

# The Zen of Research

Leon Emry Borgman  
Department of Geology and Geophysics  
University of Wyoming  
Laramie, Wyoming 82071  
e-mail: mann@uwyo.edu

## ABSTRACT

Major discoveries of new results almost always require intuitive leaps of understanding by the researcher during the course of the research. These, often unexpected, insights become more explainable within the context of current split-brain investigations in neuropsychology. The use of intuition in research has a long history within mathematics, statistics, and the sciences. A general framework for focusing all the capabilities of the brain on a research problem is outlined. This includes (1) intense analytic and logical preparation, (2) frustration and incubation within the subconscious and preconscious, (3) emergence of insights, (4) logical reconstruction and verification of the discovered relations, and (5) a return to step (1).

Keywords: education – general; education – graduate; education – science; history of science; philosophy of science; science.

## Preliminary Thoughts

Many of us are guilty of deception in our published studies. Furthermore, those of us who teach often mislead and misdirect our students in their training to become competent researchers. These are serious charges. Fortunately, the deceptions and misdirections are not malicious. We are just trying to make our teaching and presentations clear and easy to comprehend.

The difficulty lies in the difference between how we actually discover and create new results in research and how we pretend we do it in our presentations. Real research is fuzzy and dirty. Some general need is perceived, or there is a vague intuitive feeling that a conceived relation may be true. This leads often to pilot studies or preliminary investigations to see if something can be done to clarify or focus the feelings. Generally a number of somewhat more precise questions are framed from these preliminary studies and are then investigated in more depth. If we are lucky, somewhere during the process we will get one or more, often abrupt, insights into the basic structures. From these insights, the problems can be reframed and still more thorough and detailed research planned. After a reasonable number of dead ends and substantial effort in pursuing possible lines of study, we may finally arrive at a clearer conclusion.

How do we communicate the results in publications or seminars? A well defined statement of the problem to be solved is followed by a very logical sequence of steps, experiments, and data which lead inexorably to the conclusion. All of the fumbling around, misimpressions, and intense effort to gain insight are hidden.

The distinction between real and presented research has been nicely summarized by Reichenbach (1947, p. 2) in defining logic.

When we call logic analysis of thought the expression should be interpreted so as to leave no doubt that it is not actual thought which we pretend to analyze. It is rather a substitute for thinking processes, their logical reconstruction, which constitutes the basis of logical analysis.

It would appear that very little damage is done by the gentle deception of logical reconstruction. After all, we are only trying to be very clear and understandable.

A real danger is present however. Davis and Hersh (1981, p. 281-284) discuss this point. Students or junior researchers may never develop their full potential if they fail to grasp the true nature of scientific study. They may expect to start always with well defined questions which can be treated with textbook procedures in a comfortable, rational way. The real tragedy is that they may spend their entire professional careers collecting and processing data that leads nowhere. The excitement, thrills, and frustrations, the grand roller coaster of real messy research, may forever elude them.

## Questions

Questions of the following type are often asked by obviously perplexed and somewhat frustrated students: (1) Why did you work the problem that way? (2) Why can't you just give us the formula to solve the problem without all the theory? (3) Why do we have to do word problems? More advanced students may ask more sophisticated versions of these questions: (4) How should I develop innovative problems and lines of investigation for my thesis? (5) What is the best education for a research career? (6) Where do I get the ideas (insights) for starting a valid investigation? These are serious questions and deserve careful answers. It is often difficult for the textbook-trained student to move into the fuzzy, uncertain world of research. Fortunately, both modern and ancient knowledge shed light on these questions.

## Split-Brain Studies

The human brain has two sides or hemispheres connected by a narrow trunk called the corpus callosum. It has been discovered that, as a last resort, certain brain illnesses can be controlled by completely severing the corpus callosum. Surprisingly, the individual involved is relatively unaffected by this radical action. Subsequent experiments on individuals who have undergone this surgery reveal a striking fact. The right and left brains can function independently of each other.

We all have two separate, fully functional brains! Furthermore, the left brain appears to control primarily logical, verbal, and sequential brain activities, whereas the right brain is the center of intuitive, nonverbal, and whole-pattern perception. Sperry (1973) suggests that these findings have a critical relevance to our educational systems.

The main theme to emerge...is that there appear to be two modes of thinking, verbal and nonverbal, represented rather separately in left and right hemispheres, respectively, and that our educational system, as well as science in general, tends to neglect the nonverbal form of intellect.

