PART III: THE ROLE OF CREATIVITY AND INNOVATION IN ENGINEERING

ROLE OF CREATIVITY AND INNOVATION IN ENGINEERING

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INTRODUCTION

The exciting part of engineering is creating new systems and/or products — this is the essence of engineering as opposed to "handbook" engineering which could for the most part be handled by engineering clerks or designers. Several basic tools or traits are needed to be a creative and practical engineer:

1. common sense,
2. a strong interest and curiosity about things,
3. thorough understanding of the fundamentals, i.e., physics, chemistry, materials, etc., and
4. perseverance.

Some of the traits can be reinforced with the proper kind of training and leadership in high schools and universities (government and industry can help).

Successful product innovations come about because of needs indicated by the marketplace. Innovations result from needs or problems such as:

1. poor or inadequate product performance/quality,
2. costs being too high (of either product design or manufacturing technique),
3. meeting new needs (i.e., new government regulations).

Innovations come from individuals as opposed to corporations. Therefore, the proper incentives, tools, and environment need to be created to provide the proper conditions to allow innovation to take place.

We need to educate entrepreneur engineers or scientists; people who are willing to assume more responsibility and risk mistakes -- when mistakes are made they learn from them and then if they have the "stuff" they are able to dive back into the problem and solve it. An entrepreneur must go beyond generation of an idea — he must be prepared to tackle marketing, production, cost analysis, customer need etc. — an enormous task.

For an innovation to be significant (economically) much more than originating new ways of doing things is required — implementing these new ideas through commercialization is often more difficult and more important than originating the concept. Problem solving can be fun and a rewarding experience in itself, but frankly, all of the entrepreneurs whom I know personally have been driven by the profit potential.

We must all think of world markets for our ideas and products; it is no longer feasible to focus only on one's own backyard. I think Japan has done this very well, but I don't think U.S. firms have made that commitment. This requires a great deal of travel and study in order to understand other people's needs and problems (for example, at the 2nd Annual Korean Conservation Show - September '86 there was a lack of U.S. participants, but many Japanese and European firms made good showings). The United States is missing the boat again.

EXPERIENCE

Advanced Mechanical Technology, Inc. (AMTI) was founded in 1976 by Drs. Walter D. Syniuta and Joseph Gerstmann, former members of the Mechanical Engineering faculty of MIT. Previously, we were colleagues at a company where we directed the development of a modern automotive steam engine. This development effort resulted in the spin-off of a number of innovative technologies and products, including compact burners and fluid heaters, improved high-pressure pumps, and ceramic engine components.

As a startup company short of capital, AMTI began as an R&D and consulting organization. Within a year, the company bought a small machine shop to provide hardware capabilities and to produce a line of multi-component force sensors that were sold primarily for metal processing research. With a limited market and only word-of-mouth advertising, force-instrumentation sales remained low. In 1978, however, a researcher at Boston Children's Hospital ordered a pair of force-sensing platforms to be used for gait analysis of patients with locomotive disorders. Based on the favorable publicity resulting from the successful Children's Hospital research, the decision was made to invest in developing and promoting biomechanical applications of the force platform. Today, the Instrument Division manufactures and markets a range of systems for measurement of force, motion, and muscular activity and is a leader in the biomechanics instrumentation field.

At the present time AMTI's largest operating division is its heating products subsidiary. The company's first heating product was the HeatMaker, an integrated residential appliance which combines space heating and water heating in a single compact package. This product utilized technology resulting from the earlier steam engine work, and was developed with funding from a large gas utility. The company's most recent product is the HotMaker, an innovative high-efficiency commercial water heater that was developed with support from the Gas Research Institute.

While AMTI's manufacturing divisions account for most of its growth today, the Research and Development Division remains the focal point of the company. Operating as an independent profit center, the division maintains a high level of expertise in the technical areas of interest to the company, thereby providing a far greater R&D resource than could otherwise be afforded by a manufacturing organization. While it is not constrained to product development, the R&D Division continues to spawn innovative approaches which lead to new products that will pave the way for the company's future growth.

