Generativity Theory

Robert Epstein
United States International University
and Cambridge Center for Behavioral Studies

Automatic Chaining A process wherein a sequence of behaviors emerges when one behavior accidentally produces a stimulus that makes another behavior more likely. Also called auto-chaining.

Creativity Competencies Skills that are essential for the expression of creativity. The four core competencies for individuals are capturing (preserves new ideas as they occur), challenging (seeks challenges and manages failures), broadening (seeks diverse training and knowledge), and surrounding (makes frequent changes in the physical and social environments).

Extinction The cessation of reinforcement.

Frequency Profile A graph of overlapping frequency curves, each showing a moving sum or moving average of occurrences of various behaviors in small intervals of time.

Generativity Theory A formal theory of the creative process that suggests that new behavior is the result of an orderly competition among previously established behaviors.

Insight A cognitive process said to occur when the solution to a problem occurs to someone suddenly, without obvious precursors.

Probability Profile A graph of overlapping probability curves that shows how the probabilities of different behaviors in an individual change over time.

Reinforcer A consequence of behavior that strengthens that behavior.

Resurgence The reappearance of previously reinforced behaviors that occurs when a current behavior is no longer effective.

Transformation Functions A series of equations which, when employed iteratively in a state model, generate curves that can predict complex behaviors in an individual continuously in time.

GENERATIVITY THEORY is a formal, predictive, empirically based theory of ongoing behavior in novel environments. Because it can be used to predict and engineer novel performances, it is also a theory of creativity. Generativity Theory suggests that novel behavior is the result of an orderly, dynamic competition among previously established behaviors. By using specific equations, called "transformation functions," in a state model, the theory can predict ongoing performances in individual subjects continuously in time. The theory has also been used to engineer novel, complex performances in both humans and animals. Management techniques derived from Generativity Theory have recently been applied in *business and industry to enhance and direct employee creativity. Most recently, Generativity Theory has led to the development of tests that measure creativity competencies in both individuals and managers.*

I. BACKGROUND

Generativity Theory has its origins in pigeon research conducted at Harvard University in the late 1970s and early 1980s. In a series of studies conducted by Robert Epstein, B. F. Skinner, and others, pigeons were shown to be able to behave in a variety of complex ways typical of human behavior. In the first of these studies, published in a satirical article in *Science* in 1980, pigeons appeared to demonstrate a form of "symbolic communication." The two pigeons, named Jack and Jill, were in adjacent chambers separated by a clear plastic partition. Jack initiated each exchange by pecking a sign labeled "What Color?" Jill, having seen this, thrust her head through a curtain where she could see one of three colors hidden from Jack's view—either red, green, or yellow. She then pecked the corresponding alphabet letter on her side of the partition—"R" for red, "G" for green, or "Y" for yellow. Jack, having observed this, rewarded Jill with food by pecking a sign labeled "Thank You," thus operating an automatic feeder in Jill's chamber. Finally, Jack pecked one of three colored disks on his side of partition which corresponded to the letter Jill had illuminated. Jack's feeder was then automatically operated, after which he initiated another sequence. Even though the colors behind Jill's curtain changed randomly at the beginning of each sequence, the birds were able to "communicate" with each other accurately for extended periods of time on more than 90 percent of the trials. Random selections of alphabet letters and colors would have yielded about a 33 percent rate of accuracy. Thus it appeared that the pigeons were able to communicate "messages" to each other using arbitrary symbols.

This study was conducted to demonstrate the power of operant conditioning techniques in establishing complex performances, reminiscent of an early study of Skinner's in which pigeons were taught to play Ping-Pong. It was intended in part as a form of criticism of current research on chimpanzees, in which it was common for researchers to "anthropomorphize"—that is, to mistakenly attribute higher-order human cognitive abilities to animals, often ignoring simpler explanations for the human-like behavior they observed.

The Jack and Jill study was perhaps more of a political statement than a scientific study, but it soon led to a series of studies—with unlikely titles such as "The Spontaneous Use of Memoranda by Pigeons," "Spontaneous Tool Use in the Pigeon," "'Self-Awareness' in the Pigeon," "'Insight' in the Pigeon," "The Spontaneous Interconnection of Four Repertoires of Behavior in a Pigeon," and so on—which, over time, shed significant light on the laws that govern the emergence of novel, complex behavior in both animals and people.