Many of the split-brain experiments are dramatic in their emphasis of the left-right dichotomy. Most such experiments exploit the fact that the left hand and eye are controlled by the right brain, while the right hand and eye are controlled by the left brain. Edwards (1979, p. 30-31) has vividly described some of these results.

In one test, two different pictures were flashed for an instant on a screen, with a split-brain patient's eyes fixed on a midpoint so that scanning both images was prevented. Each hemisphere then received different pictures. A picture of a spoon on the left side of the screen went to the right brain; a picture of a knife on the right side of the screen went to the verbal left brain....When questioned, the patient gave different responses. If asked to name what had been flashed on the screen, the confidently articulate left hemisphere caused the patient to say, "knife". Then the patient was asked to reach behind a curtain with his left hand (right hemisphere) and pick out what has been flashed on the screen. The patient then picked out a spoon from a group of objects that included a spoon and a knife. If the experimenter asked the patient to identify what he held in his hand behind the curtain, the patient might look confused for a moment and then say, "a knife". The right hemisphere, knowing that the answer was wrong but not having sufficient words to correct the articulate left hemisphere, continued the dialogue by causing the patient to mutely shake his head. At that, the verbal left hemisphere wondered aloud, "Why am I shaking my head?"

In another test that demonstrated the right brain to be better at spatial problems, a male patient was given several wooden shapes to arrange to match a certain design. His attempts with his right hand (left hemisphere) failed again and again. His right hemisphere kept trying to help. The right hand would knock the left hand away; and finally, the man had to sit on his left hand to keep it away from the puzzle. When the scientists finally suggested that he use both hands, the spatially "smart" left hand had to shove the spatially "dumb" right hand away to keep it from interfering.

In other words, the right brain appears to attack problems with a rapid, complex, nonverbal, intuitive,

nontemporal, nonsequential, spatial, and concrete mode of approach, based on a holistic perception of overall patterns. The left brain, in contrast, solves problems through methodical, sequential, logical, verbal, linear, digital, analytic, and symbolic modes of action. Levy (1968) suggests that both modes developed in evolution separately so that they wouldn't interfere with each other. In a fight or flight situation, instant response to an overall pattern of danger might have survival advantage, while a slower and more reasoned response might prove fatal. Contrarily, a reasoned response would be appropriate for many situations where the nonverbal mode was unsuitable.

Thus, it appears that each person has (at least) two brains or "advisors" for solving problems. Each "advisor" is better at some things than the other. In the normal person, where the two sides of the brain can communicate with each other, cooperation, conflict, and domination of one side by the other are all possible. The best researcher is a person who can coordinate all these abilities most effectively to achieve the goal sought.

### TRUTH versus Algorithm

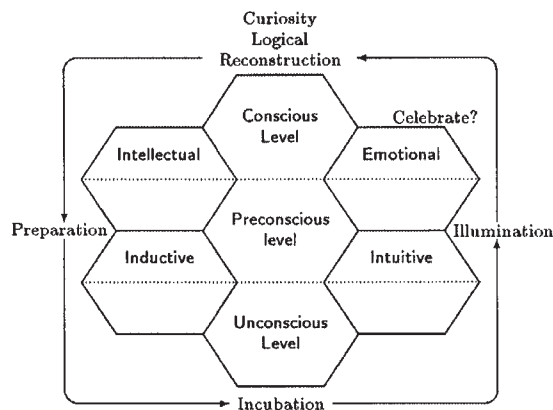
Are the researchers in split-brain studies exactly right in their division of brain function? Probably not. Studies in the last decade, mainly for children less than nine years old, have shown that some of the functions ascribed to one half of the brain can be controlled by the other half in cases where the first half is severely damaged in an accident. Bunderson has investigated a more complex model with a four-way subdivision of functions proposed by Hermann (1989, Appendix A, p. 337-379). Whether these specific models are perfectly representative is unimportant for this discussion. The important thing is that studies of creative people by Csikszentmihalyi (1996) show that those who are recognizably creative, generally follow the techniques that grow from these operational models.

### The Subconscious

Where does the subconscious fit within this general left-brain and right-brain scheme of things? We are all familiar with the common show-business trick of imparting suggestions under hypnosis which are not remembered consciously later but which lead to often startling behavior.