DISCUSSION AND RECOMMENDATIONS

Let me begin by posing the question that was asked in the session outline; "Does current engineering (science) education teach entrepreneurship and venture capital?" — the answer is NO! Those persons who are interested go off to business school to get an MBA (where they get formal training relative to accounting, marketing, financial analysis, etc.) -- many of the entrepreneurs get their knowledge by on-the-job training. This is not acceptable.

I would like to raise a couple of issues pertinent to the U.S. market. First, I have testified on behalf of two bills which have passed the U.S. Government; both of these bills have become law and are beginning to have a positive effect.

1. SBIR's — a National Science Foundation initiative;
2. Patent ownership — for universities, small business and non-profit organizations who will own patents and/or proprietary information which results from research conducted with Government funding (you want people to bring their best ideas forward for funding).

Now we need to go a bit further. We must allow U.S. Government funding to go beyond pure research with some product development permitted. We need cooperation between government, universities, and industry, which seems to be the case in Japan. Solving manufacturing and/or cost problems are just as much of a hurdle (or riskier) as technical barriers.

With regard to government-funded research, I find that often requests for proposals appear almost to dictate the approach to be taken by the potential proposers. This approach stifles creativity/innovation.

I am also opposed to those who would split the technology community into two pieces: "basic scientists" and "applied engineers". Some government agencies only agree to fund basic research, so a funding agency may reject an otherwise good proposal because it is construed as being "clinical" in nature and thus cannot be funded. The SBIR program on the other hand, is a good one because it allows scientists, non-scientists, engineers or university professors to apply for funds. Sometimes basic research is needed while at other times applied research is necessary.

Only last week I participated in a U.S. DOE program review and one of their principal problems appeared to be the question of "technology transfer": DOE has great ideas which have been funded but no one seems to be taking these ideas to market. Better cooperation between educational institutions, industry and government is needed in the United States. European governments are now trying to encourage technology companies to work with academic research groups in the hope that this will lead to more innovation and marketable products.

Industry, government and educational institutions need to work together to provide the climate and talent for creativity and innovation as follows:

a. Engineering (science) education should include elementary accounting, financial analysis, selling, marketing, business (product) planning, venture capital, banking, and manufacturing cost analysis -- these courses should be made available (or required) within the engineering department; not the business school.

b. Students need to be motivated and their creative/innovative talents must be practiced -- this can be accomplished by making the appropriate courses available and visible -- educational institutions need to attract entrepreneurs to their staff (non-business school departments) either permanently or on a part-time basis in order that students will have an opportunity to feel the excitement of doing something new. Industry and/or government could provide funding to encourage this type of interaction.

c. Summer programs should be provided (government/industry funded) which would allow science/engineering students to work in foreign industries -- the world market.

CREATIVITY TRAINING AND DESIGN-FABRICATION PRACTICE IN CONTROL ENGINEERING

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INTRODUCTION

In an institute such as the Tokyo Institute of Technology, writers' creativity is always highly valued. Among other assets like curiosity, reasoning and patience; creativity is thought to be indispensable in good research engineering work. Speaking in the broad sense of the word, creativity is found in a good design, in an effective way of manufacturing, in a newly discovered method of problem solving, etc. However, regardless of nationality, people of the same profession (engineering, in our case) seem to agree on what creativity is, although its exact definition is beyond the writers', and most everybody's capability. We can perhaps write down some keywords that are pertinent: idea, imagination, intuition, originality, uniqueness, effectiveness, simplicity, beauty.

In engineering, creativity refers not only to developing abstract ideas but also to manufacturing real objects by combining materials. The evaluation of engineering creativity is perhaps easier than that of creativity in general because one can evaluate the products of engineering creativity by their measurable performance indices, their sales in the competitive market and so on.

With this common understanding of the part creativity plays in engineering, and how the products of creativity can be compared, we come now to the question of engineering education. Can we teach, develop and evaluate creativity? In general, this is no easy question to answer. However, based upon their experience with courses offered at the Tokyo Institute of Technology, the writers believe this to be possible.

CREATIVITY TRAINING

It is important that one person frees oneself from fixed ideas if one wishes to become creative. There is a theory that different parts of the brain function in distinctive and unique ways, each performing its own role. Creativity may be brought into full play through use of the frontal lobe of the brain (see Figure 1).

