Generativity Theory and Education

Robert Epstein

It's not easy to fault Albert Einstein, but on one matter, anyway, he was wrong. Einstein believed that creativity was beyond objective, scientific analysis—and hence, beyond our ability to engineer. "One can organize," said Einstein, "to apply a discovery already made, but not to make one" (quoted in Winokur, 1984, p. 69).

Every subject matter that science has tackled has appeared mysterious at first. The ancient Greeks credited Helios with the task of moving the sun across the sky each day. Every morning Helios left a magnificent palace in the east and crossed the sky in a golden chariot. At night he rested in a lesser palace and then took the river-route home. An appealing image, to be sure, but a spurious explanation for the sun's apparent movement across the sky. After all, the sun isn't even moving. The Helios story is way, way off.

In its pre-scientific stage, creativity, too, has given rise to spurious explanations and mythical tales, tales that proliferate to this day. For example, corporate trainers now tell us that creativity resides in one side of the brain and claim that they can train you to use the appropriate side. The image, once again, is powerful, but it has no basis in fact. Right-brain, left-brain distinctions are based on a minuscule number of cases of people with seriously defective brains; it's not at all clear that these distinctions, if valid, have any implications for normally functioning brains. Normal people have one brain, not two, thanks in part to a huge structure—the *corpus callosum*—that connects the two hemispheres.

"Spontaneity," said Samuel Butler, "is only a term for man's ignorance of the gods." When something seems to come from nothing—*ex nihilo*—there's one thing we can be sure of: It doesn't. We just don't know enough yet to understand the phenomenon.

Over the last decade or so, creativity has finally begun to give way to a more rigorous understanding. The behavior we call "creative" has been studied in laboratory settings with both animals and people, and that behavior has proved to be orderly and predictable—understandable in objective, scientific terms. The implications for a struggling educational system, for lackluster business and industry, and for personal growth and productivity, are enormous. A thorough understanding of creativity will do nothing less than put us in the driver's seat of that golden chariot that crosses the sky each day.

Generativity Research and Theory

Origins of the Theory

Generativity research began with pigeons, who proved, contrary to popular belief, that a sow's ear can be turned into a silk purse. In the late 1970s, B. F. Skinner and I set about to make fun of some research that was being conducted with chimpanzees. Some rudimentary accomplishments of chimps were being glamourized and anthropomorphized to an extreme, we believed. We thought we could make the point by producing comparable performances in lowly pigeons. Our approach, at least sometimes, was as follows: A pigeon was provided with some human-like training and then placed in a *new* situation like one a child might face. If new, human-like behavior emerged, we argued that comparable human and chimp performances could be attributed to a simple training history. Somewhat to our surprise, we were able to produce a number of spectacular examples of human-like behavior in pigeons: problem solving, cooperation and competition, even "moral" behavior.

For example, as we reported in *Science* in 1981 (Epstein, Lanza, & Skinner, 1981), a pigeon that has been trained to use a mirror to locate objects in real space can subsequently—and without additional training—use a mirror to locate an object on its body which it cannot see directly. Such behavior in chimps and children has been attributed by some researchers to "self-awareness." We argued that "self-awareness" was a fuzzy idea that only called attention away from the real origins of complex behavior.

Over time, I realized that our simple "Columban simulations"—*Columba livia* is the taxonomic name for pigeon—had other, larger implications. We had provided training, to be sure, but in our test situation, *the pigeons always did something new, sometimes something dramatically new.* The training was the starting point for novel performances. How were those

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Epstein, R. (1993). Generativity theory and education. *Educational Technology, 33*(10), 40-45.

performances related to previous training? Could a new performance be predicted, and, if so, to what extent?

I began, over the next decade, to study many novel performances, ultimately with human adults and children. Other researchers have followed suit. An increasingly clear picture of the creative process has emerged (Epstein, 1985a, 1990, 1991).

