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CREATIVITY IN SCIENCE THROUGH VISUALIZATION

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Summary.—The fact that attempts to gain insight into the creative process have been so unsuccessful suggests that they have overlooked at least one basic ingredient in the process. This ingredient may lie in the nature or way the individual mind goes about remembering and manipulating data. The hypothesis is advanced that the creative persons appear to have stumbled onto and then developed to a high degree of perfection the ability to visualize—almost hallucinate—in the area in which they are creative. And their visualizations seem to be of a sort that lend themselves to easy manipulation in the thinking process. This is illustrated by reports from many of the great inventors of the past and it is easy to demonstrate that individuals differ enormously in the kind and degree of their ability to think in such manipulatable visualizations. If correct, this aspect of creativity suggests many research attacks and many potential changes in education for creative activity.

In all of the work on creativity with which I am familiar, it seems painfully evident that at least one vital ingredient is missing and that various investigators are groping in dark corners for something whose nature they do not understand. These gropings take the following forms.

First, there are those who attempt to describe in words the gross features of the creative act as seen from outside the creative person. They finally agree, as has been illustrated elegantly (Beveridge, 1957), on the now-familiar steps in the creative process: (1) a problem is sensed and (2) relevant data are gathered. (3) Logical thinking goes as far as it can in trying to solve the problem but the problem is not solved and there follows (4) a period of frustration, perhaps more appropriately called tantalization, because it is pleasant rather than unpleasant, but nothing seems to be happening. This period is followed by (5) the so-called flash of insight and, eventually, by (6) some process of verification. There seems to be a certain validity in these steps, but, like so many other purely taxonomical approaches, they serve only as the elements of a framework on which to hang other observations. They are surprisingly sterile in "explaining" why some individuals are so much more successful in the creative process than are others and in providing clues to how the process might be taught or encouraged in ourselves or in others. This approach is about as useful as the following analysis of artistic painting: (1) The artist procures canvases and oil paints, (2)

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he selects a subject, (3) he contemplates the canvas for a considerable period of time, thinking about the subject, (4) he gets an idea for a painting, and (5) he puts it down on the canvas.

Of course, the taxonomical approach does serve some useful secondary purposes. It makes the would-be creator, and his boss, a little more tolerant through the vital "induction" period when nothing seems to be happening and when everyone is likely to feel that the creator is simply wasting time. Also, it serves to point out the importance of other steps of the process such as the collection of pertinent data, the saturation of the mind with thoughts about the problem, and the importance of verification of the creative idea once it flashes into the mind.

But, as mentioned above, the taxonomical analysis does not explain what occurs during the induction period and, hence, it does not help in explaining (1) why creative ability is so unequally distributed among individuals, (2) why it correlates so poorly with other mental activities, or (3) how it might be induced or taught.

The second approach that has been taken to the problem, and the one that has been more popular recently, is the procedure of simply correlating apparent creativity scores with other, almost randomly selected, characteristics of the individual or of his background or surroundings. Nothing could be said against this approach if it succeeded in isolating factors that correlate highly with creativity. But, in general and in this case in particular, this approach is not automatic. Rather, it depends for its success not so much on the quality of the correlating but on the creativity that goes into the selecting of the factors with which to attempt to correlate the property being investigated. This depends on skill in recognizing the properties of the phenomena being investigated, in this case, creativity. Unfortunately, creativity can easily be counterfeited by high quality serendipity or even by the clever random picking of alternatives to what is being done at any particular time and place.

Again, if this correlational method had succeeded, one could not quarrel with it. But, it has not succeeded and attempts end with a pitifully small list of generalizations which—while they might conceivably be used to screen large numbers of applicants for jobs that required creativity—are themselves of little use in promoting creativity in oneself or for producing it in others by admonition or teaching.

Then, what is the missing ingredient in the study of creativity? As a result of discussions of the intimate details of their own creative processes with a number of demonstrably inventive individuals in a large research institute, the hypothesis is advanced that the generally overlooked ingredient in creativity lies in the area of "how" the individual "knows." Creative individuals appear to have stumbled onto and then developed to a high degree of perfection an unusual ability to visualize mentally—almost hallucinate—in the areas in which they are creative. As will be explained later, the word visualize is here used in its

broadest sense to include the mental synthesizing of many sensory experiences, not just ocular experiences. Furthermore, successful creating seems to depend on the degree to which these mental images can be manipulated and the skill with which the individual can sense the properties of these new combinations of things. This hypothesis obviously requires elaboration.

