CREATIVE ENGINEERING

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This paper, which has been slightly abridged, deals primarily with the problems that confront the engineering industry of the country as a whole and the methods by which they can satisfactorily be overcome by individual effort and training. Its sense can, however, with advantage be translated into a naval context. The paper is reproduced by permission of the Author, who is Technical Director of the Brush Electrical Engineering Company, and the Institution of Mechanical Engineers, before whom it was read.

INTRODUCTION

Among the many important changes which have taken place within recent years, one vital and significant fact must engage the attention of all responsible people in the United Kingdom—particularly those connected with the engineering industries—and that is the decline of our economic position. Our industrial lead established in the nineteenth century has vanished. We can no longer live on the food and raw materials paid for by the foreign investments of our forefathers. Previously the nation enjoyed a higher standard of living than was warranted by the work done, but now we have reached a position in which we must live on present earnings. We must earn our living in a highly competitive world by exporting goods and services to people who want to buy them, and our standards of living will depend entirely upon the quality and success of our efforts in that direction. It has been truly said that the ultimate wealth of a nation lies in the energy and ability of its people. We have few other natural resources. Dependence on coal as a source of exportable wealth is no longer possible on any significant scale, and if we depend merely on human energy others can out-number us. It therefore becomes a paramount necessity for us to use our ability, traditions, and skill, to do things better than others. This leads to the suggestion, which is not new, that we should endeavour to develop products and services which contain a high degree of brain power in relation to the raw materials used. Improvements on raw materials constitute the sale of our brains. A familiar example of such a product is the jet engine, which contains a vast amount of invention, research, and engineering development to which there is no short cut. We must seek to excel in the quality of our invention, research, design, development, and manufacture. In other words we must develop and foster our creative abilities, and it is the purpose of this paper to consider what creative ability is, as applied to engineering, and how it can be developed.

THE NATURE OF CREATIVE WORK

Creative engineering comes about by creative thinking, that is, bringing something new into being by a process of thought. It may be a new design, process, machine, product, manufacture, a new device, a new principle or theory, or it may be a new plan, or system, or form of organization, or a new application of data already known. The essence is that it is something new, which was not known or realized before, and to have value it must be better—it must constitute an improvement on previous knowledge. It therefore contains a considerable element of invention, but it may also include discovery. The discovery of the law of gravitation by Newton and the discovery of America by Columbus, are examples where the object or principle existed in the physical world but became known or explained as a result of the work of some individual. Today the word ' research ' is used much more than ' invention ' or ' discovery ', and research requires the use of the creative faculties. Applied research is essentially the co-ordination of facts and data, based on experiment, observation and reasoning, to find the solution to a problem. The statement of the problem might in itself be a piece of creative thinking. However, the subject goes beyond the processes of analysis by logic or experiment—it includes consideration of those powers of the mind which are called intuition, insight, and imagination, or even ' the flash of genius '—although it is not proposed to stress the role of genius. It obeys its own laws. A popular conception of our research and development laboratories may well be that they are inhabited by incredibly gifted individuals who occasionally produce some startling new marvels, but those nearer to the picture realize only too well the immense efforts that have to be expended sometimes to achieve only a small advance. However, the lightning flash of discovery is in some way related to systematic scientific thinking.

In order to consider how proficiency in creative thinking can be developed by the individual, it is necessary to examine what characteristics or aptitudes play a part, because if useful traits can be recognized they can be stimulated and developed by conscious endeavour. Creative ability is generally considered to be rare, and when it does appear it is usually regarded as a gift of nature. Some observers have the opinion that the creative instinct is more widely distributed than is recognized. The whole principle of the natural order of our universe is creative. The evolution of life is creative and it is a simple truth that most men find aesthetic pleasure and satisfaction in making or creating something by hand or brain. This suggests that we are born with inherent creative faculties which many of us fail to use to the best advantage, or even to use at all.