Multiple Repertoires

People have long speculated that creativity was a "coming together" of some sort. Arthur Koestler (1964) thought it was the result of "bisociation"—the merging of two distinct ideas. Rothenberg (1971), a psychiatrist, attributed it to "Janusian thinking," after Janus, the god of two faces. In a little known scientific article published in 1935, the eminent psychologist Clark Hull attributed novelty in behavior to "the assembly of behavior segments." So-called "creative" people often describe their creative moments in similar language: Einstein spoke of "combinatory play," for example, and paleontologist Stephen Jay Gould has attributed his creativity to his ability to "make connections" (Shekerjian, 1990).

Generativity research elucidates the dynamics of the combinatorial process. In one study, published in *Nature* in 1984 (Epstein, Kirshnit, Lanza, & Rubin, 1984), pigeons with various training histories proved able to solve the famous "box and banana" problem of Wolfgang Köhler, who studied how apes solved the problem, and attributed their solution to "insight"—another mystery. In our experiment, a pigeon has received food for pecking at a small facsimile of a banana, and it has also learned to climb and to push a small box toward targets at ground level. Jumping and flying toward the banana when it's out of reach has been "extinguished"—that is, food has been withheld for jumping and flying. In the test situation, the banana is suspended out of reach, and a box is placed on the floor about a foot away.

A pigeon with appropriate training behaves in a remarkably human-like fashion in this situation. At first, it appears to be "confused": It stretches repeatedly toward the banana, motions toward the box, turns in circles, and so on, and then, quite suddenly, pushes the box directly toward the banana, climbs, and pecks the banana (Figure 1).

Altering the training histories of different birds allows us to see how various components contribute toward success or failure in this situation. For example, if you never train climbing, the bird pushes the box until it's beneath the banana, and then the bird stretches toward the banana and stumbles. One bird we tested mounted the box briefly and then fell off before pecking the banana. If jumping and flying have not been extinguished, a bird jumps and flies toward the banana for several minutes before finally pushing the box and climbing.

Detailed analyses of videotapes of such performances reveal the dynamics of competition and combination as the various repertoires compete, and more complicated performances, involving up to four separate repertoires and five types of training have been studied (e.g., Epstein, 1985, 1987). The analyses have allowed moment-to-moment accounts of the emergence of novel performances (Epstein, 1990, 1991).

Generativity Theory

Generativity Theory can only be stated precisely as a series of equations or as a computer algorithm. Stated roughly in words, the theory is as follows: *Various processes operate simultaneously and continuously on the probabilities of many behaviors. Novel behavior is an outcome of the resulting dynamics.*

If that is unclear, try thinking about "ideas" or "neural circuits in the brain" instead of behaviors. Typically, many ideas compete for our attention at the same time. Sometimes the competition is fierce—we feel the competition as "confusion"—and sometimes not. Similarly, many neural circuits are active simultaneously in the brain; again, sometimes the competition is intense and sometimes not. The dynamics of competition operate according to certain rules, which I call "transformation functions," and these rules, specified in a computer program, can be used to simulate or to make predictions about real behavior.

Two Strings

One of several problems I've studied with adult humans is Maier's (1931) famous "two string" problem. Two long strings are suspended from a high ceiling, perhaps 10 meters apart. The subject is informed that it is her task to connect the ends of the strings together. She is also shown a small object—sometimes, a long stick with a hook at the end of it—and told that she may use the object to help solve the problem.

The following performance is typical in this situation: The subject will pull one string toward the other and reach, but the second string is too far away to grasp. The rules of geometry notwithstanding, most subjects will then grab the second string and try pulling it toward the first. Subjects will often repeat these futile steps several times, although less and less frequently as the minutes pass.

Eventually, the subject will pick up the stick to try to extend her reach. That also fails. At some point the subject will tie the stick to one string, often still trying to use the stick to extend her reach. The subject may give up at this point, letting the stick, now tied to the string drop toward the floor. The string, weighted at the end, swings slowly in a small arc, pendulum-style.