The general mental attitude of a student is very essential for him/her to become creative. When one sees a task as duty or something

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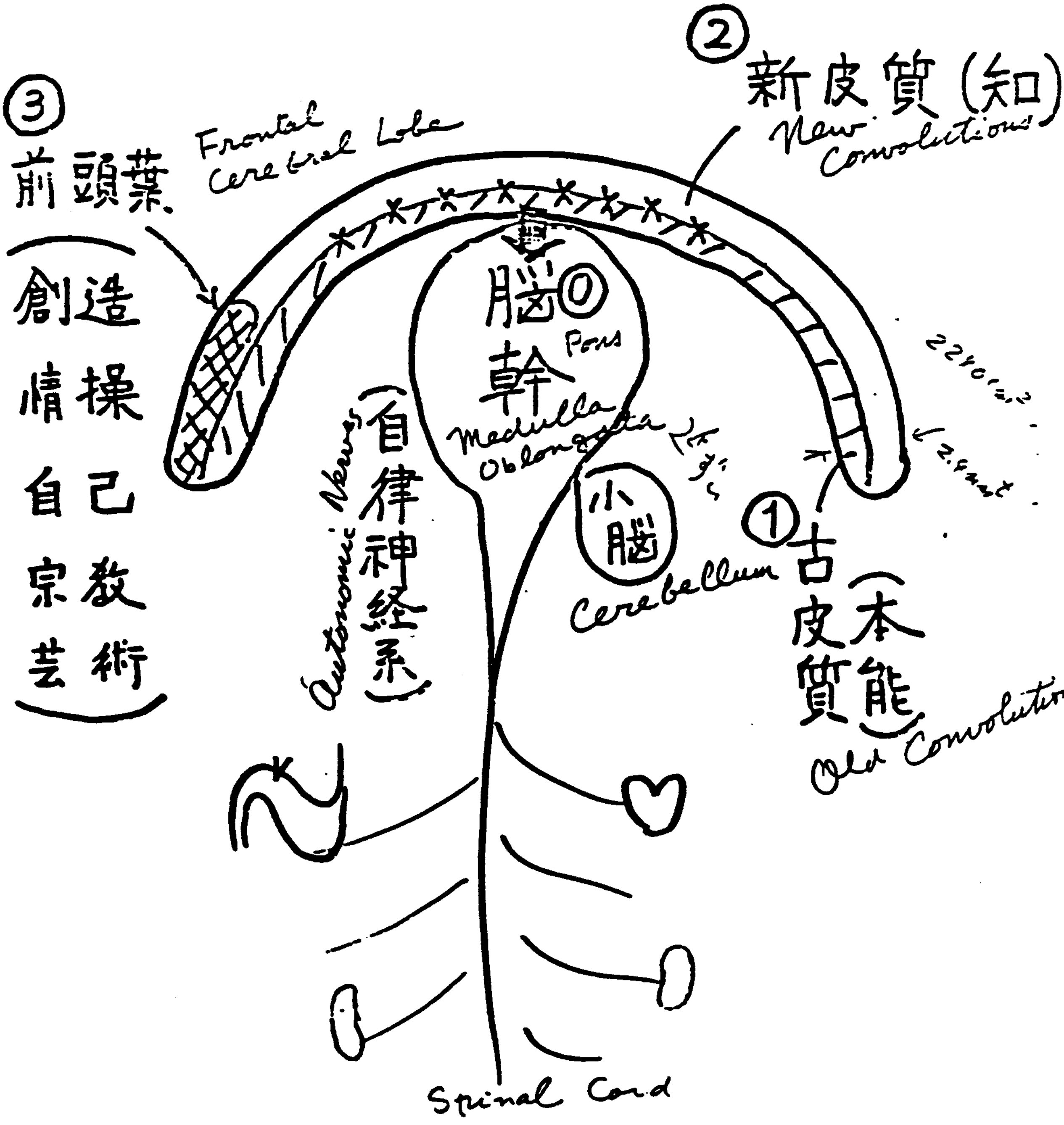
③
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Pons
Medulla Oblongata
小腦
Cerebellum
①
古皮質
（本能）
Old Convolutions
（自律神経系）
Autonomic Nerves
Spinal Cord

Fig. 1

that needs constrained effort, there is little room for creativity. If, however, he/she can see the task as pleasure or something that is enjoyable to do, he/she is likely to become more creative. Making everything enjoyable is often encouraged in the sayings of oriental sages. Students are thus oriented toward developing this sort of mental attitude.