II. "INSIGHT" IN THE PIGEON

In perhaps the most striking of these studies, published by Epstein and his colleagues in *Nature* in 1984, pigeons solved a classic problem—the so-called "box-and-banana problem"—first studied by Gestalt psychologist Wolfgang Köhler in the early 1900s. In one variation of the problem, a banana was suspended out of reach of a group of chimpanzees, and a wooden crate was placed on the floor a few feet away from the position of the banana. The chimpanzees' attempts to reach the banana by reaching and jumping proved fruitless. After a few tries, most of the chimpanzees did little else of interest in this situation. But one chimp, named Sultan, paced back and forth between the banana and the crate for several minutes, apparently confused and frustrated. Then, suddenly, he moved the crate into position beneath the banana, climbed onto the crate, and managed to jump from there and retrieve the banana. Köhler could offer no explanation for this remarkable performance other than to suggest that it demonstrated "insight." [*See* INSIGHT.]

In the *Nature* study, Epstein and his colleagues first gave pigeons various types of training and then confronted them with the box-and-banana problem. All of the pigeons received food for pecking a small facsimile of a banana when the banana was within reach. Subsequently all of the pigeons readily oriented toward and pecked the toy banana whenever it was placed nearby at eye level. Some of the pigeons were also taught to push a small box around the floor of their chamber. Still others were taught more precise pushing: to push the box toward targets placed at different locations along the base of the wall of the chamber. Some pigeons were also taught to climb onto a box and to peck the banana directly overhead, and some pigeons learned that jumping and flying in the direction of the toy banana when it was suspended out of reach did not produce a food reward; in effect, they learned to ignore the banana when it was suspended out of reach.

After training, each pigeon was confronted with the classic problem: The toy banana was suspended out of reach, and the box was placed elsewhere in the chamber. None of the pigeons had ever seen this particular arrangement before. Each pigeon behaved in new ways when confronted with this new situation, and the general finding was that the new behavior that emerged was systematically related to the training the bird had received prior to the test. For example, birds that had learned (a) to climb and peck, (b) to push the box directionally, and (c) to ignore the banana when it was suspended out of reach, solved the problem in a remarkably Sultan-like (and human-like) way. At first they motioned back and forth between the box and the banana in apparent confusion and then, suddenly, began to push the box toward the banana, sighting the banana as they pushed. When the box was beneath the banana, they stopped pushing, climbed, and pecked. The entire performance typically took about a minute to complete (Figure 1).

A bird that had not learned to ignore the banana when it was out of reach spent about 4 min jumping and flying toward the banana before finally solving the problem in a rapid fashion. A bird that had been