Some recent studies in this area of nonconscious, or subconscious, brain activity are reported by McKean (1985). Patients under anesthesia may "hear" comments made by the medical staff without later conscious knowledge of the comments. Yet these nonconscious perceptions may affect their actions in a way similar to hypnotic suggestions. In other experiments, words or pictures are flashed onto a screen so briefly that the experimental subject is not consciously aware of the projection. Yet the subject is able to answer questions about the projected material and be right a much higher fraction of the time than pure chance would predict.

It may be that the subconscious is a part of right-brain activity. However, this seems unlikely since



**Figure 1. Diagram of patterns of thought relative to Freud's major levels of consciousness (after Hulburt, 1981, p. 11). Thought enters typically at the top and proceeds counter clockwise about the pattern.**

many gifted, artistic, right-brain-dominated individuals are able to consciously control right-brain functions. A reasonable working hypothesis would be that we all possess at least three modes of brain activity: the verbal, logical left-brain mode, the intuitive, holistic right-brain mode, and the vaguely defined, but influential, subconscious area of activity.

Freud suggested an additional level of consciousness intermediate between the conscious and the subconscious, which he called the preconscious. Hurlburt (1981, p. 11) gives a succinct diagram of this model of mental activity and the creative process. A modified version of his diagram is given in Figure 1. In the diagram, the right side represents right-brain activity and the left side represents left-brain functions. The subconscious resides at the bottom. It is unlikely that the diagram is completely correct. However, it provides a good working model for visualization of how the mind works.

Various patterns of thought can be mapped within this diagram. The artist, for example, might start in the preconscious part of the emotional frame and proceed counterclockwise around to the intellectual frame for the planning and execution of a painting. At various steps, a return might be made to the intuitive and emotional frames for further insight and inspiration. The researcher probably would start at the top of the diagram, or on the right side, and proceed counterclockwise with experimental design or exhaustive exploration of the problem as it is understood at that time whenever the intellectual frame is reached.

### The Psychology of Invention in Mathematics

The use of intuition and the subconscious is, of course, well known to most experienced, veteran researchers if the researcher has achieved reasonably substantial accomplishments. Davis and Hersh (1981, p. 391) give an interesting essay on the various aspects of intuition in mathematical work. Goldberg (1983) discusses intuition in a broader context. The books by

Polya (1954) (see also Davis, 1981, p. 385 and following) give an insight into the diversity of mechanisms in mathematical creativity.

A delightful introduction to experiences along this line in the discovery of mathematical relations is given in the extended essay by the eminent mathematician, Jacques Hadamard (1945). He quotes the nineteenth-century mathematician, Henri Poincaré (Hadamard, 1945, p. 14) as follows:

One evening, contrary to my custom, I drank black coffee and could not sleep. Ideas rose in crowds; I felt them collide until pairs interlocked, so to speak, making a stable combination. It seems, in such cases, that one is present at his own unconscious work, made partially perceptible to the over-excited consciousness, yet without having changed its nature. Then we vaguely comprehend what distinguishes the two mechanisms or, if you wish, the working methods of the two egos.

This sleepless night initiated a major body of work by Poincaré. Hadamard also quotes Gauss (Hadamard, 1945, p. 15), who was referring to an arithmetical theorem which he had tried to prove unsuccessfully for years:

Finally, two days ago, I succeeded, not on account of my painful efforts, but by the grace of God. Like a sudden flash of lightning, the riddle happened to be solved. I myself cannot say what was the conducting thread which connected what I previously knew with what made my success possible.

Hadamard, rather ruefully, outlines the common fault of focusing too tightly on specific results relative to his studies concerning a generalization to hyperspace of the notation of curvature of surfaces. Only thinking of the particular problem he had posed, he failed to notice that a slight extension would have led to a significant result, later discovered by Ricci and Levi Civita as the principle of so-called "Absolute Differential Calculus" (Hadamard, 1945, p. 51). Albert Einstein in a letter to Hadamard (Hadamard, 1945, p. 142) comments:

The words or the language, as they are written or spoken, do not seem to play any role in my mechanism of thought. The psychical entities which seem to serve as elements in thought are certain signs and more or less clear images which can be "voluntarily" reproduced and combined.

