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UL BOOK LC 92085053 ISBN 0819409103

Neutrons, x-rays, and gamma rays : imaging detectors, material characterization techniques, and applications, 21-22 July 1992, San Diego, California / John Carpenter ...<et al.>, chairs/editors. -- Bellingham, WA : SPIE, c1993. (Proceedings / SPIE--the International Society of Optical Engineering ; v. 1737)

STATUS h DT 08/24/93 AD none

NOTES

001 1L CN ¦a engn ¦b QC;673;.N41;1993 ¦d 09/03/93

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ITEM RECORDS 1

088 IP-153

099 UMR1068

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650-0 Creative ability in technology.

650-0 Creative thinking.

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THE UNIVERSITY OF MICHIGAN
INDUSTRY PROGRAM OF THE COLLEGE OF ENGINEERING

CREATIVE ENGINEERING

R. E. Carroll

March, 1956

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CREATIVE ENGINEERING

Raymond E. Carroll

The recent loss of some of our great creative geniuses plus the information that the Soviet Union is currently expending tremendous efforts in the training of large numbers of technical personnel, brings into sharp focus the importance of improving our understanding and use of creative thinking in science and engineering.

What do we know about how a successful engineer gets his "bright ideas" which lead to solutions? How does he grasp some significant factor from a maze of seemingly unrelated data? When everyone else is giving up, he is likely to say, "I feel that there is a simple solution to this one. Let's give it a little time, and it will come to light." If often does. Have answers to complex situations or difficult problems come to you when you were concentrating on something entirely different, or when you just awoke in the morning?

We believe there should be more open communication on this subject between engineering people. That is, the subject of the <u>mental</u> processes which lead to the development of new concepts, processes, materials, or designs, or unique applications or combinations of old ones.

There have been a great many reasons why engineers and many other supposedly progressive people have not talked much about improving mental processes. One attitude is, "Leave such things to the psychologists." At first, this may seem quite reasonable. Engineers should concentrate on inanimate things. But there are very good reasons why investigations of creativity should not be left to the psychologist alone. You yourself can develop your effectiveness to a much higher degree if you have some understanding of the principal factors affecting your efforts; your ability to come up with new ideas is certainly one of these important factors. If you refuse to assume any responsibility for improving this ability and assign all responsibility for investigation in this realm "to the psychologists", you are losing an opportunity by default. Likewise, in order to develop more workable theories, leading to improved training techniques, the psychologists must be stimulated and encouraged by observing an active interest in this subject by those who are constantly doing creative work, and who, at the same time, understand scientific methodology.

A second barrier to communication about this subject is the belief that creativity is a vague, elusive thing, resulting from queer and delicate personality balances. "Analysis may cause change, and may result in deterioration of this ability". The cloak of mystery has hidden many truths for ages, but the scientific man finds answers to questions because he is not afraid to look, even though some change may result. It may well be that the analysis of any human ability will result in change. However, this should be a challenge, not a discouragement. The physicist does not give up his efforts to define a particle more accurately when it is proved that observation of this particle will change its velocity or direction. Furthermore, this creative ability which scientists and engineers have and want more of is a basic human ability or combination of abilities, and is certainly not so ephemeral as to be in danger of disappearing under the light of objective investigation.

The literary man, the musician, the painter, the sociologist, the psychologist, the scientist, and the engineer must work on this problem separately, each from his own point of view, and sometimes cooperatively with representatives of other fields. This will make for progress in achieving greater understanding of creative thinking.

Before doing any creative thinking, or attempting to obtain useful solutions, the problem must first be defined. In the case of many of our complex engineering problems, the definition itself is no simple matter. This could be a good topic of discussion in itself, but for present purposes we will say only that a good understanding of goals to be achieved is a prerequisite to useful creative engineering.

Many investigators agree that the creative process can, for convenience of analysis, be divided into four primary steps. These are:

1. inventory
2. incubation
3. illumination
4. revision

Inventory requires a great deal of conscious effort. When a problem faces us which demands a solution, we must bring together all possible resources. Formal training should be reviewed, personal experiences relating to the subject should be remembered critically, discussions with experts in the field should be arranged, and library research added to all other efforts. Sometimes, certain physical experiments are required in this initial step, when the answer to one or more rather specific questions will open or close the door to whole areas of possibilities. This inventory step is exceedingly important. It must be filled with tremendous intellectual activity, coupled with emotional drives. There should be a certainty that a really satisfactory solution exists, that the door can be opened by hard work, and there should be a strong desire to achieve a solution.

During the incubation step in the creative process, the problem is relegated largely to the unconscious. In other words, the person puts it aside temporarily and busies himself with other things. The desire for a solution remains, but conscious effort is suspended. Let us stress the point that this "unconscious" stage in creative developments is not a phase of getting something for nothing. There had to be intense activity preceding it, and there is still a great amount of intellectual activity during that stage, although much of this activity is below the conscious level. The incubation time varies widely--sometimes a complete shift of attention for only a few minutes will be long enough. In other cases, days pass before a sign of step three appears.