One difficulty of a great many people, even those with keen intelligence, is that they do not think deeply or systematically. They can be recognized by the impulsive nature of their judgements, the superficiality of their approach to problems, their conversation echoes the newspapers, their opinions are second-hand and very often emotion is used as a substitute for thought. Superficiality and temperament should have no place in engineering, and they are hindrances to creative engineering. Emotion is useful only when it provides the inner driving power that causes the truth to be followed at all costs. Random thinking, wishful thinking, and passive observation, while pleasureable at times, tend to train the mind away from its creative faculties, while too much reading can be as bad as too little. Inability to cope with discouragement and frustration can bring all efforts to a stand-still if they are not overcome. There are some words written by Emerson which sum up much of this—'One class of man speaks from without, as a spectator, or as acquainted with the fact on the evidence of third persons. The other speaks from within his own mind, as from experience, as from a possessor of the fact.'

The problems which come before the engineer in the course of his work, taken as a whole, are infinitely varied in character, yet they can be grouped into three classes, depending upon the mental processes used in handling them.

In the first class are the simplest problems, which are those that the engineer solves off-hand by virtue of his training and with the exercise of some imagination. The solutions are largely based on experience and, in general, the work of dealing with them proceeds easily and without any great effort.

In the second class, more difficult problems are encountered which resist immediate solution, and a certain amount of casting about has to be done to find possible answers. Reflection will need to be employed in finding ideas, and the mind so used will throw up various suggestions. A suggestion that seems to meet the case is selected and tried out. If it solves the problem, well and good. If not, more deliberate thinking must be applied in the search for ideas and the inquirer may resort to literature or discussion with others in order to stimulate the flow of ideas. Sooner or later a suitable answer is found along these lines.

The third class contains problems which do not yield to the previous treatment. The solution may well be outside the scope of the worker's experience, imagination, and reasoning power, but it does not follow that no solution is to be found. He still has recourse to another mental process which has variously been called inspiration, illumination, or the flash of genius. This process is worth detailed consideration and analysis because it is just at this point so many engineers drop the problem altogether in the belief that it is insoluble. Sometimes the solution will come when it is not deliberately being sought.

A classic example of this is the discovery of penicillin by Sir Alexander Fleming. He had long been looking for an agent which could be actively used to kill bacteria as an antidote to disease, and although many substances were known and tried, none had been found which was sufficiently stable for general use in medicine. One day while he was engaged on a different research altogether, in which it was necessary to cultivate new strains of bacteria, a culture plate became contaminated with a blue-green mould, *penicillium notatum.* Fleming observed that the plate was covered with colonies of bacteria except for a clear space round a few spots of mould. The idea occurred to him that the mould produced something which interfered with the multiplication of bacteria, and thus went on to further investigation which resulted in the isolation of penicillin. This is a notable case in which the investigator followed up a clue provided by an exception to the expected result.

Another example, which is well recorded in the annals of mechanical engineering, is the invention by James Watt of the condenser for the steam engine, which opened the way for the general application of steam power. Watt became interested in improving the Newcomen engine when he discovered, while repairing a model at the University of Glasgow, that its method of operation was extremely inefficient. Power for each stroke was developed by first filling the cylinder with steam and then cooling it with a jet of water. This cooling action condensed the steam and formed a vacuum behind the piston which was then forced to move by the pressure of the atmosphere. Thus with every stroke the cylinder was alternately heated and cooled, and calculation showed Watt that this process wasted three-fourths of the heat supplied to the engine. Therefore, if he could prevent this loss of heat, he could effect a considerable improvement in the efficiency of the engine. He worked on this problem for two years but could find no solution to it. Then, one Sunday afternoon, he took a walk on the Green at Glasgow, and this is his account of what happened (Dickinson, H. W., 1936, *James Watt*):—

> ' I entered the green and had passed the old washing house. I was thinking of the engine at the time. I had gone as far as the herd's house when the idea came into my mind that, as steam was an elastic body it would rush into a vacuum, and if a connexion were made between the cylinder and an exhausting vessel it would rush into it and might then be condensed without cooling the cylinder. I had not walked further than the Golf Course when the whole thing was arranged in my mind.'