Unfortunately, in thinking about knowledge we seem to have been contented generally to consider simply whether or not a person *knows* a certain fact in science or other fields of human interest. *How* he knows it has not been of much concern, except, perhaps, to those who hope to associate knowing with specific mechanics of the brain. We teach a high school student Ohm's law and we are content if he can repeat it to us and can solve simple problems that obviously call for its application. But, we offer the student no suggestions as to *how* he should remember Ohm's law. We do not even tell him that there are different ways in which he could grasp and remember the law. Then we wonder why the graduates we produce vary so widely in their later ability to succeed in real life situations where electrical circuits must be manipulated to produce unique results!

It appears obvious that in this illustration there are at least two distinctly different ideational processes that could be invoked in remembering Ohm's law. The first and least creative of these would be illustrated in the extreme if one put the words voltage, current, and resistance into a jingle and learned the jingle, like "Thirty days hath September . . . ." With such a jingle and with some ability simply to identify those numbers in a problem that corresponded to voltage, current, and resistance, one could make quite a successful showing on most examinations concerning Ohm's law! We remember songs that we can sing or whistle in this manner.

But really creative electrical engineers seem to use quite a different ideational process in thinking about Ohm's law. They seem to be able to produce a vivid, almost hallucinatory, vision and feeling about something like a fluid stuff, trying to flow through a solid stuff which opposes the flow, and they feel that the harder the electrical stuff is pushed, the more rapidly it flows through the resistance opposing its movement. Furthermore, the electrical stuff is kept within bounds. The bits of stuff that resist the flow of the current are mentally combined in various ways, for example, so that the current must flow through a number of them in sequence, or so that it can split up and flow through any one of a number of them in parallel. This vivid and manipulatable image system of the flow of electrical currents has to be elaborated considerably when current must flow through inductances and capacitances but this can be done with the same success, to the final result that one is able to perform a myriad of mental experiments in a very short time.

This striking variety in ideational processes in *knowing* can be explored by anyone in simple areas. It is interesting to ask a number of persons to solve a simple problem in mental arithmetic, say, to subtract 46 from 100, and then to

ask them what went on in their heads as they solved the problem. I have found the following gamut of processes used. Some persons simply grope around with words, perhaps dividing the problem up into subtracting 6 from 10 and 4 from 10, which they do simply by remembering the words associated with these operations and then somehow combining these results to give the final answer. Others mentally write out 100 with 46 beneath it and picture the process of writing down the answer below the two. Finally, some individuals have specialized equipment for just this operation. They visualize two juxtaposed scales from zero to 100, one starting at the right and one at the left. With this mnemonic gadget the required subtraction involves simply finding 46 on one of the scales and reading off 54 on the other!

Now, while no brief can be held for one or the other of such methods of subtraction, it appears obvious that some of them are vastly more potent than others and that, if creating involved sensing rapidly the answers to many such subtractions, the individual equipped with some of the methods would far outstrip those equipped with more cumbersome ones.

Another interesting example involves the ability to visualize combinations of cubes. Try asking a number of persons to visualize a large cube made up of 27 smaller cubes, that is, three on each edge of the composite cube. Then, ask him to imagine painting the entire outer surface of the large cube. Finally, ask him how many of the smaller cubes he has painted on zero, one, two, or three sides. After he gives the result, ask him to describe the mental process he used in arriving at the answer. A surprising variety of answers come from this simple test. Some persons, even some professionally engaged in science and art, simply are unable to solve this problem mentally because they cannot visualize a cube in any way! Others stumble around with crude visualizations of a cube and end up by guessing at the answer. Some can visualize an opaque cube fairly well but must infer from the one view what is on the other side. The most potent approach seems to be that of the person who can visualize a transparent cube and simply count the smaller cubes whose sides are covered with paint, a process something like counting one's fingers with his hands held up in front of him.

Again, it is obvious that these different individuals, many of whom can give the correct answer to this cube problem, nevertheless would be expected to vary quite widely in potentially creative situations that involved exploring a large number of possible combinations of cubes or similar geometrical objects.

In still another provocative problem, persons may be asked to give verbal directions for driving a car from one location to another, and then asked what they visualized mentally as they were giving the directions. Again, a wide variety of mental processes will be disclosed. Surprisingly, many persons report seeing the route as from a low-flying helicopter.

The fact that different persons use vastly different visualizations in thinking is suggested by some other informal reports. One person has declared that he

dreams only in words, that he does not use any form of visualization in dream states. It has been claimed by some semanticists that the human being thinks only in words. This seems an utterly absurd statement to many of us who spend a large part of our waking hours in visualizing and thinking in pictorial representations. This, of course, does not deny the fact that it is quite possible that semanticists do, in fact, think only in words; it would be logical that "word thinkers" would be drawn to this specialized field.