Does this attitude conflict with the commonly accepted notion that innovation and creativity come from perspiration and hard work? Yes, if we are not dealing with a group of young people who have more or less the same level of intellectual achievement gained only through some amount of hard work. The Japanese university students are fairly homogeneous in this respect. They take a competitive examination of high standards even to enter well-known preparatory schools. To pass the entrance examinations of universities, they are trained with carefully planned special courses and programs in their high schools and preparatory schools. However, when they begin their university life, some of them show symptoms of purposelessness and lack of independent thinking. Professor Mori's creativity training course is designed for those students to open their eyes to being creative.

For example, the course includes time for meditation. The student actually sits on a piece of futon during the class and is guided to free his/her mind from the hitherto accustomed style of thinking.

The student is asked to submit a report on some problems which require his/her free unprecedented thinking. Some examples of the problems are:

1. Give as many ways of using a paper clip as you can think of.

2. What are examples of mutually complementary things?

Creativity is necessary if we are to avoid stagnation and mannerism. Japanese industry has been developing in the improvement of already existing products and in the mass-production of them. Now would seem to be the time to change this orientation from an emphasis on quantity to quality; from improvement to innovation.

DESIGN-FABRICATION PRACTICE IN CONTROL ENGINEERING

Historical Sketch

Professor Morita and others saw the importance of design in engineering from the establishment of the Department of Control Engineering about 25 years ago. Unlike some of the traditional departments where design means learning traditional patterns of drawings, calculation methods, ways to use handbooks, etc.; the aim of the Department of Control Engineering was to emphasize novelty of ideas, to devise systems hitherto non-existent, and to utilize common sense in general design methods rather than exclusively following specialized traditional techniques.

At the graduate level also, a similar course is included in the curriculum. It is on a higher level, requires research, may or may not involve designing mechanical devices, but must include some experiment.

One of the first tasks assigned by Professor Morita was: "Propose and prove a method of controlling humidity in the basement room No. xxx."

It was a room in a newly constructed building of the department and the whole basement still smelled damp, with moisture permeating through the fresh concrete walls. So the task was eminently practical. One group of 5 or 6 graduate students took responsibility for this assignment. Other groups were assigned different tasks. This sort of practical problem-solving was enjoyed by students and staff, and somehow formed the basis of a later revision of the undergraduate curriculum.

Back in late 1970s, the undergraduate curriculum was reviewed and much discussed among the staff members. The idea of linking fabrication with design was born in those discussions. The general scheme was to form four groups, totalling about 35 third year undergraduate students, who were given one common task to accomplish within a semester. The task involved investigation, innovation, design, fabrication, experiment and competition with other groups. One important limit was budgetary, as each group could spend only up to 50,000 yen ($330) for its design.

The first task was assigned in the fall semester of 1981, and the contest took place in February, 1982. The writers and staff members of the department tried to actively publicize the contest, and were successful in gaining students' enthusiasm for the task and competition. The contest was open to the public and attracted a considerable number of spectators.

Since then, five more tasks have been assigned, all involving contests, some of which were aired on television. On several occasions, the course was introduced to other professionals and to the general public via meetings and written reports.

The Task

The first task in 1981 represented the model to be followed in later years. The students registered for the course assembled in their classroom to receive their first assignment which read as follows:

> You are now engaged in a task the outcome of which even we professional staff members are not sure. However, this is the situation in which you will find yourself when you have a job as an engineer. You know what you have to accomplish, but you do not know how. With no model to follow, no books in which to seek ready answers; you are obliged to rely on your own resources to create a hitherto non-existent device, machine, system, process, etc. This course is to prepare you for such situations.
>
> You will learn ways to attack difficult problems, appropriate conduct in a project group, and means of utilizing technical resources. You will have to exercise your creativity to a full extent.
>
> You shall belong to one of the four groups which will compete with one another in making a vehicle capable

of carrying an adult, and moving by two 1.5 volt dry cells only. No other energy source can be used, except that you have 30 minutes to store energy drawn out of other cells before starting to move the vehicle.