Like all great ideas, it is simple and obvious once it is stated. The essential feature to be noted is that Watt had set himself a problem which after two years of work, his reason, imagination, and systematic thinking had failed to solve, then, suddenly, while indulging in a quiet reverie, the solution came to him.

THE CREATIVE METHOD

The steps by which this process of creative thinking is achieved can now be formulated.

First comes the conception of the problem, or perception of the need. Very often this arises in the course of the engineer's work and is very obvious to him. It may arise from intellectual curiosity or a variety of causes. Sometimes considerable thought and investigation is needed to get at the root of the problem but, once it is recognized, it should be formulated in the clearest possible terms. Clear definition of the problem can sometimes go a long way towards showing the nature of the answers required.

Next, the engineer must think intensely and deliberately about the problem. It must be viewed from every angle and all the factors involved must be carefully considered. The price of inspiration is hard preliminary work. Every facet must be understood, by reading and by discussion, and every means of acquiring knowledge of the subject must be used.

It is clear that only a trained bacteriologist could have understood the significance of Sir Alexander Fleming's culture plate, and only one who was deeply interested in the problem of finding a means of combating the growth of bacteria would have appreciated the meaning of the few exceptional bare spots that he observed while looking for something else. Such opportunities occur only to those whose minds are stored with ideas that are ready to crystallize into constructive thought in response to the right stimulus. Therefore, interest in the problem must be maintained, if necessary, over a long period. This is the critical point. If all efforts to solve the problem fail and it is recognized that a serious obstacle has been encountered, the non-creative engineer will give it up as hopeless and accept defeat. There it ends so far as he is concerned. Such a failure is, of course, exasperating but it happens to everyone who tries to solve difficult problems. Frustration is the prelude to illumination. At this point the study should be continued with intense interest until every detail has been considered even to the point of exasperation, then it can be handed over to the subconscious mind. This may be followed by a period of relaxation in which interest is taken in other things. The problem can be forgotten by the conscious mind altogether during this stage, but it appears to be important that no other interest should become more dominant. Somewhere within the mind the desire to solve the problem must be the dominant interest and then, in moments of calm and relaxation following intense and fruitless speculation, the revelation comes into the mind with apparent spontaneity.

An attempt has been made here to describe a process of the mind which is difficult to put into precise words, but those who have experienced such moments will recognize the analysis. The solutions provided by this means are not always clear-cut and ready-made. Very often they provide only a basis for further work. But the creative thinker must be ready to catch the fleeting thought and work it out with faith that it will lead to the desired solution. Some faculty within the mind provides a sense of conviction if one is on the right track. Newton's reply to a question on the methods he used to formulate the law of gravitation is reported to be ' by always thinking about it.'

It is evident that creative engineering is based on the use of both the logical and the intuitive faculties, either separately or in combination. The logical method includes all forms of reasoning and deliberate thinking, the acquisition of knowledge, observation, reflection, the formation of judgements, and so on.

Intuitive methods include the use of insight, imagination, intuition, inspiration, illumination, and subconscious activity.

The former methods are sufficient to yield solutions to many of the problems which arise in the normal course of work, but if necessity is the ' mother of invention ', intuition may be called its father.

DEVELOPMENT OF CREATIVE ABILITY

How can these valuable qualities be acquired and developed ? Dr. E. G. Bailey, in a James Clayton lecture given in 1949, stated :—

'It has been noticed that the people, in many walks of life, who have shown abilities to develop ideas, lead industry, and invent, have had certain characteristics in common : they have been doers and workers, regardless of the extent of their formal education : they have had good memories and an accumulated mass of knowledge which always seems to be available to meet immediate problems.

' Many competent people use the instinctive approach to a great many problems in their day-to-day work. They are careful observers, with good selective memories, and they have their knowledge well classified for immediate use upon call.