The experiences quoted above attest quite clearly to the importance of right-brain and subconscious mental activity in creative mathematical and statistical research. The same thing can be said for other types of research and, indeed, for all aspects of human creative efforts. Koestler (1959) asserts, "Every creative act involves...a new innocence of perception, liberated from the cataract of accepted belief." Thus, many nonscientific domains of human activity provide relevant information for the improvement and understanding of real-world research.

### Duality in Religion and Literature

Two examples will be cited. The first is the remarkable parallel to modern right-brain and left-brain concepts found in the Chinese Taoist work, the I Ching or Book of Changes (Wilhelm, 1967), written more than twenty-six centuries ago. According to the I Ching, human activity encompasses a duality of two opposing interacting attributes called Yin and Yang. As summarized by Edwards (1979, p. 34), Yin is: feminine, negative, moon, darkness, yielding, left side, warm, autumn, winter, unconscious, right brain, and emotion, whereas Yang is: masculine, positive, sun, light, aggressive, right side, cold, spring, summer, conscious, left brain, and reason. Although not all of the words align themselves with current right-brain and left-brain concepts, enough of them do to reveal that the ancient Chinese work shows remarkable similarities to this fairly modern concept.

The second example is from the poetry of Rudyard Kipling, written more than seventy years ago (Edwards, 1979; Kipling, 1927):

I would go without shirt or shoe,  
Friend, tobacco, or bread,  
Sooner than lose for a minute the two  
Separate sides of my head!

### Left-Brain Educational Tradition

Unfortunately, the western educational tradition has generally ignored or suppressed development of right-brain abilities, while emphasizing those of the left brain. Hadamard discusses the tradition (Hadamard, 1945, p. 67 and following). The Greek word, "logos," simultaneously meant both language and thought. Thus, thought was conceived as being inextricably related to language. Among the philosophers, Hegel asserted, "We think in nouns." Max Müller stated, "No thought is possible without words." In the present century, the logical pragmatists refused to accept for philosophical study any statement which could not be worded as a testable proposition.

A good summary of this bias is given by Picken (1980, p. 57):

Western thinking...appears to be based on three assumptions: first, that conscious states of mind are more important and influential than unconscious ones; second, that scientific rationality is the paradigm of all knowledge; and third, that aesthetic intuition is inferior to scientific understanding.

Each of these independently has been called into question in recent times. Freud and Jung showed...how the unconscious mind shapes behavior and decisions more than most people realize. Recent investigations into the nature of revolutionary scientific discoveries have suggested that truths are usually uncovered before proofs are devised for them. As for rationality being more important than intuition, the entire advertising industry, it might be pointed out, is based upon a profound appeal to the irrational side of human nature."

The development of intuitive, holistic, and whole-pattern thinking abilities is almost totally absent in our scientific, mathematical, statistical, and engineering curricula. Instead, overwhelming emphasis is placed on memorization and development of standard textbook subject matter. The study of these topics is not bad in itself. But, without a balance toward some corresponding development of right-brain abilities, sending a young researcher out to do creative work is like training a boxer to hit only with the right hand. Somewhere along the line our students have to learn to use the rest of their brains, especially since right-brain intellect seems best at synthesizing large quantities of facts into creative insights or patterns.

One consequence of the left-brain emphasis in education is that most students don't really understand how to proceed when they are put into a situation requiring right-brain effort. The two modes of thought can be characterized as the "freight train" approach and the "peeping Tom" approach. In the "freight train" approach the problem or "train" is set on the track with a well defined route and destination. A full head of steam is generated and away the student roars with the comfortable knowledge that the destination will be reached if a reasonable level of effort and the standard methods and directions are maintained. This, of course, corresponds to a left-brain orientation. Students are very comfortable with that general framework, since they can measure their progress, reach milestones, and feel a very satisfactory sense of achievement. In the "peeping Tom" approach (that is, right-brain orientation), the student looks at the problem from every available perspective, often only being able to perceive it vaguely or dimly as though seeing it through a curtained window. There is very little sense of direction or specific processes, and only after much effort is an overall sense of structure obtained. Engineering and science students generally hate such an approach and give poor faculty ratings to teachers who impose such an open-ended regime on them. Yet, when the two approaches are compared with real-world research and with the rational reconstruction of research as discussed at the beginning of the paper, it is clear that real research is much more like the "peeping Tom" method, while the artificial logical reconstruction is similar to the "freight train" scheme.