The members of the group must cooperate closely. The following are hints for group discussion.

Brain storming

- Criticism of another's opinion must be put off till the last moment;
- Welcome unusual, out of the blue, opinions;
- Listen to another's opinion and make it a stepladder to elevate your idea;
- Think in terms opposite to others.

Advantages of a group discussion

- You will have many ideas;
- Your idea will be made concrete if articulated in front of other people;
- There may be a chain reaction of ideas;
- An individual is no match to a group of specialists.

Professional attitude

- Make records of the discussions;
- Define the discussion and carefully proceed from major issues to minor issues, never mixing them up;
- Focus your discussion;
- Once the goal is set, concentrate on it, ignoring all else;
- Think realistically, that is, think in terms of quantity. Never tarry at an impasse.

Your contest will take place on xx, February 1982. Your vehicles have a runway 70 meters long, and the fastest one will be the winner. To conclude the

> course you are required to submit a report including the design, drawing, experimental data, and discussion. The last, but important condition is your expenditures. Your budget is not limitless. We will give each group up to 50,000 yen ($330) to buy materials. You are required to perform the labor yourself, although you have access to the machine tools, the laboratory instruments, etc., which are necessary for fabrication and experiment.

The tasks given in 1982-1983 and in 1983-1984 were modifications of the above. In the fall semester of 1984, the task was changed. Instead of two dry cells, two amorphous silicon solar batteries were used to blow out rubber balloons. Last year (1985) two solar batteries were used to make a one-man elevator capable of ascending and descending by one vertical meter. The competition among the cell-driven vehicles had been done sequentially: i.e., after the first vehicle completed its run, the second started. Likewise the third and fourth performed in sequence. With the solar battery tasks, the style had to be changed. Individual competitions were held concurrently, because of the obvious consideration that the solar radiation conditions should be equal for the four competing groups.

The Performance

It was remarkable that the students' performance outran the staff members' expectations. As was indicated in the beginning of the assignment, the staff members were unsure whether there would be a moving vehicle using only two tiny dry cells. In fact, to cover 70 meters (200 feet) of road, although paved, with no energy source other than solar, carrying a male student, plus vehicle, weighing altogether 70 kilograms (150 pounds) or more, seemed a fantastic feat. The fastest group went 70 meters in 23 seconds; the slowest group in about 7 minutes. However, all groups received a big round of applause from the spectators.

In the elevator contest, the number of ascents and descents in 30 minutes was counted. The highest score was 250 times and the lowest score barely 1 time.

So there were considerable differences in the quantitative performance of the students from one group to another. However, the evaluation did not take the quantitative results too seriously. The process and product were equally important. The lessons that the students learned from one another were perhaps more valuable in the end than their individual achievements.

DISCUSSION

The writers have found the course quite satisfactory. It draws students' attention, feeds incentive, nourishes the spirit of cooperation, and rewards students with a sense of accomplishment. A key to the success of this sort of course is the selection of the task. The task should be neither too easy nor too difficult, and should inspire students' creativity and their devotion of time and energy.

The comments the writers have received on the course from the students, the instructors, spectators and bystanders, are mostly favorable. However, there have been some criticisms also. One is that the course is too theatrical. Another is that the students are having too much fun and are not being trained adequately. We may defend ourselves against such criticism in different ways, but for the moment we think it sufficient only to point out two general considerations. One, there is no established formula or theory which purports to produce better students with less publicity, and more penance imposed either by teachers or by students themselves. Two, if the students are having fun, they naturally concentrate on the task, become more creative and work harder.

From the writer's experience with the courses introduced, several fundamental questions seem to arise. Let us briefly comment on them.

- Is creativity always desirable in every field of human activity?

It is important to note that creativity has become a favorite topic in Japan only after its economy improved, its society stabilized and commodities became plentiful. Probably, creativity is necessary if human beings are to proceed to the next stage of development. However, creativity seems to require a favorable environment in which it can flourish.

Undoubtedly, creativity can be found in many fields of human activity; viz. literature, art, music, architecture, science and technology. One common background of these fields is what we may call human culture. Creativity, therefore, is a product rather than part of our culture. It is desirable because it is a sign of vibrant culture, society and environment. Creativity should be balanced with a proper sense of values, for man can be equally creative in evil plans and terroristic hardware.