' We may place the more competent persons into three classes with respect to the methods of performing their work—the " dependables ", the " planners ", and the " men of vision ".

(*a*) The " dependables ", whether workers or top executives, go to their place of work each day ready to perform their duties in the same manner as yesterday, but with resourcefulness enough to fix a breakdown or oil a squeaking bearing.

(*b*) The " planners " have the ability to keep the organization free from discord and disruption or the machine from squeaking or breaking down, and are also able to speed up their work and obtain greater efficiency at less cost and with more harmony.

(*c*) The " men of vision " not only keep the organization or machine in good operating condition but are creative beyond " good enough ". They are continually building a better organization, developing better methods, providing better machines, and planning to sense future trends, and attain better standards.'

THE INFLUENCE OF EDUCATION

A well-developed capacity for self-instruction is more important than formal education in the formulation of intuition, and it has long been recognized by educators that mere instruction by lecturers and by cramming knowledge into students' minds does not necessarily produce a fully educated person. What the student learns for himself is more important than what his instructor tells him. Thus he becomes a ' possessor of the fact ' as defined by Emerson.

The increasing emphasis on research in our technical colleges and universities is undoubtedly a step in the right direction. While research is essential for the advancement of knowledge it is immensely valuable as a method of teaching, and the inclusion of more research within the teaching curriculum is strongly advocated. It is well recognized that work in the laboratory is a necessary complement to classroom instruction, but all too often such work takes the form of exercises which do not test the students' powers of ingenuity or originality. We cannot discover or develop these qualities by causing the individual to memorize, to repeat facts, or to carry out set experiments on which he probably knows the answer before he starts. Opportunities to do creative work should be present at all levels of education. Increasing attention to this aspect is now being given in primary education, and creative activities are being included more and more into the school syllabus. There are obvious dangers in overdoing it—but any aptitude or talent a boy may have in this direction should be given opportunities for expression, and then, when it is observed and recognized, there should be means for its direction towards channels for proper development.

In the later stages of education, the examination system dominates the students' activities and also the attitudes of teachers. In general, it is not until an engineering student reaches the post-graduate or Higher National Certificate stage that he is free to turn his attention to original or creative work. So far, no real or acceptable alternative to examinations has been found as a measure of educational success and the system is likely to continue. The challenge of our times to the educational system is that it should develop the initiative, ingenuity, and resourcefulness of the students, and abilities which may be lying dormant should have opportunities of becoming apparent and realized. If such opportunities could be devised and applied, many surprises would follow—not least to the students themselves.

CONCLUSION

The period following apprenticeship is the time when creative ability should develop its full power—and previous promise be fulfilled in performance. It is at this point that the young engineer must learn to concentrate his effort if he is to make an effective contribution. Some specialization is inevitable and it is, in fact, encouraged in certain fields. His field will broaden later as responsibilities increase. It is not possible to recommend too strongly the need for concentrated work. It is in these earlier stages of specialization that creative engineering comes to full fruition, and here it can gain full scope, before the care of administrative responsibilities begin to overlay purely technical interests. Experimental engineers are normally only too eager to discover creative talent in young men and, if it is shown to the young engineer that ideas, initiative, and inventiveness will be encouraged and put to his credit, he will usually respond if these qualities are in him.

Whatever is done by school, college, and university, or by industry or the State and community, the main contribution to creative engineering must come from the individual himself. All the external factors and influences can but provide the opportunity and the right environment—the individual must provide the rest. Something within him must click into position and provide that fusion with circumstances which results in creation to provide some advancement of the frontier with which he is in contact.

To the characteristics, qualities, and methods needed for creative engineering, it is necessary to add one more. The attitude of faith. When the ultimate end is vague and obscure, as it often is, the will to persist must arise from an inner conviction that the objective is worth pursuing and that the worker is on the right road.

Courage and determination are indeed necessary but they need to be underpinned by faith as the ultimate driving force. Faith in the value of what the worker is doing and faith in his ability to accomplish the purpose in view.