Williamson and Hudspeth (1982) report an attempt to incorporate holistic, right-brain training into engineering education at Oregon State University. They utilize a problem in ocean engineering which involves a number of intangible factors related to the ocean environment. The students are asked to design a suitable structure to support a set of oceanographic instruments in a nearby offshore area. The students are not graded on whether they arrive at some "correct" design but rather on how well they establish a consistent set of assumptions upon which to base their design decision and how well they proceed to build on that. They should not, for example, utilize uncertain, three-significant-figure data as input to a very detailed, highly precise, finite-element solution of the structural analysis. It is wasteful to spend large amounts of computer time on uncertain input.

Approximate, graphical solutions would be more appropriate in that case.

Wherever possible, Williamson and Hudspeth provide the problem statement and organization to the students in graphical and diagrammatic formulations, rather than as equations or standard design tools. This encourages the students to examine and develop the problem with the spatially oriented, holistic right brain. The problem is open-ended, the data are vague and uncertain, and there is no single "right" answer.

### The Mystical Tradition

Suppose we wish to develop a training program which would act to offset an overemphasis on left-brain thinking. Where would we seek appropriate material? Development in nonverbal, intuitive, holistic mental activity would be needed. Certainly, within our Western traditions, music and art would provide some basis if they were taught to emphasize creativity, rather than motor skills.

Within a worldwide frame of reference, there exists a body of practice which is almost purely right brain in orientation. Zen Buddhism is perhaps the most pure rejection of the verbal side of thought in existence. Hoover (1977, p. 477 and following) provides a fascinating introduction to Zen culture in terms readily grasped by the Western person.

Thus, Zen became the religion of the antirational, what might be the counter mind. The counter mind has taken on more concrete significance in recent years with the discovery that the human mind is not a single entity but is divided into two quite different functional sections. We now know that the left hemisphere of the brain governs the logical, analytical portion of our lives, whereas the right hemisphere is the seat of our intuitive, nonverbal perception and understanding. As far back as the ancient Greeks, we in the West have maintained an almost unshakable belief in the superiority of the analytical side of the mind, and this belief may well be the most consistent distinguishing quality of Western philosophy. By contrast the East in general and Zen in particular have advanced the opposite view. In fact, Zen masters have deliberately developed techniques (like illogical riddles or koan) to discredit the logical, verbal side of the mind so that the intuitive perceptions of the right hemisphere, the counter mind, may define reality.

The general flavor of Zen teaching may be partly grasped by the Western mind through an examination of startlingly brief, but expressive, Zen proverbs, koans, and haiku (Capra, 1975; Hoover, 1977; Johnston, 1974, Ornstein, 1972). Most of these are directed toward encouraging the direct perception of the world around us without the artificial veil of man-made logic, models, or words. This is achieved with the use of words which are almost immediately discarded as unnecessary because the mind is absorbed in intense physical experience, a logical dilemma, or a similar

nonverbal activity. For example, consider the following two proverbs:

Those who know, do not speak.  
Those who speak, do not know.

A finger is needed to point at the moon.  
Once the moon is recognized, we should not trouble ourselves with the finger.

A statement attributed to Einstein (Capra, 1975, p. 27) is very much in the same spirit:

As far as the laws of mathematics apply to reality, they are not certain. And as far as they are certain, they do not refer to reality.

A fascinating haiku poem closely related to the present discussion was written by Matsuo Basho, 1644-1694:

Do not follow  
In the footsteps of the ancients  
Instead, seek what they sought.

Basho's words may be interpreted as saying, "Don't just follow the methods developed by earlier authorities (logical, left brain). Instead, try to develop new insights into the problems just as they did in their time (creative, right brain)."

The Western world also has a mystical tradition, although it is not as well known by our population as the Eastern population knows their tradition. An excellent introduction is provided in the book *Silent Music* by Johnston (1974). The title is taken from the writings of St. John of the Cross (1973):

My beloved is the mountains  
The solitary wooded valleys,  
Strange islands, ...  
Silent music.

This is a sort of Western koan of contradiction (silent music!), growing out of our own mystical traditions.

### Implications for Research and Training

What does the preceding material have to do with the best approaches to research and the best types of training to prepare for research? An interesting summary for characteristics of gifted and talented children is given by Witty, Conat, and Strang (1959, p. 21-22). A selection of these is given below. The likely hemisphere of brain activity is inserted in brackets into the quotations, as suggested by one of the reviewers of the present paper.