Aha. The subject immediately swings the stick in a large arc, walks to the other string, grasps it and walks

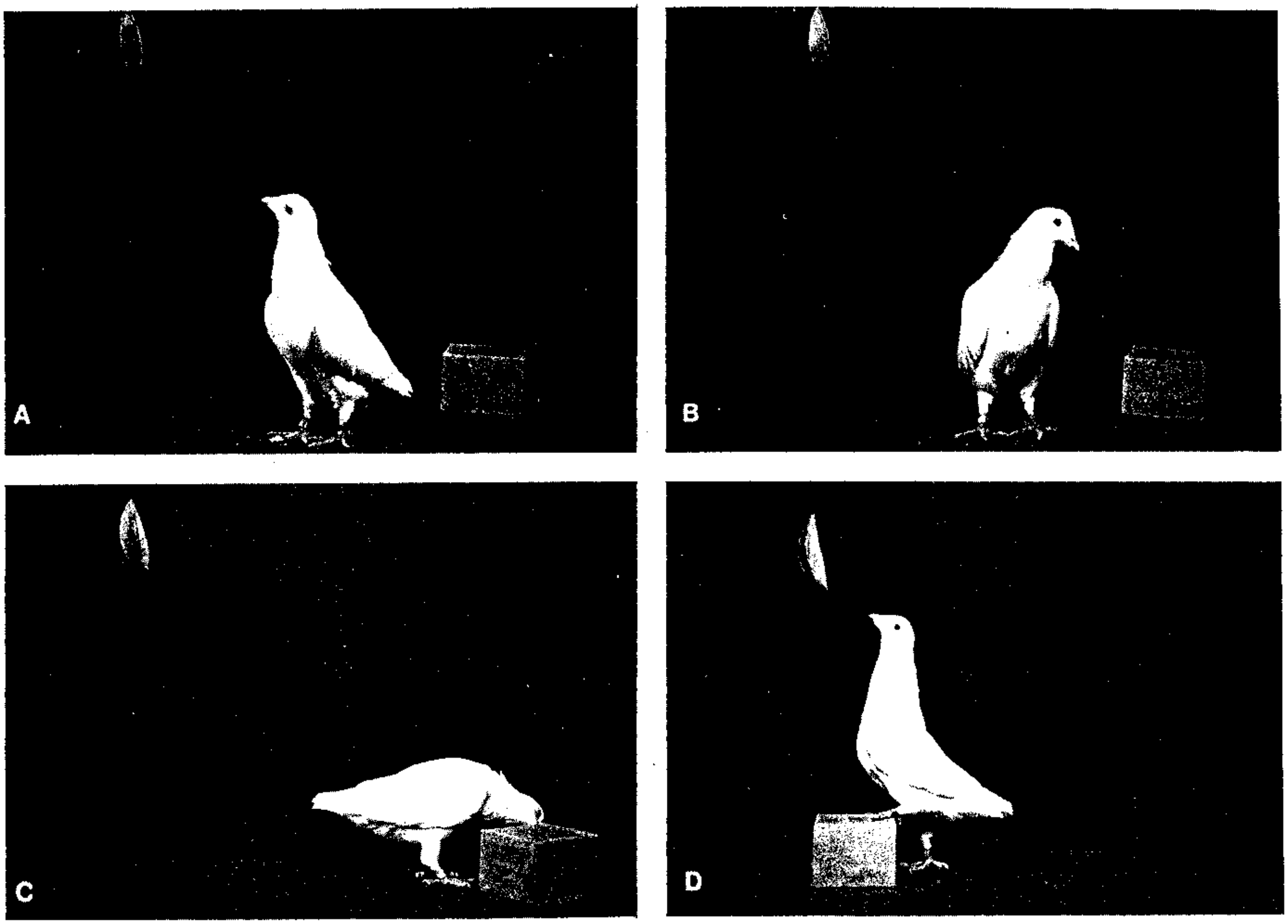

Figure 1. "Insight" in the pigeon. (A, B) The bird looks back and forth from banana to box. (C) It pushes the box toward the banana. (D) It climbs and pecks. (Photo by R. Epstein.)

back toward the swinging string, catches the stick when it swings near, and ties the ends of the strings together.