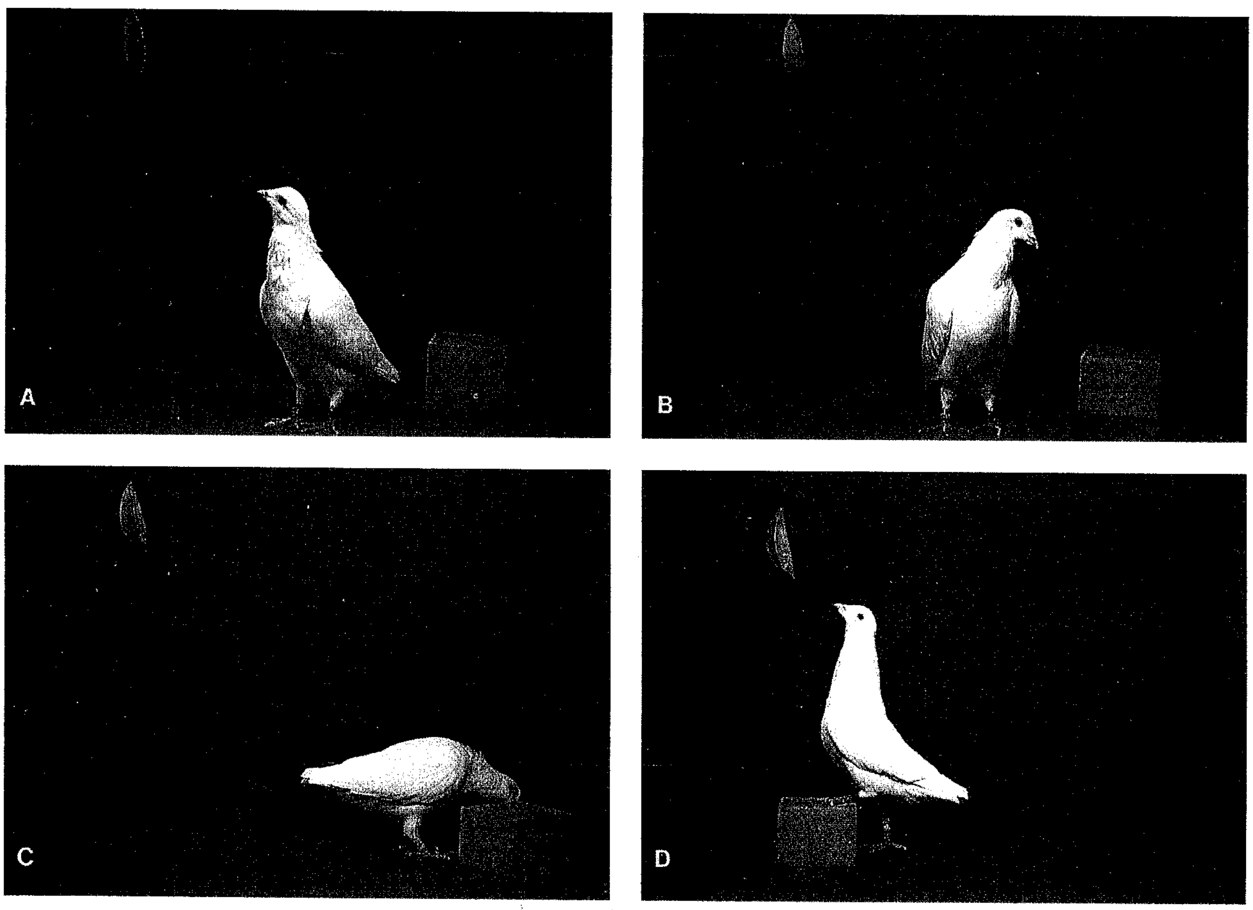

FIGURE 1 "Insight" in the pigeon. When faced with the box-and-banana problem for the first time (A and B), at first the pigeon looks back and forth between the banana and the box in apparent confusion; (C) then, suddenly, it begins to push the box toward the banana, sighting the banana as it pushes, and (D) stops pushing when the box is beneath the banana, climbs onto the box, and pecks the toy banana.

taught to climb and peck but that had never learned to push the box toward targets rarely looked up while pushing the box around the chamber. After 14 min of pushing, it happened to look up when the box was beneath the banana, at which point it immediately climbed and pecked—a performance one might label "trial-and-error." Birds that had never learned to push did not push the box during the test, and birds that had never learned to climb also failed to solve the problem.

The point is that a wide range of novel performances—from failures to trial-and-error performances to "insightful" ones—can be understood, at least in part, by looking at the particular training history of the animal. What's more, the authors offered a tentative moment-to-moment account of the emergence of the novel performances in terms of laws and principles that govern the transformation of previously established behaviors in novel situations. The account can be considered an early, informal version of Generativity Theory.

III. THE TWO-STRING PROBLEM

In a series of publications beginning in 1985, Epstein introduced a formal methodology for analyzing, predicting, and engineering complex novel performances in animals and people. In an application of this methodology with human subjects, Epstein showed that the behavior of people confronted with Norman Maier's classic "two-string" problem can be modeled using principles from Generativity Theory which have been cast into mathematical form. In the two-string problem, the subject is shown into a room in which two long strings are suspended from a high ceiling. The researcher points to an object, such as a pliers, which is positioned on table, and says, "Your task is to tie the ends of these strings together. If necessary, you may use this object to help you."

