learning the new actions required by the innovation, an individual is thereby infected with the memes of the innovation. In carrying out the activities associated with the innovation, as well as in teaching others to do likewise, the individual is further infected. The more thoroughly an innovation is learned and taught, the greater the degree of infection by memes. Learning innovations in general probably leads to benefits for those who learn them; for example, it increases employability in the present culture.

Novelty and More Hierarchically Complex Behaviors

Novel behavior is one psychological dimension of an individual's response to a new or strange situation. A novel situation may consist of a sudden or unpredictable change in a known state of affairs. Novelty has two aspects that are important to creativity. First, novelty spurs the development of more hierarchically complex behaviors; second, creativity requires attention to novelty as well as an original response. People who are overwhelmed by novelty and the accompanying uncertainty are precluded from creative discovery. They avoid confronting novel and anomalous findings and observations. In this section, we discuss how novelty is involved in stage change, a particular form of learning. Such stage change quite often is necessary for a truly creative act.

It has been shown that novelty greatly aids (if not induces) continuous intellectual development within domains and discontinuous development across domains by forcing transitions between lower and higher stages (Grotzer et al., 1985). Furthermore, development of this kind is dependent on new, more hierarchically complex behavior obtaining outcomes that the individual prefers. Novelty in ordinary problem solvers often produces some development. Ordinary problem solvers working on problems at or near their stage of development can nevertheless be motivated by novel problem types, as long as the problems and information are not too novel. It has been shown that too little novelty seems to remove the incentive to keep learning, and too much novelty can be aversive (e.g., Kagan, 1974).

Novelty and the Creative Behavior

Strikingly similar in some aspects but just as strikingly different in others is the problem solving of truly innovative thinkers. Such thinkers seem to be much less limited by considering information with a high degree of novelty. Two examples will be provided here. First, both the Nobel Prize–winning physicist Louis W. Alvarez and his son, Walter Alvarez, searched for information that suggested that there had been an asteroid crash in the sea off of the Yucatán Peninsula. Although this seemed to be not likely to many others, by sticking with the problem and not being dissuaded by the fact that what they were saying was so novel that many dismissed their idea, they ended up convincing the field that not only had an asteroid crashed into the Earth at that location, but it had most likely wiped out the dinosaurs (Fastovsky & Weishampel, 1996).

A tangible and full-bodied historical example of this type can be found in the creative work of Charles Darwin (e.g., 1855, 1872/1898, 1877, 1969). The behavior responds to some novel aspect of the environment that others have missed. Consider the example of Darwin's observation of finches, as discussed earlier. This is an example of discovering a phenomenon. The initial discovery itself did not have much impact on Darwin's conceptualization, but years later he made sense of the phenomenon by proposing his theory of evolution. The finches had evolved and now filled the same niches that mainland birds of much greater variety had filled. In one case, the niches were filled by a variety of finches (system one), and in another by many separate mainland species (system two). Darwin saw that evolutionary forces had transformed the birds differently (a metasystematic comparison of systems one and two). In both of these examples, the scientists involved understood these phenomena without support. Hence, this is cross-paradigmatic.

THE PERSONALITIES AND TRAITS OF MAJOR INNOVATORS

Necessary but Not Sufficient Traits of Environments and History that Allow for True Creativity

Why are extremely creative major contributions so rare? Our assertion is that so many of the personality characteristics to be discussed (also see Shavinina & Ferrari, 2004) may be partially or wholly necessary, and finding so many of them in one individual is relatively rare. In addition, one would have to find not only this confluence of personality traits but also postformal reasoning in their chosen scientific domain. To begin with, each characteristic has a reasonably small probability. Their joint probability, therefore, is quite a bit smaller. One issue is that extremely creative scientists have an unusual set of traits. Many of these tendencies to act in particular ways can be directly related to major innovation. In traditional personality theories, when tendencies are somewhat stable over time, they are called *traits*. Although some of these tendencies are partially inherited, some portions are learned or acquired (Bouchard, Lykken, McGue, Segal, & Tellegen, 1990). When we are assessing these tendencies, we cannot tell which it is without doing twin studies or similar studies. In either case, in the present no one has access to what it is that created these tendencies in scientists who have completed their work. Even so, it is important to keep in mind that traits are not causes of behavior. They are just intermediate results that serve as convenient explanations for a person's behavior. Behavioral analytic or learning theories would tend to explain these tendencies with respect to the individual's history and present circumstances and might be more useful in terms of understanding adult learning and development.