The third step, illumination, describes the point at which some key to the whole solution suddenly carries into conscious thought. This bright idea may be a fleeting thing, appear quite insignificant, and be easily lost unless the individual is very alert to such things. Occasionally, the illumination is a strong experience, showing up as a complete solution, with major complexities fully resolved.

More often a great amount of hard work follows the illumination -- this being called the revision step. When the work of revision is complete, the illumination itself may be hardly recognizable.

These four steps in the creative process are pretty well agreed upon in principle. The wild variable is step two, the incubation period, which is largely out of conscious control. The engineer has an extreme dislike of any process which is "out of control", and the engineer is not alone in this respect.

Creative people have for a long time been trying to modify step two in some way, to hasten its progress, and to put it under at least some conscious control. Before we examine some of these efforts, and attempt to suggest new ones, let us theorize a little concerning what may happen during the incubation period, which allows the possibility of the emergence of fresh, newly created ideas.

Experience teaches us to classify items, materials, processes, etc., in our memory. This is a real necessity in laying the groundwork for logical thinking. Our critical judgment is based on a wealth of cataloged information. For everyday, ordinary operation, this mental cataloging is very useful and necessary. But it can be a real barrier to arriving at new and untried combinations of principles and things. For a simple example, a wheel is mentally cataloged as two concentric circles, with a substantial structure between the outer and inner circle. Generally, the central circle has a much smaller diameter than the outside diameter of the wheel. Dozens of other very normal possibilities are connected with the wheel's catalog system. We may think of vehicles, steel, rubber, air, bearings, lubricants, large and small wheels, etc. But even now, when the precision broaching of square holes is common practice, how many engineers may normally think of a wheel with a square hole in the middle as a possibility, even when this will result in a much better drive between the shaft and wheel? How many people would stand holding an empty fire extinguisher and let a small blaze get out of control, not thinking to use a large pitcher of lemonade which was only a few feet away? Our mental catalogs, which we use in evaluating ideas, have been trained to relate "wheel" with "round", and "lemonade" with "drink", so that other associations are difficult to form.

What we do in the incubation stage, then, is to relegate the problem to a part of the mind which is almost totally devoid of evaluation and critical judgment. The various elements of the situation are allowed to intermingle freely, on the chance that some new combinations will occasionally emerge into consciousness for a brief examination. These chance combinations in the unconscious have been compared with mutations in biology--mostly without value, but occasionally a definite improvement. The more material there is to start with, and the more activity there is during the process, the more mutations or new combinations will be produced. And so, this unconscious area has the advantage of not being inhibited by critical judgment. It also has another distinct advantage--that of operating speed. Our conscious thought is timed by sequences of real events, of material things or ideas of them in physical motion, and by the mixture of words with images. While we can think consciously of an action many times faster than it can take place in reality, clear, conscious thought does take time. The unconscious seems to operate in a sort of fourth dimension, handling, in a rather haphazard way, a whole complexity of events or ideas at one instant, without requiring a sequencing. The best illustration we have of this is in dreams of complex happenings, the dream occurring in a fraction of a second, and the conscious reconstruction taking a far longer time.

We can picture this incubation stage as similar to the throwing of a large number of carefully prepared machined parts of differing geometry into a bucket. The parts begin to move around frantically, trying to find new ways to fit together, regardless of possible utility in any of the new combinations. As we watch, we realize that most of the combinations are under the surface, and hence out of sight. Occasionally, we observe a new combination on the surface. Perhaps there is some influence which tends to force the better combinations toward the surface. But even so, an exercise of critical judgment forces us to conclude that most of these are worthless. We continue to feed activating energy to the operation, and to keep alert, and finally some worthwhile new combination appears which probably never would have been obtained in a lifetime of deductive, rational thought.

Many artists, and some inventors, have resorted to alcohol or drugs in an effort to get a look at, and thereby exercise some control over, this subconscious process. Some weird artistic expressions have resulted, being perhaps a reflection of inner personality struggles, but the kind of things we are looking for--new, practical ideas--cannot be obtained in this way. The reason seems rather obvious: the ability to recognize a new and useful and meaningful pattern is one of those which is lost first when alcohol or drugs begin to affect the brain. True, suspension of the inhibiting critical judgment is achieved, but the light monitoring of the operation by the highest center of intelligence, so necessary in recognizing valuable patterns, is lost.

Our only promising approach toward improving this four-step process of creative thinking seems, at present, to be the substitution of a definite, trainable, conscious technique for the unpredictable step two. Or perhaps we should say, the use of an alternate step two as a matter of habit, treating the occasional illumination arising from the unconscious as a bonus, very welcome, but not to be relied upon in any kind of planning.

If, as we suppose, the principle advantages in the rumination of ideas in the unconscious are the absence of critical judgment and the high speed of trial-and-error combinations obtainable, let us see what we can do toward achieving these conditions consciously.