The subject immediately takes hold of one string and pulls it toward the other, only to find that the strings are so far apart they cannot be touched simultaneously (see Figure 2). Typically, and the laws of geometry notwithstanding, the subject then takes hold of the second string and pulls it toward the first. Some subjects repeat this pattern several times. Eventually, the subject

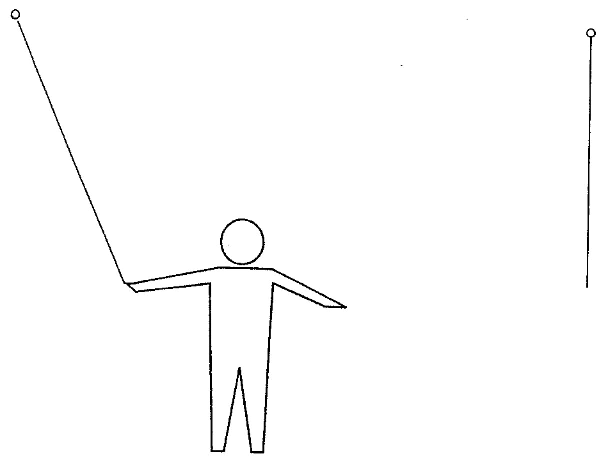

FIGURE 2 When faced with the two-string problem, subjects usually begin by pulling one string toward the other. After they find that they cannot reach the second string, they often pull the second string toward the first.

may try to use the object to extend his or her reach, but that does not work either, since the object is never long enough to allow contact with the other string. The solution to the problem is to tie the object to one string and to set that string in motion in a large arc—in other words, to construct a pendulum. Then the subject simply walks over to the second string, pulls it back toward the swinging string, and catches the swinging string when it swings within reach. With one string now in each hand, it is a simple matter to tie the ends together.

Epstein showed that outcomes in this performance can be systematically altered by changing simple features of the object on the table. For example, given a relatively long object (but not long enough to allow contact with the second string), subjects have enormous difficulty solving the problem; some cannot solve it at all, presumably because long objects are typically used for reaching, not for constructing pendulums. Given a relatively short object, subjects solve the problem readily—usually within a minute or two.

Of greater importance, Epstein showed that simple principles of behavior, instantiated in a computer model, can predict different types of performances under different stimulus conditions. In Figure 3, for example, overlapping probability curves are shown for a performance involving a short object. The curves show a fairly smooth transition from (a) pulling one string

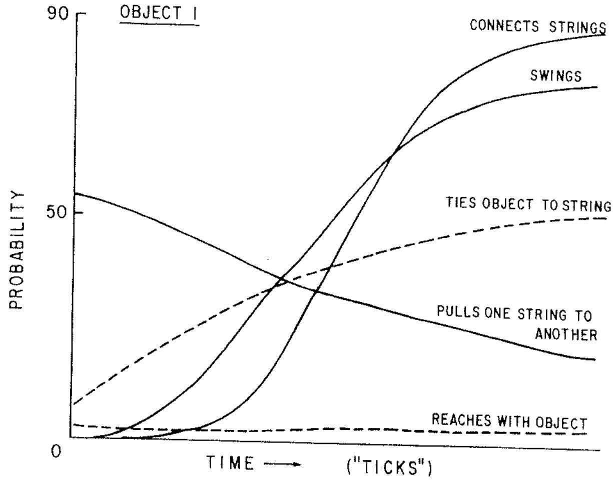

FIGURE 3 A probability profile generated by the transformation functions mentioned in the text (Figure 4), shown for five behaviors in the two-string problem. The *x*-axis is labeled "ticks," which are cycles of the computer algorithm. The profile was generated with parameters for the short object (Object 1), which produced rapid solutions to the problem and no irrelevant reaching. Note that pulling one string toward the other decreases steadily in probability and that other behaviors increase in probability in an orderly sequence. Tying the object to the string makes swinging more likely, which, in turn, makes connecting the strings more likely.

toward the other, to (b) tying the object to a string, to (c) setting one string in motion, and to (d) connecting the strings.

IV. REAL-TIME PREDICTION

According to Generativity Theory, novel behavior (including the verbal and perceptual behaviors we often call "ideas") is the result of an orderly and dynamic competition among previously established behaviors, during which old behaviors blend or become interconnected in new ways. If the process is so orderly, why does creativity seem so mysterious, and why do people often feel confused or frustrated before or during creative episodes? [*See* NOVELTY.]