This fascinating performance proves to be remarkably orderly when the tools of generativity are applied. Moment-to-moment accounts of such performances are possible. For example, the "aha" portion of the example described above exemplifies the simple process called *Automatic chaining:* Behavior often changes the world in a way that occasions other behavior. When you open a refrigerator door seeking a glass of water, you may find a chocolate cake on the top rack, which suddenly makes eating more likely. When a subject drops the stick and accidentally sets the string swinging, relevant behaviors, such as throwing and catching, are immediately made more likely.

Processes such as automatic chaining, cast into a series of simple equations—the *transformation functions*—have been used to simulate performances on the two-string problem and many others (Figure 2). Computer simulations of novel, problem-solving performances, often look very much like real performances. In other words, novel, problem-solving performances—the kind we sometimes call "creative"—are orderly and predictable.

Current Research Strategy

Currently, generativity research consists of the following:

(1) A human subject, either a child or an adult, is given a simple, mechanical problem to solve, and the performance is videotaped. Problem solving is a good context in which to study novel behavior, because, by definition, one is faced with a "problem" when one must behave in a new way to succeed. The new problems we study are similar to the two-string

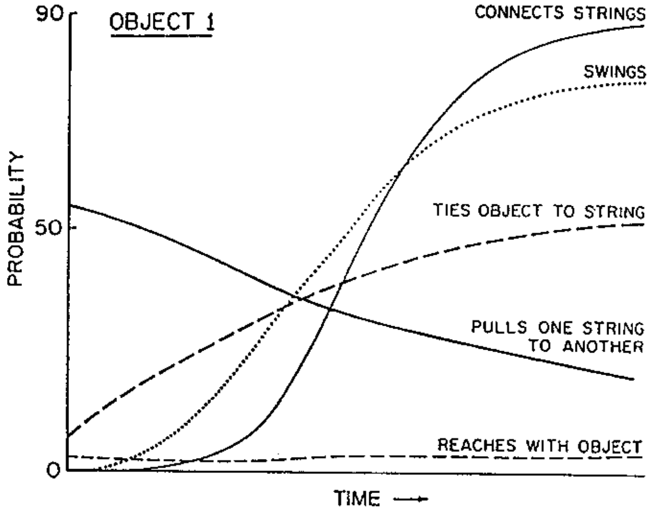

Figure 2. A probability profile generated by the transformation functions described in the text, shown for five behaviors relevant to Maier's two-string problem. The profile was generated with parameters for a short object (Object 1), which produced rapid solutions to the problem and no irrelevant reaching. Note that pulling one string to 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.