Every individual has many levels and types of judgment. Materials and workmanship which are completely unacceptable in the construction of a house or garage may become quite satisfactory when applied to a fishing shack; language acceptable at the club is not acceptable at a formal dinner party. What we need, then, is to be able to attain at will a state of mind with noncritical attitudes--a state of mind in which we can comfortably consider all kinds of normally unrelated ideas as interesting possibilities for new and valuable relationships. The lack of critical examination of each item before it is considered saves much time. Then, after a quick consideration of each idea, a very rapid and undiscriminating judgment is made. Without taking time to put reasons into words, the decision is either, "Accept for later consideration," or "Reject". If this sequence is developed as a habitual thought pattern when one is looking for ideas, much material can be scanned rapidly, some of which can be preserved for a more critical evaluation. It is very important, however, that one does not get stuck by trying to verbalize all the possible reasons for rejecting one idea while retaining another. A certain amount of recklessness is required here, and any tendency to use language as a thinking tool at this stage will decrease speed.

If one has trouble getting started in this noncritical thinking about the many unusual ways to solve a problem, it may be helpful to use a checklist as a starter. If the problem involves a mechanism, the list may say:

Do the following with the presently-used mechanism:

1. substitute plastics or ceramics in some locations
2. double the operating speed
3. submerge it in water
4. work it upside down
5. change the drive or power source
6. compare it with an airplane or submarine
7. If you had a rigid, frictionless material with very high melting point, where would you use it in this mechanism?

8. Would a material of high inertia, but low weight, make it work better? how about the opposite--large weight and low inertia? (Impossibilities such as these may lead to considerations which will result in a practical improvement.)

9. Will it operate in a vacuum? In an atmosphere of oxygen?

10. If price were no object, what changes would you make?

11. Can you visualize it ten times the present size? What essential changes?

etc., etc.

Two to four or five people working together on a "free expression" session like this, where nothing is considered silly, can often resolve a stubborn problem on which previously no progress had been made.

After the inventory stage of a problem, we consider quickly and uncritically all kinds of even remotely possible solutions, noting any which seem to show promise, without considering negative aspects. Almost invariably, if the inventory work has been well done, and if there is a conviction that a possible and economical solution does exist, one or more satisfactory solutions will come to light. This is a modification of the illumination step, and is then followed by revision, which usually involves a great deal of hard but satisfying work. The full impact of critical judgment is brought to bear here.

We would like to mention the great importance of using only mental imagery in our new step two, when operating on an individual basis. If you say to yourself, "Maybe if we coat the aluminum with a thick layer of copper, it will give the right combination of properties," this takes too much time. Just picture the copper-clad aluminum in use, and decide "possible" or "impossible". In your mental pictures you can try many complex combinations of things very quickly. Whole processes can be run through this way in a very short time. Very accurate approximations can be arrived at by using imagery, provided you have had plenty of experience and training to back it up.

Visualizing objects in perspective, in color, with sound and motion is an ability which varies widely. Some unfortunate people see no mental pictures at all--just blackness, or grey, vague shapes. To illustrate the other extreme, some small children cannot always differentiate between their mental images and reality. It is said that Nikola Tesla, inventor of the a-c motor and induction coil, did his inventing by the use of vivid imagery, sometimes feeling that others should be able to see his "pictures", since they were so real to him.

Every effective engineer does think uncritically at times, and every man in engineering work must have at least a fair visual imagery. But the willful dropping of critical judgment at the right time, and the development of a clear, accurate visual imagery by conscious practice, will make possible planned creativity to a degree not presently dreamed of.

Our new Creative Engineering Outline:

1. Inventory

2. Individual or Group "Idea Session"
   Suspension of critical judgment--use of imagery
   Much higher speed and more-reckless-than-usual thinking

3. Illumination

4. Revision

If this process is used by groups, here are some suggestions that may be helpful. First, of course, as much control as possible should be exercised in choosing members of the group. Overly conservative individuals, or those who continually overemphasize the value of some idea which they once produced, should be avoided. To the man who exaggerates the value of a single idea, new thought is a scarce commodity, and he will be unable to help much.

Secondly, consider that a group of four or five well-chosen people is ideal. Larger groups will work, but require a highly skilled chairman. Third, there should be an understanding before "idea-generating" or "creative" meetings regarding the handling of patentable ideas which may be expressed during the discussion.

Fourth, the chairman should announce that this is a meeting for the offering of "crazy" ideas, and for the consideration of all remotely possible solutions. No criticism of a negative kind should be allowed during the first phase (step two in our formula).

Fifth, and finally, someone should be assigned to take notes, and voice recordings may be made, but such records must be cared for so that they are never "quoted out of context" or otherwise improperly used.

We have a tremendous reservoir of engineering knowledge; we have organizations and facilities for analyzing, measuring, processing, and synthesizing almost anything imaginable. But the individual engineer grows in creative ability by trial and error, by observation of others, and by listening to occasional suggestions and advice. It is highly probable that a more scientific approach, in academic and industrial programs, to the development of this most valuable human resource, will lead to extremely gratifying results.