The air of mystery surrounding creativity is probably due to several factors. For one thing, when behaviors are competing, the nervous system is in some sense overloaded, and we feel that overload as confusion and frustration. It is difficult enough to experience this process and harder still to try to analyze it while it is occurring. The process of interconnection is also fairly complex—typically so complex that it takes the power of a computer to analyze the process. The computational complexity of the process alone is probably enough to make it seem mysterious. New ideas often seem to come out of the blue, mainly because we cannot track the antecedent events or processes.

Computer simulations model the interconnection process using a mathematical "state" system. In each cycle of the algorithm—in other words, each state of the system—several behavioral processes are assumed to be occurring simultaneously, with each operating on the probabilities of multiple behaviors. Each process is represented by a simple equation, called a "transformation function" (Figure 4), and each cycle is assumed to represent a very small interval of time. At the end of a cycle, the resulting probabilities are plugged back into the same equations to begin the next cycle. Surprisingly, with repeated cycling, the probabilities change in increments small enough to yield relatively smooth curves (Figure 3), which together comprise a "probability profile"—a graphical picture of how the various behaviors are expected to change over time.

The equations shown in Figure 4 are labeled with the names of empirically established behavioral laws, such as extinction (the decrement in responding that

(1) *Extinction:* $y_{n+1} = y_n - y_n * \epsilon$

(2) *Reinforcement:* $y_{n+1} = y_n + (1 - y_n) * \alpha$

(3) *Resurgence:* for $\lambda_{yy'} < 0$ and $y'_n - y'_{n-1} < 0$, $y_{n+1} = y_n + (1 - y_n) * (-\lambda_{yy'}) * y'_n$

(4) *Automatic Chaining:* for $\lambda_{yy'} > 0$ and $y'_n - y'_{n-1} > 0$, $y_{n+1} = y_n + (1 - y_n) * \lambda_{yy'} * y'_n$

FIGURE 4 Equations used to generate the probability profiles shown in Figures 3 and 5. y_n is the probability of behavior y at cycle n of the algorithm, y'_n is the probability of behavior y' at cycle n of the algorithm, ϵ is a constant for extinction (it determines the rate at which the probability of behavior y decreases over cycles of the algorithm), α is a constant for reinforcement (it determines the rate at which the probability of behavior y increases over cycles of the algorithm as a result of certain environmental events), and $\lambda_{yy'}$ is the constant of interaction between behaviors y and y'.

occurs when reinforcement is withheld), reinforcement (the strengthening of behavior that occurs when behavior has certain consequences), resurgence (the reappearance of old behaviors that occurs when current behavior is ineffective), and automatic chaining (the sequencing of behaviors that occurs when one behavior accidentally generates a stimulus that occasions another behavior). Other laws can easily be incorporated into this type of model, and equations can be refined so as to represent various laws more accurately.

Epstein has also developed a new method for plotting the behavior of an individual subject in graphical form. This type of graph, called a "frequency profile," yields overlapping curves that are similar to probability curves in some respects, and it can be generated in real time or post hoc. A frequency profile is generated by computing a moving average or sum across binary values that represent the occurrence or nonoccurrence of each of the individual's behaviors in small intervals of time. Comparing the curves of a probability profile to the curves of a frequency profile allows one to evaluate the accuracy of a simulation (Figure 5).

In recent years, Epstein and his colleagues have used this methodology to study and simulate the behavior of both adults and children performing a wide variety of tasks. Typically, a subject is asked to solve a problem using various toys or unusual objects. The performance is videotaped and later coded, which allows a frequency profile to be constructed and models to be generated. Most recently, subjects have been given problems to solve on a computer touch screen, so that both frequency profiles and probability profiles can be generated in real time. This methodology may soon allow relatively complex novel performances in individual human subjects to be predicted continuously in real time.