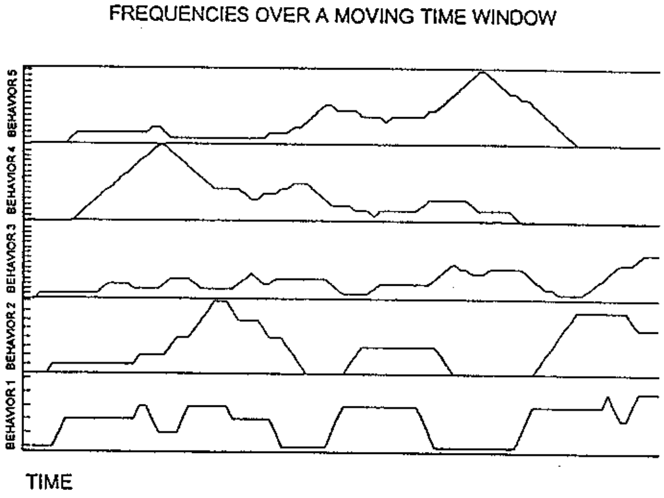

Figure 3. The Frequency Profile. A profile is obtained by plotting the frequencies of each behavior over successive, overlapping time windows. In the figure above, five concurrent behaviors are plotted for a single individual solving a problem on a computer screen. The first 118 seconds of the performance are shown, with a 15-second moving window, shifted in successive 1-second increments. The graph shows a smooth transition from behavior 4 to behavior 2, followed by a period of confusion and then a transition to behavior 5. Behavior 3 eventually begins to dominate. The window size, resolution, and increment size can all be varied. At one extreme, when the window size equals the number of observations, the profile yields a traditional "cumulative record." At another extreme, when the window size equals 1, the profile shows a simple frequency count for each behavior.

problem and the box-and-banana problem. They require people to move around and manipulate objects. Alas, to reveal the details of new problems here would lessen their value in the laboratory. The fewer savvy people, the better.

(2) From a detailed analysis of each videotaped performance, a *behavior chart* is created. The chart is a kind of checklist that shows whether each of many different behaviors occurred during various brief, successive time intervals—time "bins."

(3) The behavior chart can be used to derive a *frequency profile* (Figure 3), a set of curves that describes a unique performance by a single individual. The frequency profile gives us a visual picture of the dynamic relations among the many behaviors we have observed.

(4) Finally, the generativity model is used to simulate the performance we have studied. The model generates a *probability profile*, like the one shown in Figure 2. When the simulation is successful, the probability profile (generated by the model) resembles the frequency profile (generated by the subject).

Real-Time Simulation

Programming is well underway that will take this approach to creativity a step further. On a computer touch screen, a subject can now solve simple mechanical problems by tapping areas on the screen. Every response is recorded and monitored by another computer, which is running the generativity equations. The model will eventually be used to predict subsequent behavior in real-time. After every response, the predictions will be refined, just as predictions are continually updated in real-time simulations of missile trajectories. This approach may some day allow the moment-to-moment prediction of novel performances in real time.

Applications

In recent months, I've written the words and music to twenty-three songs. As I've learned to understand the creative process, I've also learned to harness the process productively in my own life, and so, I believe, can everyone.

Generativity Theory has clear implications for our everyday conceptions about creativity. People believe, for example, that creativity is rare, but generativity research shows, without question, that *everyone* is creative. *Generative processes are operating all the time in every person.* Then why do we label so few people "creative"? And why do so few people seem to produce "creative" works?

The answer has to do with *skills.* The people we label "creative" have stumbled onto skills that utilize generative processes efficiently. *Anyone can learn such skills, and the skills can be taught in our schools.*

Four Skill Categories

The skills that tap generative processes can be grouped into four broad categories.

(1) **Capturing.** New and interesting ideas pop into everyone's head all the time. So-called "creative" people have developed skills of various sorts to capture new ideas. Even ideas that don't seem very good might lead to great things later. The key is to preserve the new and unusual.

Artists carry sketchpads, and writers carry notebooks. Composers carry pocket tape recorders or composition books. I have composition software installed in all of my computers, including the notebook computer I carry when I travel.

Simple capturing skills can be taught to anyone—even to small children. The simplest skills involve making small changes in one's environment. Primary school children can be encouraged to keep "idea boxes" on their desks or "idea holders" inside their notebooks or lunch boxes. An idea holder is a special place where interesting ideas—interesting designs, funny word combinations, even ideas for new inventions—are captured and preserved, for use later.

People who excel at capturing take note of the conditions under which ideas flow, and they deliberately arrange these conditions as often as possible. Salvadore Dali, the great surrealist painter, deliberately induced the hypnogogic state—the semi-sleep state we all experience briefly just before falling asleep—to capture bizarre images. At times he lay on a sofa with his hand balancing a spoon on the edge of a glass on the floor. Just as he drifted off, he dropped the spoon. The sound of spoon against glass startled him, at which point he immediately sketched out the bizarre images he was seeing.