Personalities that Withstand Social Conformist Influences

Innovators do not have nonconforming personalities in general, but they do withstand social conformist influences (Roe, 1952). Actually, effective innovators have a mix of both nonconformity and conformity. In thinking up their ideas, they may need independence. People who are worried about themselves and their reputation and standing cannot take the risks to be creative. The independence required might be partly due to some kind of temperamental or inherent characteristic of the individual that goes beyond just resisting the social pressure to conform. Temperament studies have looked at such things as fearfulness and adaptability (Rothbart & Bates, 1998; Thomas & Chess, 1977). As suggested in the section on novelty, the presence of too much fear or too little adaptability may interfere with the kind of intensive engagement with the environment that could lead to innovations. A lack of fear, especially of fear of rejection by others, could help an individual in resisting social pressure. Attention deficit disorder has also been associated with creativity (Cramond, 1995), possibly because there is inattention to social signals of condemnation and therefore a lower tendency toward social conformity. Because of the lack of social control in the immediate sense, we deduce that major innovators tend to be noncompetitive with others because they do not use others as a frame of reference. They are not as concerned with other people's opinions of them as less creative scientists and do not compare their own activities and success with others. Instead, in terms of social comparison theory, the comparison may be to one's own previous performance or the performance of some historical figure (Rheinberg, Lührmann, & Wagner, 1977). Therefore, creative actions often *require* that there be a certain detachment from the social order and from social approval.

Another long-standing and related aspect of people's behavior that has been less studied is the individuals' tendency to pursue their own agenda, almost no matter what. One important aspect of this trait could be called persistence (Howe, 2001, 2004). Great discoverers seem to often have more resistance to giving up in their continued confrontation with problems. Learning studies have illuminated some of the environmental factors that can lead to persistence of behavior (Mace, Lalli, Shea, & Nevin, 1992; Nevin, Tota, Torquato, & Shull, 1990), including receiving a great deal of free rather than contingent reinforcers.

Environmental variables can also help make individuals less subject to social control. One such variable is independent wealth. Let us take the case of Darwin again, someone who was independently wealthy. Darwin's quest for the truth was unfettered by concerns for employment. Although some were extremely upset by what he was doing, he could not be fired and he lived quite well. Einstein described the life of a patent officer as ideal, getting paid for doing what one likes. There was little work in that position that he did not enjoy. And it left him with plenty of time to work on his own theories. Hence, again, his discovery behavior was not under the control of an employer or social institution.

It should be noted that to effectively spread their ideas, highly creative scientists may also need some degree of connection to society. Both Darwin and Einstein, for example, continued to live within society, belonging to professional organizations. Thus, they were connected enough to society that they could communicate their ideas to others. Raskolnikov in Dostoyevsky's (1914) *Crime and Punishment* is a good example of someone who chose to live outside of society and therefore was not very effective.

Ambition and Curiosity

One definition of ambition is a strong preference to achieve great things. In highly creative scientists, ambition is often directed toward solving problems, not becoming acclaimed, respected, or powerful. This seems essential to creative behavior because many creative acts require persistence and enthusiasm for the enterprise. There is very little research on such ambition. It is not clear how ambition can be learned, but clearly it can be dampened. Children who grow up in a culture of creativity see it as normative and may learn to feel empowered (see the examples later of the empowering environments in which the children of some highly creative scientists grew up). These individuals learn that following one's dream is often rewarded, often raising their ambition.

Another major trait of the great discoverers was that they were extremely curious. This would be reflected in extremely high scores on the Holland (1996) factor called investigative (I), if ever assessed. This means that discovering was extremely reinforcing for them. The great curiosity of people presses for their own development and the learning of the next stage's behavior. Having high investigative interests should also propel stage change. Interest raises the reinforcing value, which in turn increases the rate of self-presentation of problems because such self–presentation is reinforced. The increased rate of attempting problems would raise the probability of solving them. This is because the number of attempts at solving a problem probably matters.