- Is creativity desirable in engineering?

It is hard to draw lines between creativity and other qualities required of an engineer; to name a few, ingenuity, dexterity, craftmanship, and skillfulness. All seem to be desirable in engineering as long as the scale of judgment is technical. For example, the assigned tasks introduced in the previous sections of this report will be better done if the students possess more of these qualities.

To make a hitherto non-existent kind of vehicle may not require a large amount of creativity. Perhaps more important is the team work. If one self-appointed creative person, genuine or false, insists too strongly on his/her opinion at all times, the vehicle will never be completed. In that case, individual creativity has an adverse effect. However, the scale of judgment is a bit less technical, of course.

- What is the difference in creativity in various disciplines?

Professor Mori is an electrical engineer and Professor Morita is a mechanical engineer. Both are interested in control engineering.

They like to design, manufacture and experiment; therefore they know what is meant by creativity in their own fields of interest. To extend the concept of creativity into other fields of engineering is probably not fully justified at this point. Can a similar task be devised for chemistry students, for example? The writers must ask the opinion of chemists.

- Can creativity be measured?

As was mentioned in the introduction to this report, the writers assume that there is a common understanding of the meaning of creativity in engineering or in a special branch of engineering; at least among the specialists. So far, the writers' courses have been evaluated only by fellow teachers, or the people who are interested in this sort of education. The real evaluation will come in 20 or 30 years, when the graduates of the institute exhibit their creative talents in their respective working places. No attempt is being made, however, to trace the path of their achievements 20 years after graduation.

- Is creativity, or its degrees, fixed at birth, or can anybody be creative?

Engineers' products coming out of a manufacturing line are exactly alike, but no two engineers are just alike. Creativity is related to these unique qualities of people. No creative idea will emerge out of a group in which everybody tries to imitate everybody else. But mere differences of opinion will not guarantee a creative idea. No can one hastily make a judgment as to who is creative and who is not. Observing the work of the student groups, one can see that there are different levels of inborn creativity. Naturally outspoken students lead the group, but in the course of the discussion, the seemingly shy students may begin to show their real creativity. The role of an educator is to help them in finding these hidden qualities.

- What is creativity after all?

It is still a mystery.

THE ROLES OF SOCIAL SYSTEMS ENGINEERING IN THE INNOVATION OF JAPANESE ENGINEERING EDUCATION - FROM HARD TO SOFT SYSTEM THINKING

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INTRODUCTION

As modern society changes more dynamically than ever, so must technology in order to meet ever-growing social demands. It follows that, as technology progresses, so also does society, by incorporating technological achievements. In this way there will develop much closer interactions between technology and society, of which technology becomes a more indispensable part. This results in the increasing importance of engineering education, especially at the university level, in terms of its potential future impact on society.

The primary objectives of this paper are to discuss the roles and place of systems engineering, especially social systems engineering, in the engineering education of Japan, and to provide a brief overview of the ongoing attempt in Tottori University to inaugurate a new Social Systems Engineering department. The point will be made that social systems engineering is expected to play an important role in future engineering education, which will inevitably be forced to restructure itself in response to social changes. The paper concludes by referring to the manner in which social systems engineering may contribute to the encouragement of creative thinking and activities, as well as technological innovations.

SEPARATE ENGINEERING VS. SYSTEMS ENGINEERING

In order to illustrate the unique roles of systems engineering, let us first examine what has principally motivated the advent of this new type of engineering.

Complexity of the Real World

Cursory inspection of the world suggests that it is a giant complex with dense connections between its parts. Since it is simply not feasible for us to deal with it in that form, we are forced to divide it into areas which we can manage to examine separately. Checkland (1981) claims that:

> Our knowledge of the world is thus divided into different 'subjects' or, 'disciplines', and in the course of history these change as our knowledge changes. Because our education is from the start conducted in terms of this division into distinct

subjects, it is not easy to remember that the divisions are man-made and are arbitrary. It is not nature which divides itself into physics, biology, psychology, sociology, etc., it is we who impose these divisions on nature; and they become so ingrained in our thinking that we find it hard to see the unity which underlies the divisions.