There is evidence that this same process of visualization applies to much more complex fields than the almost trivial ones discussed above. Reports concerning development of major inventions of the past suggest that the inventors were visualizing extremely complex situations when their revealing flash came to them. This is well illustrated by the now famous visualization by Kekule, as reported by Beveridge, which led him to the discovery of the benzene ring through a vision of a series of linked atoms biting its tail like a snake. Michael Faraday was one of the first to "see" the electrical and magnetic lines of force that now are standard tools for physicists to visualize otherwise mysterious phenomena in this area. Albert Einstein apparently believed that thought consisted entirely of dealing with mechanical images and not at all of words. The mathematician Jacques Hadamard reported that he thought exclusively in visual pictures. However, these men did not seem to realize the uniqueness of their ability to visualize in manipulatable images. They seemed to assume that all persons had much the same ability.

Inventors with whom I have talked report thinking visually about complex mechanisms and organic chemical molecules combining with other molecules. So, it appears that ideas which can be grasped when drawn on paper can be visualized without being put onto paper, perhaps with many shorthand approximations for unimportant parts. Also, the nature of the *seeing* or sensing is peculiar. It is almost a *feeling like* the object being visualized. One can *feel* the pressure of contacting objects, or the erosion of material by friction, or the flow of heat from one point to another, or the swing of the oscillating electrical circuit, or the bending of light as it passes from one medium to another, or the appropriateness of a well-designed structure to hold a maximum load, with every part equally strained in the process, or the eternal bouncing about of the molecules of a gas, or the almost physical transfer of energy from the gasoline, through the motor, transmission, and to the driving wheels of the automobile. It is as though one's own kinesthetic sensing mechanisms were associated with the physical object and that he thus sensed directly what was going on in the external system. In highly-developed visualizers, this process probably is carried over for other than physical phenomena. Thus, poverty can be seen and felt as a pervading vapor that penetrates a house with its odors and depression, and history might be strung out along an imaginary line extending back as far as one wishes.

Our primary interest here is with a hypothesis about scientific creativity,

with no necessary concern as to whether or not it applies to other fields like art, music, or poetry. It can be imagined, however, that it could also apply to the other fields where physical things are involved, such as art, architecture, and the like. A little more guessing may be involved in musical composition, but it is not difficult to imagine that the really inspired composers actually hallucinated the over-all effects of music and only later wrote down the required notes. But, the effect is only being considered here as it applies to scientific creativity.

It is not intended to imply that such visualizing ability is the sole prerequisite for creativity. Obviously, other factors are important to creative thinking, such things as factual knowledge, a liking for the intellectual work involved in creating, motivation, a feeling of discontent with some aspect of life, and the ability to put oneself in a playful and leisurely frame of mind in which he can toy around with bizarre concepts without feeling guilty. These other factors are important, but they have been treated by Beveridge and by many other authors of current books on the subject.

Many studies might be conducted to investigate the importance of this type of mental visualizing to the creative act. Of course, this would require depending on the reportings of creative and uncreative persons as to what went on in their minds while they were groping with a problem. However, later work might involve problems given to persons in the form of visualizations of situations in such a way that solutions must necessarily involve visualizing, while others might require little visualizing for solution.

Perhaps the final test of the efficacy of this method will come when it is demonstrated that persons, children or adults, can be taught to visualize or not to visualize and when it can be shown that this leads to an important difference in creativeness in later life. It is exciting to think how much easier and more effective education might be if it could involve teaching the correct, or one of several correct, mnemonic devices to the student rather than simply pressuring him to cobble up some such mental device on pain of failure for nonrecall.

It is much more questionable that the adult, who has already formed a whole complex of mental habits in a particular field, can remake these images so that he will be more facile in creating in his field, but this is worth trying.

Other implications of these insights into the creative act seem obvious. First, research should be conducted to try to identify and classify more exactly the nature and structure of the mysterious process of mental visualization or voluntary hallucinating. Answers should be sought to such questions as: How well does this ability correlate with productive creativity? How elaborate can such mental images be? How and to what extent can the individual sense from such mental images complex facts that he did not possess before giving attention to such mental images? Can this type of mental visualizing be induced in oneself or in others? Especially, could children be taught to use mental visualizing rather than rote memorizing?

With the answers to these and other such questions, we might be able to learn a great deal more about the nature of creativity and to devise more powerful methods of assessing its presence and of teaching it to others.

At least here is a positive lead that is so apparent to the creative persons with whom I am familiar that they never stopped to consider whether or not it is special. When asked if they use life-like visualizations when they are inventing, they are inclined to say, "Why yes. Doesn't everybody?"

REFERENCE

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