Cognitive Styles

Field independence has been associated with creative functions in adults (Minhas & Kaur, 1983). This classically defined cognitive style has been measured by the rod and frame task (Wapner & Demick, 1991; Witkin, 1949; Witkin et al., 1954;) as well as by paper and pencil tests (Witkin, Oltman, Raskin, & Karp, 1971). For example, in the Group Embedded Figures Test (GEFT) manual of Witkin and colleagues, subjects are required to recognize and identify a target figure within a complex pattern. The more figures found, the better the individual is at the process of separation and is said to be more field independent. Minhas and Kaur (1983) support the idea that field-independent individuals display a penchant for novel types of acts. The degree to which people are field-independent correlates with their ability to resist social pressure and the influence of social cues. Field-independent people are more likely to exhibit creativity and are more likely to resist the social pressure to conform to tradition. There is also an overlap between field independence and intelligence. Ohnmacht and McMorris (1971) found that neither field independence nor lack of dogmatism alone is useful in explaining variations on a task presumed to reflect creative potential. However, when considered together, these variables become significant. Using the proclivity to produce transformations of visual information as a measure of creativity, Ross (1977) also found a high correlation between creative behavior, locus of control, and field independence. Locus of control is a personality construct referring to an individual's perception of the locus of events as determined internally by their own behavior versus fate, luck, or external circumstances.

Tolerance of Ambiguity, Risk Taking and Tolerance for Rejection

Tolerance of ambiguity, the taking of risks, and some degree of tolerance for rejection are necessary for creativity. Students doing research often ask why the professor does not simply give them the right method for understanding a new problem the first time. The professor then says, "If I knew the right method for solving this problem, I would have learned it from somebody who had already answered the question." Research suggests otherwise. Ambiguity is more tolerable for older adults, making the ambiguity in the creative process less of a threat. Labouvie-Vief (1985) noted that older adults were at ease when working with ambiguity creatively (also see Arlin, 1984; Labouvie-Vief, Adams, Hakim-Larson & Hayden, 1983). Younger adults focus on reaching a conclusion that makes sense when presented with logically inconsistent statements, whereas older adults concentrate on the problems inherent in the premises. They comment on the inconsistencies, question them, and sometimes introduce ideas that might resolve them. They go beyond the information given in the problem on the basis of their own personal experience and knowledge.

To be creative, individuals also must take risks and be able to withstand rejection. Smith, Carlsson, and Sandstrom (1985) found that creators use fewer compulsive or depressive defenses and are free from excessive anxiety. They also found that creative individuals have access to their dream life and to their early childhoods. More often than noncreative individuals, they tend to remember both positive and negative qualities of these life experiences. Finally, creativity requires one to separate oneself from one's creations. Otherwise one would rarely be self-critical of one's creative output. If one were always satisfied, there would be no development, no reaching for more. Being challenged by (rather than upset at) not knowing the details or the direction of one's enterprise seems essential, as does the ability to withstand and overcome disconfirmation or failure at a particular step in the enterprise. All of these require risk-seeking behavior. The passion involved is for the enterprise of discovery, not for the self, a particular act, or a need for social approval. This independence may lead to a sense of isolation from others, which, although painful, may also prove to be surprisingly necessary.

Timing of Creative Acts

Even with all of the personal traits just mentioned, when it comes to creation, timing is everything. Timing of creative acts may have three sources, each conflicting with the others. First, learning and developing higher order hierarchical complexity action takes time. A great deal of this time would be spent thinking about and working on whatever problems the individual was interested in and actively engaging with the material. This kind of engagement would lead to increased learning and ultimately to stage change. Some of the most integrative and highest order acts may not take place until middle age or later, as was the case with both Copernicus and Darwin. Second, one needs a great deal of time to develop one's own ideas, and in an arena within which those ideas will not be demolished before they can attain integrations. Third, there is a long social agenda of the work one is supposed to carry out rather than doing the work that takes one down one's own creative path. This social agenda entails diversion of a certain amount of time and energy to work on other people's problems. One might then simply adopt their frame of reference rather than pursuing one's own.