- 1) An awareness of and concern about unsolved problems – the attitude of inquiry.
- 2) Fluency of thought – ideas come readily; later they are evaluated for quality [right brain] and logic [left brain].
- 3) Concentration – ability to enter wholeheartedly [right brain] and personally into an experience [right brain].
- 4) Integration – ability to find unity in the diversity of nature, to discover unexpected likenesses, and

- to relate or connect things not previously related or connected [right brain].
- 5) Flexibility and spontaneity guided by a goal or purpose.
  - 6) Originality and individuality. The creative person has the courage and inner directedness to resist conformity. Not content with what is now accepted, he looks forward to what may be accepted [right brain].
  - 7) Ability to analyze and abstract [left brain].
  - 8) Ability to synthesize [right brain].
  - 9) Ability to go beyond the facts and discern new implications, to imagine more than evidence obviously shows, to speculate on relations that may not at present be verifiable [right brain].
  - 10) Keen satisfaction in creative activities.
  - 11) Vivid imagery [right brain].
  - 12) Superior abstract and verbal intelligence [left brain].

Item 11, vivid imagery, suggests value in art training. Item 4, integration, would indicate the validity of training in or at least appreciation of music. (Interestingly enough, recent studies reported in the newspapers indicate that music training has a higher correlation with the development of ability in intricate logic than does experience with computers.) Item 3, concentration, might support using meditation or similar “centering” activities in training. Some of the martial arts are particularly good for this, as are certain sporting activities.

Many of the items indicate the strong desirability of high proficiency in the numerous left-brain activities. However, modern education seems to offer very satisfactory opportunities for development in these directions.

There are other personal attributes that seem to be needed, such as fluency of thought, a curiosity and attitude of inquiry, and personal toughness to resist conformity. Some of the attributes are often present in young children but disappear with the onset of puberty or through non-use in the pressure of professional activities.

The intellectual giant Charles Darwin expresses this loss in his own life (Darwin, 1929):

Up to the age of thirty, or beyond it, poetry of many kinds...gave me great pleasure...I have also said that formerly pictures gave me considerable, and music very great delight...I have tried lately to read Shakespeare, and found it so intolerably dull that it nauseated me. I have also almost lost my taste for pictures or music.

...

If I had to live my life again, I would have made it a rule to read some poetry and listen to some music at least once every week; for perhaps the parts of my brain now atrophied would thus have been kept active through use. The loss of these tastes is a loss of happiness, and may possibly be injurious to the intellect,...

In modern parlance, it may be expressed as “Use it or lose it.”

The essential sequence of events in scientific discovery is illustrated beautifully in an account by the physicist Freeman Dyson (Csikszentmihalyi, 1996, p. 81-82). Dyson was a graduate student at Princeton where Richard Feynman was a professor working hard to relate quantum mechanics to electrodynamics. Feynman had an elaborate theory that was hard to understand from his intuitive disjointed presentations. Meanwhile, another physicist, Julian Schwinger, had another unification of electrodynamics and quantum theory which, while logical and elegant, didn't seem quite complete either. Freeman Dyson had studied much of Feynman's theory as a student and happened to hear some invited lectures by Schwinger at Princeton. It seemed to Dyson that both Schwinger and Feynman were talking about two parts of the whole picture, so he set out to see if that was true. In Dyson's words,

I spent six months working very hard to understand both of them clearly, and that meant simply hard, hard work of calculating. I would sit down for days and days with large stacks of papers doing calculations so that I could understand precisely what Feynman was saying. And at the end of six months, I went off on a vacation. I took a Greyhound bus to California and spent a couple of weeks just bumming around. This was soon after I had arrived from England, so I had never been to the West before. After two weeks in California, where I wasn't doing any work, I was just sight-seeing, I got on the bus to come back to Princeton, and suddenly in the middle of the night when we were going through Kansas, the whole sort of suddenly became crystal clear, and so that was sort of the big revelation for me, it was the Eureka experience or whatever you call it. Suddenly the whole picture became clear, and Schwinger fit into it beautifully and Feynman fit into it beautifully and the result was a theory that actually was useful. That was the big creative moment of my life. Then I had to spend another six months working out the details and writing it all up and so forth. It finally ended up with two long papers in the Physical Review, and that was my passport to the world of science.