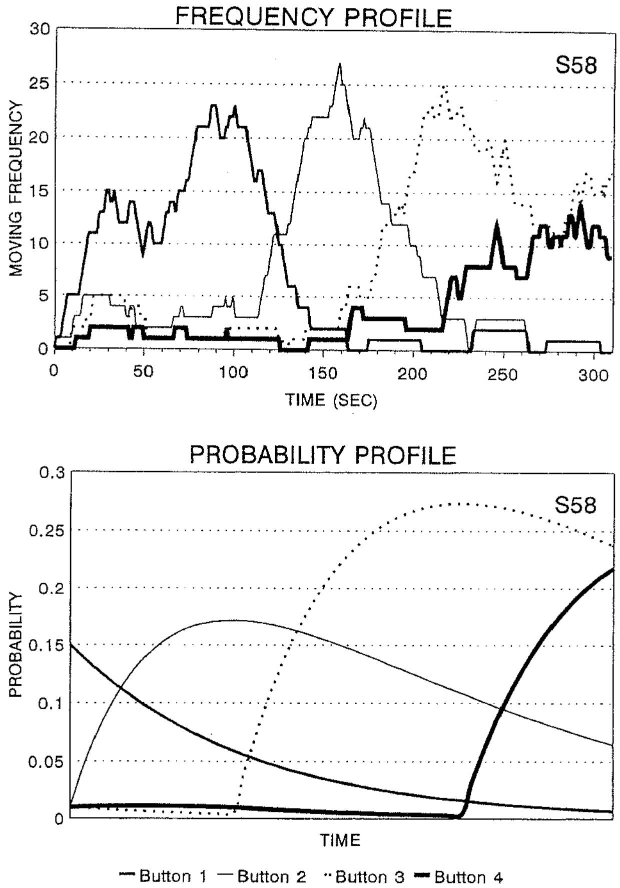

FIGURE 5 A frequency profile (top panel) and a corresponding probability profile (bottom panel) for an individual subject who is trying to solve a simple problem on a computer touch screen. Over a 5-min period, the subject gradually shifts from one strategy to another in an attempt to move a spot across the screen. Actual (top) and predicted (bottom) curves follow the same pattern.

V. CREATIVITY COMPETENCIES

Generativity Theory suggests that the generative mechanisms that underlie creativity are universal. After all, variability is the rule in behavior; no one brushes his or her teeth the same way twice, and it is rare that we repeat the same sentence. We also negotiate our way through new supermarkets and malls reasonably well; in other words, novel stimuli reliably produce novel, fairly effective behaviors in just about everyone. We all solve problems, large and small, throughout the day. We all daydream, we all have fantastic dreams at night, and we all enter the fertile "hypnagogic" state—the odd semisleep state we experience just before we fall fully asleep. Moreover, generativity models seem to work well with everyone; only parametric changes are needed to accommodate different individuals.

But if generative mechanisms are universal, why do so few people express creativity? There are two principle reasons. First, as part of the socialization process that begins when children enter the first grade (at about age 6), children are severely discouraged from expressing new or unusual ideas, and daydreaming is strictly forbidden. In kindergarten, virtually all children are creative, whereas very few children express creativity by the end of the first grade. This is not because of some sudden change in the brain; it is due entirely to educational demands. Second, the expression of creativity depends on a set of "competencies"—particular skills and abilities that underlie successful performance. For obvious reasons, creativity competencies are not taught in our school systems. A small number of people manage to acquire some of these competencies by accident or through certain role models—the uncle who composes music, for example, or the inventor who lives down the street. The vast majority of people, however, have very few of the skills needed for the expression of creativity. Alas, the children who continue to express creativity throughout the school years are the ones who are difficult to socialize. In other words, our society inadvertently makes creativity the nearly exclusive property of antisocial personality types.

Generativity Theory suggests four core competency areas—capturing, challenging, broadening, and surrounding—that are critical for the expression of creativity in individuals, as well as eight competency areas that allow teachers and managers to elicit creativity in others. Validated tests, called, respectively, the Epstein Creativity Competencies Inventory for Individuals (ECCI-i) and the Epstein Creativity Competencies Inventory for Managers (ECCI-m) have been developed to measure both core and managerial competencies, and training programs now exist to boost competencies that are weak. The four individual creativity competencies are as follows:

1. *Preserves new ideas* ("Capturing"). The individual preserves new ideas as they occur and manages resources to aid in this process. The elite group of people we tend to call "creative" typically have superb capturing skills. Artists carry sketch pads compulsively; writers carry notebooks or tape recorders and keep such tools by their beds at night; and inventors record ideas on napkins, sleeves, or skin when proper writing materials are unavailable. It is easy to learn capturing skills and to surround oneself with the tools that make capturing likely.