LEARNING POSTFORMAL STAGE PERFORMANCE

Learning

In addition to personality traits, the learning of postformal action seems necessary for major discoveries. Thus far, we have discussed the effects on creativity of functioning at postformal stages, but we have not spent much time on how individuals may learn and develop postformal actions. Learning is part of the process by which stage transition takes place. Therefore stage transition describes how next-stage actions are learned by individuals. Commons and Miller (1998) and Commons and Richards (2002) have described both stage transition and reasons transition takes place or fails to take place. An illustration of certain aspects of the transition stages is included here (table 12.3). The first three steps (deconstruction) start with initially high loss of perceived reinforcement opportunity. This loss may initiate learning of the next steps. But during the advance through these initial steps, more reinforcement is obtained. This happens because when lower stage actions fail, individuals begin to try a variety of new actions, some of which lead to more reinforcement. Psychologically, the results are consistent with Rosales-Ruiz and Baer's (1997) work on behavioral cusps. A *cusp*, as defined by Rosales-Ruiz and Baer, is "a behavior change that has consequences for the organism beyond the change itself, some of which may be considered important" (p. 537). The proposed psychological mechanism of transition seems to be consistent with these theories. Most Piagetian or neo-Piagetian theories do not clearly operationalize the steps in transitions or the empirical basis for transition.

There is very little empirical work on raising postformal stage. For a discussion of adult stage transition, however, see the entire special issue of the *Journal of Adult Development* (Commons, 2002). The early work on inducing stage change was in moral development with children (Blatt & Kohlberg, 1973). There has been some work on the effects of higher education on ego stage (Mentkowski, Moser, & Strait, 1983). Kallio (1998) showed improvement in freshman in formal operational reasoning with direct training and with metacognitive training. The CASE Thinking Science activities studies (Adey & Shayer, 1994; Adey, Shayer, & Yates, 1995) provided examples of formal operational problems in 32 lessons over two years. The CASE activities were designed to familiarize pupils with the language and apparatus (concrete preparation); provide "events" that cause the pupils to pause, wonder, and think again (in table 12.3, step 0: cognitive conflict); encourage the pupils to reflect on their own thinking processes (metacognition); and show how this thinking can be applied in many contexts (bridging). Torosyan (1999) encouraged consciousness development in the college classroom through student-centered transformative teaching and learning. He obtained in increase of up to one stage. Woods (2000) introduced problem-based learning (PBL) in several university level courses in which students' current level on the Perry scale were mostly position 2.5 to 3.5. After running a three-hour workshop to help them "adjust to change" and grieve the loss of their old ways via PBL and then applying PBL, they improved. Hart, Rickards, and Mentkowski (1995) have used the Perry scheme of intellectual and ethical development as a college

TABLE 12.3. Stage Transition

	Relation	*Name*	*Personality*	*Description*
Step 0	a = a′ with b′ where a′ and b′ previous stage actions	Temporary equilibrium point (thesis)	Fault finders	People at this step have experienced a huge drop in perceived reinforcement rate because they see the failures of their behavior of the present order to obtain what others obtain. People get stuck here because much of their current order behavior that is similar to the "failure behavior" is maintained by reinforcement. At low orders of performance in the social domain, this may result in antisocial behavior. These people perceive tremendous unfairness. They quite often have unshakable negative depressive scripts. They deny the value of new ideas.
Step 1	b	Negation or complementation[a] (antithesis)	Naysayers	This may consist of persons who enter therapy, as well as rebels, radicals, and discontents. They have given up their old ways. If "a" is wrong, then the opposite of "a" is right. This step is associated with the second largest drop in reinforcement rate because people may drop their previous successful behavior "a" and substitute behavior "b" for it.
Step 2	a or b	Relativism (alternation of thesis and antithesis)	Relativists	In this culture, this is quite often the largest group of people in transition. They fill academia. They stop progress by insisting that there is more than one way to look at things but cannot even decide which ones are more likely to be true or good. There is some gain in reinforcement, but the conflict between whether to choose "a" or "b" produces anxiety, angst, mood swings, and uncertainty about roles and values.
Step 3	a and b	Smash (attempts at synthesis	Movers	Such persons are moving from smash to consolidate. They create great trouble for themselves and others by throwing ideas and actions together in a creative, haphazard way, taking a great deal of risk.
Step 4	a with b	New temporary equilibrium (synthesis and new thesis)	Unshakables	To these persons, everything is okay even . if it is not okay. They avoid conundrums, apparent contradiction and comparisons to people they look up to. Since they have just obtained this new equilibrium, everything is good enough.