Dyson's experience illustrates the salient features of creative research. A hunch (right brain) is followed by intense left-brain work to develop the concepts logically. Then there is a period of relaxation and incubation (right brain and subconscious) leading to a sudden insight. This is followed by more intense logical left-brain effort, and the cycle continues.

### The Creative Research Sequence

The following list gives an expanded summary of reasonable elements in successful research.

- 1) Research is a cyclical process, with both a non-verbal, intuitive side [right brain] and an ana-

lytic, logical, verbal side [left brain]. Both aspects are important to a productive research career.

- 2) A reasonable sequence of research effort might be:
  - (a) Intense intellectual effort to memorize and delineate the logical aspects of the problem and extend the associated questions beyond current knowledge.
  - (b) Frustration and annoyance at not being able to solve all the questions posed in the first step.
  - (c) A period of incubation while one's subconscious churns away under the commands tendered it during the previous two steps.
  - (d) An intuitive inspiration or insight which casts light on at least some of the aspects of the problems posed in (a).
  - (e) A verification and logical reconstruction of the intuitive insights.
  - (f) Now return to (a) above and start over again.
- 3) The overall problem should be kept as general and unfocused as is consistent with the goals of the study. Temporary, immediate versions of the problem may be tightly focused, but the overall formulation needs to be fuzzy enough to allow unexpected parallel relations to be discovered.
- 4) The researcher needs to develop and implement procedures to gain a reasonable transmission of messages between the left brain, the right brain, and the subconscious mind. Each investigator needs to find his or her own personal means to achieve this. Indeed, it is probably the most important requirement for becoming creative and productive in research. For example, it might be found useful to engage in some of the following:
  - (a) art and/or music,
  - (b) meditation (LeShan, 1974),
  - (c) self-hypnosis (Caprio, 1963; LeCron, 1964; LeCron, 1971),
  - (d) various meditative religions: Yoga; Zen, or
  - (e) maintenance of an always-present personal notebook to record thoughts while hiking, running, or while traveling. One should be sensitive to intuition and hunches. They should be written down and given serious attention as they arise from the subconscious and right brain.

The list could go on. A good preliminary step would be an assessment of the researcher's current right-brain, left-brain ability through tests in the book *Whole-Brain Thinking* by Wonder and Donovan (1984).

- 5) It is effective to keep several aspects of the study going at the same time. One aspect can be fed to the subconscious mind for silent work, while another aspect is being logically worked on with the left brain.
- 6) Concepts and innovations must be coupled to intense desire and compulsion to solve the problem. Stamina and a disregard for the discomforts of

long, hard work are definite assets. Research is hard work, which is tempered by the alternation of excitement and frustration.

### Joy in Research

One final comment should be inserted here in closing. Creative research is grand excitement and our enthusiasm for it should be communicated to our students. As Csikszentmihalyi (1996, p. 2) puts it in describing creativity,

...when we are involved in it, we feel that we are living more fully than during the rest of life. The excitement of the artist at the easel or the scientist in the lab comes close to the ideal fulfillment we all hope to get from life, and so rarely do. Perhaps only sex, sports, music, and religious ecstasy...provide as profound a sense of being part of an entity greater than ourselves. But creativity also leaves an outcome that adds to the richness and complexity of the future.

This enjoyment of research, the feeling that it is fun, was one of the few universal attributes of the large set of demonstrably creative people interviewed by Csikszentmihalyi (1996, p. 107):

What is extraordinary...is that we talked to engineers and chemists, writers and musicians, business persons and social reformers, historians and architects, sociologists and physicians – and they all agree that they do what they do primarily because it's fun!

The point in all of this is that we should relate to our students that real research can be extremely enjoyable and exciting. True, it involves stretches of arduous effort and tautly diligent concern with details. But the excitement of the ultimate discoveries are even more intense by the contrast to the exertion and frustration which had to be experienced in the work to get there.