2. *Seeks challenges* ("Challenging"). The individual subjects him- or herself to difficult and challenging tasks that require performance exceeding current levels of skills or knowledge. New ideas emerge when multiple repertoires of behavior compete, and one of the simplest ways to get multiple behaviors going is through the resurgence of old behaviors that occurs when current behavior is ineffective. When you are locked in a room, for example, every behavior that has ever gotten you through a closed door becomes more probable: jiggling the door knob, pounding on the door, kicking the door, shouting for help, and so on. From these various behaviors, new sequences or new blends emerge. Thus, learning to manage failure—and not to fear failure—is an important means of boosting creativity.

3. *Broadens skills and knowledge* ("Broadening"). The individual seeks training, experience, and knowledge outside of current areas of expertise. The more diverse the repertoires of behavior, the more interesting, frequent, and surprising the interconnections.

4. *Changes physical and social environment* ("Surrounding"). The individual changes his or her physical and social environments on a regular basis. Resurgence gets multiple repertoires competing, and so do unusual or diverse stimuli. A static environment is deadly for generative processes.

The eight creativity competencies for managers and teachers derive from the core competencies just listed, but additional skills are also required, because the manager's principle function is to develop and nurture the core competencies in other people. The eight competencies for managers are as follows: [*See* CORPORATE CULTURE.]

1. *Encourages preservation of new ideas.* The manager provides opportunities, encouragement, and resources that allow others to preserve new ideas as they occur. In the corporate setting, this can be achieved through training, by providing appropriate supplies or software, by establishing anonymous suggestion systems, and through many other methods.

2. *Challenges others.* The manager presents others with difficult and challenging tasks. One of the simplest ways to do this is by making sure that all tasks, goals, and assignments are stated in an "open-ended" form—a form that neither states nor implies boundaries or limits. A variety of "controlled failure systems" can be established to manage failure productively in organizational settings.

3. *Encourages broadening of knowledge and skills.* The manager provides opportunities for others to obtain training, experience, and knowledge outside of their current areas of expertise.

4. *Manages surroundings to stimulate creativity.* The manager changes the physical and social environments of other people on a regular basis.

5. *Manages teams to stimulate creativity.* The individual manages teams and workgroups to optimize creative output. For example, since creativity is fundamentally an individual process, the creative output of a team is greatly enhanced through a simple technique called "shifting": Team members are shifted in and out of the group so that they alternate between periods in which they work on the problem alone and periods when they work on the problem with others.

6. *Manages resources to stimulate creativity.* The manager seeks to provide others with adequate resources to allow them to develop new ideas.

7. *Provides feedback and recognition to stimulate creativity.* The manager interacts with others in ways that encourage creative thinking. This involves withholding judgment at certain times, providing incentives for the expression of new ideas, and so on.

8. *Models appropriate creativity-management skills.* The individual sets a good example by managing his or her own creativity skillfully, meaning that he or she has strong core competencies.

Through training, modification of the physical and social environments, the establishment of controlled failure systems, proper team management, appropriate evaluation systems, the proper use of incentives and feedback, and other means, the creative output of both individuals and groups can be both enhanced and directed toward desired ends.

VI. CONCLUSIONS

Generativity Theory provides a powerful framework for the scientific study and understanding of the creative process. The theory and related research have demonstrated that the creative process in individuals is orderly and predictable continuously in time. The theory also suggests that the generative processes that underlie creativity are universal and that, with appropriate training, almost anyone will display a high degree of creativity. Few people have the appropriate competencies necessary for the expression of creativity because our educational system does not teach these competencies and because society in general discourages most people from expressing creativity. Generativity Theory provides guidelines for identifying the necessary competencies, assessing current competency levels, and providing the appropriate training.

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