In fact, there has been an increasing complexity of society for which technology has been largely responsible; and, as a result, modern engineering has been forced to shift focus from a specific single entity into a more complex one, i.e., a system. Thus it is quite natural that a previously non-existent science has gradually developed into what is currently known as systems engineering.

Overlapping Disciplines

As previously discussed, the established divisions of science are artificial, devised for the sake of convenience. Therefore, it is very likely that, as society changes, these divisions may less effectively reflect the existing social situation. In reality, it is becoming more common that a particular engineering problem must be dealt with by a combination of more than two separate divisions (disciplines). Figure 1 illustrates an example of the evolving processes of two separate disciplines; civil engineering and electrical engineering; mutually overlapping as society becomes more complex. For instance, the conventional type of civil engineering has long been concerned with developing and constructing cities or regions, or with transportation and communication. Let us call these kinds of engineering objects "macrosystems," which are characterized by their seemingly closer and more direct contact with society, man and environment, and their resultant high complexities and the difficulty of identifying their whole structures.

Obviously the conventional type of electrical engineering has been related to development of the microsystem, so that its outputs have been built into the macrosystem to constitute its subsystems or components. Indeed, its role was sometimes central, especially when a marked technological innovation was achieved. However, its role was rather marginal and supplementary in assembling all the needed components or subsystems into a total macrosystem.

Conversely, the conventional type of civil engineering tended to deal with electrical devices such as "black boxes", paying little attention to how their functions can best be integrated. As a result, its contribution to the development of electrical products was somewhat marginal and supplementary. In electrical engineering, macrosystems with which civil engineering had chiefly been concerned were treated rather as the exterior of those systems of their own interest. Let us refer to these kinds of systems as "microsystems." These have unique features in that, as compared to macrosystems, they appear to be more indirectly and less closely associated with society, man and environment, and therefore tend to be considered less complex and easier to identify. It may be more to the point that a microsystem is on a relatively small scale as measured against human scale.

The above division between separate engineering disciplines becomes less consistent with the real world as society changes more rapidly and becomes more complex. Thus there is an increasing demand for engineering academia to readjust its role-sharing mechanism, so that it may more consistently mirror an ever-changing society. In this context, the increased overlapping of particular separate engineering disciplines with others was certainly a natural evolution.

Figure 2 illustrates how part of a macrosystem finds its way into a microsystem, and vice versa. The result is a growing importance of the role of systems engineering, in interlinking both systems more closely and appropriately.

Managerial Concerns

It should be noted here that behind the need for systems engineering lies growing managerial concern in the area of engineering projects. Since engineering has been required to engineer increasingly more complex products, it has inevitably been forced to go beyond its self-defined conventional boundary, within which it has mainly been devoted to "analysis" (break-down) and "synthesis" (assembling or building) of physical entities.

As the result of this, engineering now commits itself more to managerial concerns; i.e., "what is the problem to be solved?" (problem-identification or -formulation), "Do we have enough and appropriate information?, and if not, what data must be collected?" (investigation), "What is the causal mechanism behind the problem and how does it operate?" (analysis). "What is a set of rational alternative solutions?" (design), "What is overall the best alternative to select?" (evaluation and selection), and "How to integrate (assemble) the selected alternative?" (integration and assembling). Furthermore it is becoming increasingly important for engineering management to place a focus on operation and repair (Figure 3).

It is noted that the above-stated process corresponds to what is termed the process of problem-solving. A body of scientific techniques has been developed to support this process systematically. They include techniques from operation research (OR), management science, computer science, project engineering, etc.

Computer-Based Technological Innovations

As far as motivations and incentive for the evolution of systems engineering are concerned, a series of computer-based technological innovations have undoubtedly been taking a key role. In fact, without them, what is now called systems engineering would have definitely been much less operational; thus less practical and influential on society. This is still even more true in the changing technological environment, to which current society is becoming more firmly linked. This type of technological innovation contributes greatly to the increased efficiency and sophistication of "information processing," in the broad sense of the term.

The discipline of systems engineering has been making full use of such achievements and now constitutes the main and indispensable experimental tool for it. Consequently, systems engineering is now proving itself to be one of the major disciplines which deal with the more broadly defined theme of "information" and "communication".