[a] *Complementation* is defined as follows: The complement of A consists of all elements that are not in A.

outcomes measure for years and have found development. Hill (2004) applied conceptual change theory with the developmental instruction model based on Perry. This application made a modest contribution to intellectual growth, moving people from position 3 (concrete stage) to position 4 (abstract stage). Lovell and Nunnery (2004) found some increases as well in educational counselors, only a little of which seems to have been postformal.

Given all these cautions about the difficulty of producing stage change, there are several suggestions for stage change. Recognizing the need to perform at higher stages might be useful. This might include the self-assessment of one's own stage of performance, which could be an incentive to progress (see table 12.3). Informally, one hears that people enter graduate school after step 0 of transition and learning—failure of the present stage. The graduate school presentations of systematic thinking often move peoples' reasoning to the systematic stage. Hopefully, students do not spend much time experimenting with the anti–step 1. Moving to the relativism of step 2 is often accomplished by graduate school because of the necessity of learning about multiple systems, none of which seem to be completely satisfactory. Step 3—smash—is the most difficult to achieve. Emotionally, it always seems to require a leap of faith in one's own proclivity to sort out what works from what does not. Because smashing two systems together does not at first generate a simple, working system, or the next stage metasystem, one has to have something akin to faith that things will improve to get through the confusion that is self-generated. There is very little to say about moving beyond systematic and metasystematic reasoning because there are so few people who do so. There does not seem to be any institutional training or education that is even remotely sufficient. It does seem necessary to be both deeply educated in some endeavor and broadly educated as well.

Factors Contributing to Learning and Development

Both within many neo-Piagetian accounts (e.g., Case, 1974, 1978, 1982, 1985) and precision teaching (e.g., Binder, 1995) accounts, automatization of previous-stage behavior (elements) is predicted to improve the rate of obtaining next-stage performance (combinations). As old-stage tasks are completed near the maximum rate and errors almost disappear, the actions are said to become *automatized.* Such overlearning leads to automatization and chunking of the stimuli in the tasks. That is, each individual stimulus in the task no longer has to be discriminated individually, but now as a whole. This makes it possible to see the forest rather than just the trees.

Integrating Postformal Scientific Actions with Adult Social Actions

The exposure to a broad range of societal ideas through integrating career with societal activities prompts greater creativity based on higher stages. Integration of social and scientific acts primarily occurs in early adulthood and after. Whereas people meet the peak of their stage development in early through late middle age, some great innovators reach the highest orders of development earlier in life (Stevens-Long & Commons, 1991). For example, mathematicians often reach their peak in their twenties. For active individuals, developmental stage peaks between the fifties and late sixties. Generally, it is not until middle age (the forties or so) that people can recognize not only that they are underneath a social structure and climbing within it but also that they create and maintain that system. Active people engage in the process within their families, workplaces, professions, and communities. They come to see themselves as responsible parts of society. At this time, for example, many men become more active in their families by exhibiting more nurturing behavior. Many women become more active by pursuing careers and additional education. Both genders will thus become more similar to each other. In effect, this general process requires individuals to consider different systems—for example, the work system and the general social system, or the family system versus the work system—and increasingly integrate those systems. In other words, demands to move from systematic to at least metasystematic thinking are present. These kinds of demands may result in some individuals taking at least some of the steps that may make greater creativity more likely.