Many people find the "three B's of creativity" to be helpful: the *bed*, the *bath*, and the *bus.* These are settings with relatively few distractions and even fewer demands. Children and adults can easily be taught to identify such settings in their lives. Once identified, the ideal conditions can be sought or constructed.

(2) **Challenging.** Extinction or non-reinforcement—in other words, *failure*—produces an outcome called *resurgency* (Epstein, 1983, 1985c): When current behavior is ineffective, all other behaviors that were effective in similar situations in the past tend to recur. When a door is stuck, every behavior that has ever gotten you through a door tends to recur. You pull, push, kick, and eventually shout for help, depending on your particular history.

Failure is a potent fuel for the generative process, because it causes many behaviors to compete, almost immediately, and competing repertoires are the stuff of creativity. Creativity can be induced, therefore, through the careful management of failure—that is, by *challenging yourself* or your students in controlled ways.

(3) **Broadening.** The more repertoires that are available to compete, and the more diverse those repertoires, the more fertile the possible combinations. Therefore, creativity is potentially enhanced whenever we learn something new. The newer the knowledge—the more it differs from what we already know—the more interesting the possible combinations. Our students can and should be taught to broaden their knowledge as a deliberate step toward creativity.

(4) **Surrounding.** Finally, multiple, simultaneous repertoires of behavior are stimulated when we are surrounded by diverse stimuli. If you are driving toward a broken stoplight on which both red and green are illuminated, you feel confused, much as the pigeon might have felt when faced with the box-and-banana problem. The confusion you feel is a symptom of competing behaviors: pressing the brake vs. pressing the gas pedal. Again, our students can and should be taught to arrange multiple stimuli as a deliberate means of spurring the generative process.

Creativity Training in the Curriculum

Each of the four skills categories described above—capturing, challenging, broadening, and surrounding—can easily be incorporated into school curricula at every level. Even five minutes a day of creativity training would have profound effects. It would allow each child to tap his or her creativity on a daily basis, in every setting, for the rest of his or her life. It would also make many classrooms more interesting and "fun" places to spend the weekdays.

Fully developed, generativity theory may some day be helpful in designing efficient, powerful "discovery curricula." A discovery curriculum is one in which students are taught essential skills that allow them to discover higher-order knowledge on their own, rapidly and efficiently. Moreover, with essential components established, generative processes will automatically yield certain predictable, higher-order skills. Curricula designed with generative processes in mind will use teachers in efficient new ways. Many now view the teacher as a facilitator; in the creative classroom, the teacher will facilitate learning, discovery, and creativity, using proven methods. With generative processes doing much of the work, the teacher's efforts will be multiplied greatly.

Johnson and Layng (1992) recently described an approach to "generative instruction" with both children and adult learners who use this approach. They focus on establishing "fluency" in various component behaviors. When students are presented "with new environmental requirements, these behaviors can recombine in new ways that correspond to the higher level complex skills shown by experts. For example, basic number writing, addition, subtraction, and multiplication skills are the fluent components necessary to learn how to correctly factor an equation with ease" (p. 1476). Generativity theory may help to optimize such training.

Conclusions

With American education in dismal shape, and educators still obsessed with figuring out how to teach more than a fraction of our high school graduates to read, generativity and creativity would seem to be luxuries. Why worry about the three B's when we still can't teach the three R's?

Generativity Theory is not a solution to the problems in American education. For one thing, these problems are mere symptoms of much larger social ills; new curricula of any sort will not make more than a small dent in such cultural chaos. The theory does, however, suggest two simple, powerful, efficient ways to improve curricula and teaching: First, optimal repertoires can be established which will allow children to discover important information on their own—and to feel great about the discovery process. Second, skills for enhancing creativity can and should be taught. Creativity training will impact a child for a lifetime, with enormous benefits to society as the ultimate outcome. □

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