### References Cited

- Capra, Fritjof, 1975, *The tao of physics*: Bantam Books, Inc., New York, 332 p.
- Caprio, Frank, and Berger, Joseph, 1963, *Helping yourself with self-hypnosis*: Prentice-Hall, Inc., 210 p.
- Csikszentmihalyi, Mikaly, 1996, *Creativity*: Harper Collins Pub., New York, 456 p.
- Darwin, Charles, 1929, *Autobiography*, Watts Pub., London.
- Davis, P.J., and Hersh, Reuben, 1981, *The mathematical experience*: Birkhauser, Boston, 440 p.
- Edwards, Betty, 1979, *Drawing on the right side of the brain*: J.P. Tarcher, Inc., Los Angeles, 207 p.
- Goldberg, Philip, 1983, *The intuitive edge*: J.P. Tarcher, Inc., Los Angeles, 241 p.
- Hadamard, Jacques, 1945, *The psychology of invention in the mathematical field*: Dover Publications, Inc., 145 p.
- Hoover, Thomas, 1977, *Zen culture*: Vintage Books, Random House, New York, 262 p.
- Hurlburt, Allen, 1981, *The design concept*: Watson-Guptill Pub., New York, 157 p.
- John of the Cross, St., 1973, *The collected works of St. John of the Cross*, translated by Kieran Kavanaugh,

- OCD, and Otilio Rodriguez, OCD: Institute of Carmalite Studies, Washington, DC, 740 p.
- Johnston, William, 1974, Silent music: Perennial Library, Harper and Row Pub., 188 p.
- Kipling, R., 1927, Rudyard Kipling's verse: Hodder and Stoughton, London.
- Koestler, A., 1959, The sleepwalkers: Macmillan, First American Edition, 1968, New York, 624 p.
- LeCron, Leslie, 1964, Self hypnotism: Signet Book, New American Library, 208 p.
- LeCron, Leslie, 1971, The complete guide to hypnosis: Harper and Row Pub., New York, 225 p.
- LeShan, Lawrence, 1974, How to meditate: Bantam Books, 161 p.
- Levy, J., 1968, Differential perceptual capacities in major and minor hemispheres: Proceedings of the National Academy of Sciences, v. 61, p. 1151.
- McKean, Kevin, 1985, In search of the unconscious mind: Discover, February, p. 12-18.
- Ornstein, Robert E., 1972, The psychology of consciousness: Viking Press, New York, 247 p.
- Picken, Stuart D.B., 1980, Shinto: Kodansha International Ltd., Tokyo, Japan, p. 57.
- Polya, G., 1954, Patterns of plausible inference: Mathematics and plausible reasoning, v. II: Princeton University Press, 190 p.
- Reichenbach, Hans, 1947, Elements of symbolic logic: Macmillan Company, New York, 443 p.
- Sperry, R.W., 1973, Lateral specialization of cerebral function in the surgically separated hemispheres, in McGuigan and Schoonover, eds., Psychophysiology of thinking: Academic Press, p. 209-229.
- Wilhelm, R., 1967, The I Ching or book of changes, Princeton University Press, New Jersey, 740 p.

### About the Author

Leon E. Borgman is a Distinguished Emeritus Professor of Geology and Statistics at the University of Wyoming in Laramie, Wyoming. He received a BS degree in geological engineering from Colorado School of Mines in Golden, Colorado, an MS degree in mathematics from the University of Houston in Houston, Texas, and a PhD in statistics from the University of California in Berkeley, California. Current interests encompass a wide variety of topics in mathematical and statistical earth sciences, including the statistical theory of ocean waves, algorithms for long-term risk in coastal engineering, the geostatistics of mineral deposits and environmental assessment, surface and ground-water statistics, empirical-simulation techniques, and nonparametric statistics.

- Williamson, K.J. and Hudspeth, R.T., 1982, Teaching holistic thought through engineering design: *Engineering Education*, April, p. 698-703.
- Witty, P., Conat, J., and Strang, R., 1959, Creativity of gifted and talented children: Bureau of Publications, Teachers College, Columbia University, p. 21-22.
- Wonder, Jacquelyn, and Donovan, Priscilla, 1984, Whole brain thinking: William Morrow and Company, Inc., New York, 288 p.

### About the Author

Leon E. Borgman is a professor of geology and geostatistics at the University of Wyoming in Laramie, Wyoming. He received a BS degree in geological engineering from Colorado School of Mines in Golden, Colorado, the MS degree in mathematics from the University of Houston in Houston, Texas, and the Ph.D. in statistics from the University of California in Berkeley, California. Current interests encompass a wide variety of topics in mathematical and statistical earth sciences, including the statistical theory of ocean waves, algorithms for long-term risk in coastal engineering, the geostatistics of mineral deposits and environmental assessment, surface and ground-water statistics, empirical-simulation techniques, and nonparametric statistics.