All tasks must have some order of hierarchical complexity. Performance on such tasks depends on many other task characteristics, however. These include level of support (Commons & Richards, 1995; Fischer et al., 1984), horizontal complexity, fluency of performance on the component tasks, "talent," interest, and other factors. Hence, one may expect complex interrelationships between measures of performance on tasks and conditions of measurement. As discussed previously, level of support alters measured stage in a simple linear fashion. But the stage of performance should be curvilinear when plotted against the subjects' chronological age (Armon & Dawson, 1997; Dawson, 1998) and only linear when plotted against log age. This more complex relationship is due to the fact that the orders of hierarchical complexity are equally spaced in terms of difficulty. But development slows down logarithmically with age (Backman, 1925). The conceptual basis of Backman's function of growth, is the postulate that the logarithm of growth rate (H) is negatively proportional to the square of time's (T) logarithm, $\log H = k_2 \log^2 T$. Constant k_2 is always negative. Also, variability should increase with age, and it does. Yet there is some evidence that at the highest stages, there is less spread (Dawson, 1997). The proclivity to integrate relationships and systems and even paradigms from many domains probably increases with postformal stage. The more postformal in one domain, the more even performance should be in many domains.

Precursors of the Higher Stages

Commons-Miller (2003) found a number of factors that were predictive of the scientific success of the children of some of the most highly successful scientists. This information can be used here to further illuminate some of the conditions that may lead to the learning and development of postformal thinking. In the examples studied, the younger generation spent significant amounts of time with their scientist parents. But this went beyond just spending time with their parents. During this time, the children were often included as part of a family enterprise that involved doing science: asking and answering questions, carrying out or helping carry out investigations. They were treated respectfully; their opinions were sought and challenged. They started their scientific work early, as was the case for Jean Piaget (1952; Vidal, 1994; who was son of the Arthur professor of medieval literature at the University) and Richard Leakey (son of Mary and Louis Leakey). In many cases they worked with one or more of their parents (e.g., Richard Leakey; Walter Alvarez, son of physicist Louis Walter Alvarez; Mary Catherine Bateson, daughter of Gregory Bateson and Margaret Mead).

Some of the work these children of scientists did was at the paradigmatic stage. For example, Walter Alvarez and his team, which included his father, Nobel Prize–winning physics professor Dr. Louis Alvarez, Frank Asaro, and Helen Michel, combined their knowledge from a number of fields. Walter Alvarez found an interesting piece of limestone in Gubbio, Italy, in 1977 and brought it home to Berkeley as a gift for his father. The limestone included a thin layer of clay that marked a time in our planet's history known as the Cretaceous-Tertiary (K-T) Boundary. Walter and Louis Alvarez took the rock to Frank Asaro and Helen Michel, two of the most careful chemists they knew at the Lawrence Berkeley Laboratory, and asked them to analyze the clay layer. Asaro and Michel used chemistry and physics to perform neutron activation analysis to find the iridium at the K-T boundary. The Alvarezes combined their knowledge of astronomy and geology to look for the trace effects of iridium from asteroid impacts. In the late 1980s, they finally found a crater, now known as the Chicxulub crater, just the right size and age, at the edge of Mexico's Yucatán Peninsula. They then combined all of those results with evolution to propose that an asteroid about 10 km (6 miles) in diameter hit the Earth, throwing up a dust layer that encircled the planet and led to the extinction of the dinosaurs.

Very few individuals have this kind of upbringing, so such precursors are rarely encountered. Adult stage of development is normally distributed with a mean stage of formal and a standard deviation of one stage in our educated society (Dawson, 2002a, 2002b). Therefore, it is not surprising that researchers of adult development find very few individuals who engage in the metasystematic performance necessary for creativity. Some examples are as follows: Armon (1984), found 9% (3 out of 32) on the good-life interview, and 15% (5 out of 32) on the moral judgment interview. Richards and Commons (1984), found only 14% (10 out of 71 participants) on the multisystems task. Demetriou and Efklides (1985) found 11% (13 out of 114) on the metacognitive task. Kohlberg (1984; Colby & Kohlberg, 1987a, 1987b), found 13% (8 out of 60 participants aged 24 and older), who used stage 5 reasoning on the moral judgment interview. Powell (1984) reported 9% (4 out of 44 participants with IQs of 132 or higher) who performed metasystematically.

In addition to the fact that few people may encounter the conditions that could lead to higher stage development, there may also be personality characteristics that make moving beyond certain steps in the transition from one stage to another much less likely (Commons & Richards, 2002). These are described in the table 12.3.

Social Control

A society that not only tolerates but also promotes creativity produces more creative acts. This can be seen in Nemeth and Kwan's (1985) study on originality in word associations that found that participants who were exposed to persistent minority views tended to reexamine issues and to engage in more divergent and original thought. They learn to be more original, a component of creativity. On the other hand, participants who were exposed to persistent, fairly exclusive majority views tended to concentrate on the position proposed, display convergent thinking, and be less original. One might assume that all creativity depends on originality and divergent thinking.

General Characteristics of "Truly Creative" Individuals

A creative innovator will not have done society's bidding for long. One has to work on one's creative acts early on. Delaying work on one's creative program means that the other intervening activities will be reinforced, lowering the probability of ever completing one's own creative acts. True adult creativity requires building on current knowledge and then transcending it. It requires that innovators or creators have novel insights into complex problems. This often requires that the creation of a new synthesis of systems (metasystematic) or a new paradigm (paradigmatic order) or field (cross-paradigmatic order) on the part of such an individual.

IMPLICATIONS OF VALUING THE HIGHER STAGES

Baum (2000, 2004) argues that learning is a form of intragenerational change, whereas evolution is an intergenerational form of change. Intergenerational change requires intergenerational learning. Genetic evolutionary forces have generally increased the highest stage of reasoning found from the concrete stage in the common ancestor of *Homo sapiens* and chimpanzees to the cross-paradigmatic in humans. We may wonder whether such forces will, over time, actually increase the number of people functioning at the cross-paradigmatic stage. How soon might this begin to happen? Might someone even function at stages beyond the cross-paradigmatic? Of the two forms of evolution, genetic and cultural, the impact of cultural evolution as it impacts postformal stages will be discussed first.

As revealed in introductory and adult developmental psychology books, a self-reflective understanding of postformal stages is developing widely (e.g., Hoyer, Roodin, Rybash, & Rybash, 2003; Schulz & Salthouse, 1999). In this context, we find tremendous differences arising among social groups—differences that seem to be related to education levels and the power of reasoning (Kegan, 1994). Will this trend continue? Given the degree to which certain peoples and groups seem to value higher stage development, one must wonder how far some might go in their efforts to produce intellectually advanced individuals—those who, for example, could function at the cross-paradigmatic stage. Might the trend in this direction be illustrated in part by the fact that people are now paying huge sums to educate their children at top research universities, graduate, and professional schools? They are encouraging their children to obtain postgraduate education. Might some go even further in this direction and attempt to push the limits of evolution and natural selection through humanly engineered means? How far will people go in this direction?

Where might this tendency lead us? Some extremely controversial predictions are to be made in this context. We are not advocating these scenarios, merely describing their possibility and pondering their implications. At the same time, we believe we must marvel at the degree to which some people might just push the envelope of selection in their efforts to achieve some kind of competitive edge, creative transformation, or some unique version of self-transformation. As we write about these things, we are aware that some of these ideas might sound like the plot lines from various science fiction novels. When we push the limits of this kind of thinking—and translate it into practice, we might obtain very interesting but sometimes sobering or even frightening results. For example, it was sobering and frightening to find that clones aged at a much more rapid rate, reflecting the age of the DNA.

As stated earlier, evolution itself is not teleological. The direction is not inevitable. It is not directed by moral or ethical considerations. For this and related reasons, people should pay attention to the tremendous ethical controversies surrounding these issues. Our entire society should wrestle with these ethical dilemmas and address them. There is the daunting task of showing respect for all, while at the same time recognizing the inequities promulgated by the interplay of nature and nurture. How these differences should be handled in the future should be widely discussed. The consequences of such matters should be vigorously debated and ethically informed policies must be formulated. With these ethical considerations in mind, we would like to review three learning mechanisms through which one can imagine that the number of higher order creative innovators might increase: (a) cultural evolution, (b) biological evolution, and (c) computer and robotic hardware and software evolution.

Cultural Evolution

Cultural evolution now promotes people who reason at the highest stages. All Nobel Prize winners in the sciences reason at least at the metasystematic stage and many corporate presidents, Supreme Court justices, and presidents reason at the metasystematic stage (Commons et al., 2002). Could cultural evolution also produce biological evolution? With the increase in demand for people with the highest stages of postformal reasoning, certain forces have come to bear. Our society is rapidly acquiring the technological know-how that will permit experts to engage in human engineering and cloning. Commons-Miller (in press) suggests that people have begun to use a variety of mechanisms short of biological engineering to produce intellectually superior individuals. Historically, among other mechanisms, these include assortativeness. Assortativeness means that there is a demand for separation from the rest of the population (Buss, 2003). It is accomplished by means of clubs, zoning, rules promoting intragroup marriage and blocking intergroup marriages, and career specialization by groups. Assortativeness has always been a force in human cultural and biological evolution. The evidence suggests that many will be tempted to move in this direction, as those with high intelligence already do in the Mensa organization, for example.

Biological Evolution

Commons-Miller (in press) thinks that there is heavy demand for genetically improved human beings. We are already seeing changes in sex ratios in China and India by genetic selection (Hudson & den Boer, 2004). These changes are described by David Baltimore, a Nobel laureate who heads the California Institute of Technology. He suggests that these changes will encourage the rapid development and utilization of germline engineering. This in turn will lead to speciation, as Dyson (1999) also argues. He states that the speciation of humans into different groups is inevitable—and that it would be a disaster to allow such diversification without restraint. Biological evolution, as described by Darwin, requires isolation among individuals, within species. Mayr (1942) stated that a new species develops if a population that has become geographically isolated from its parental species acquires, during this period of isolation, characteristics that promote or guarantee reproductive isolation when the external barriers break down. Mate choice or sexual selection also may drive the speciation process (Higashi, Takimo, & Yamamura, 1999). Assortativeness, choosing people like oneself, might be the required force for selection. It is predicted that speciation in humans is soon likely, however controversial it is. That is, we might begin to find the differentiation of humans into more than a single species. Some groups might begin to engage in genetic engineering to isolate their group from the rest of humanity. This isolation can cause speciation.

If these individuals are sufficiently different enough and brighter and can survive inbreeding, some would argue that a new species might evolve. This new species might have a greater proclivity for creativity in general, and in science in particular, if some of the relevant traits already discussed, as well as the highest postformal stages, are selected for.

Computer and Robotic Hardware and Software Evolution

As upsetting as it might be, there is another way that people might attempt to create the extrahuman or superhuman levels of achievement by somehow linking advanced humans with superior reasoning and creative proficiencies with hierarchically complex stacked neural-net computers (Commons & White, 2003). The product or offspring might be able to solve problems in science that are not solvable by ordinary high-functioning humans. The motivation for supercomputers, on the other hand, would seem to differ from speciation. The development of computers is relentless, with most people cheering the changes. Computers, like all technology, can be used for good and evil—remember Hal in Arthur Clarke's (1968) book and movie *2001.* Such supercomputers likely could be built from stacked neural nets and in turn, reason like humans but not be limited in the number of layers. This is an important consideration, because we speculate that the number of layers of interconnected neural networks is related to the order of hierarchical complexity at which such machines will perform. It might be interesting to assess their stage of development with our MHC scoring system.

Again, the consequences of all these possibilities must be thoroughly debated and policies formulated with an ethical standard in mind. Furthermore, we argue that the debate must be spirited, and it should begin soon. The doggedness with which individuals and groups might pursue such revolutionary intellectual and creative transformations as these may prove to be truly remarkable. Could Darwin have had any idea where some of his early theorizing might lead?

CONCLUSION

The creation of major cultural innovations is multidimensional. These innovations are often accomplished by distinct groupings of individuals who display an assortment of specific traits. Darwin was chosen as an example of one with the requisite traits; however, several other major innovators were discussed as well. Most major innovators display the essential traits or characteristics discussed throughout this chapter. Several characteristics that have been proposed are absolutely necessary. Most important is the order of hierarchical complexity of tasks with which such a person could deal successfully. This includes the complexity in the area of the work as well as commensurate complexity in the social system. When these two dimensions work together, the likelihood of a major creative innovation is enhanced.

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