VERTICAL VS. HORIZONTAL DISCIPLINE

It is commonly criticized that so-called systems engineering must have long been part of science and engineering, without being explicitly named and identified as such. This argument is certainly to the point, with the reservation that systems engineering often means no more than any sort of well-trained sense of systematic thinking, which a well-experienced researcher, practitioner or manager with a particular engineering background may have gained unconsciously.

What distinguishes systems engineering from systematic thinking is that the former offers a scientific methodology for solving complex problems to which engineering is required to find solutions. At the risk of oversimplification, Figure 4 compares substantial differences between the conventional type of separate disciplines and the discipline of systems engineering. As the former might be called a "vertical discipline," the latter may be defined as "horizontal discipline."

A mechanical engineer would chiefly cut through, a particular mechanical phenomenon, for example combustion mechanism of an engine chamber, or pipe flows of recycling water, etc. A chemical engineer might principally proceed in a vertical direction, with a view to delving into the synthetic mechanism of certain chemical substances, or chemical analysis of an unidentified catalytic agent, etc. Likewise an engineer with a background in any conventional discipline is trained to study the mechanism which he believes to be pertinent to his interest, mainly by a cut-through approach.

This simple analogy sounds basically plausible but in practice faces a number of exceptions. This is particularly the case if the engineering activity becomes committed to management. It has to shift in a horizontal direction, in order to interlock itself with other, vertical, disciplines so that their common problems as well as their own particular problem may appropriately be considered at the point where disciplines overlap. By analogy with cell-division in biology, we may call this horizontal shift a "zygote".

In contrast, the discipline of systems engineering may well be conceived as the dual of the vertical discipline (primal), in the sense that its major concern is with cutting across vertical lines. A question arises: What are specific phenomena located along this horizontal axis just as civil engineering, mechanical engineering, electrical engineering, chemical engineering and so forth are located along the vertical axis? A simple answer would be that they are all kinds of managerial phenomena pertinent to engineering. More specifically, it is concerned with a whole body of scientific methodology for problem-solving, together with a set of system concepts and analogies which have been commonly found in, and thus become prototypes, of a broad spectrum of system research activity.

Figure 5 which was originally developed by Checkland (1981) offers us an overall perspective of those findings which have been made in what he calls "system movement". It is noted that a part of these findings is what is known as "systems analysis", originally developed by the RAND

Corporation (Quade et al, 1976). This RAND-style systems analysis gives the flavor of economic analysis and assessment of engineering projects, with the aid of engineering economics and operations research. Yoshikawa (1975) interprets systems analysis more generally and broadly, claiming that it deals with the entire process of problem-solving, specifically concerned with planning and management of a particular engineering project.

SYSTEMS ENGINEERING TO SOCIAL SYSTEMS ENGINEERING

A drawback to what has been known as systems engineering is its bias toward "hard systems." This is mainly due to the original nature of conventional engineering which has exclusively been associated with physical entities. It is also because an evolutionary mainstream of the discipline of systems engineering was mistakenly believed to be derived mostly from electrical engineering, mechanical engineering, control engineering, etc., major elements of which are in "microsystems." It should be acknowledged that there has been another stream flowing into systems engineering from civil engineering, environmental engineering, resources engineering, etc. Regretfully these streams from different directions have seldom merged to complement each other.

Figure 2 illustrates that in our rapidly changing society the microsystem can no longer be entirely separated from the macrosystem, and vice versa. This implies that social contexts have to be more specifically superimposed onto systems engineering. It is for this reason that systems engineering is currently being forced to shift more to "soft systems," of which hard systems are a part. The "soft system" is meant to deal with poorly-structured problems involving socio-economic, cultural and human spectra as well as purely technological ones.

This is well illustrated by a common case in which electrical engineers are asked to develop a computer-based communications system. Creation of such a sophisticated and extensive network of information and communication requires clear identification of those types of information potential users may demand as well as the modes of its utilization as related to their preferences and behavioral characteristics. A civil engineer would be entirely helpless in designing a new transportation system if he is ignorant of passengers' familiarity with and adaptability to computerization.

A common pitfall of extending to the soft system, especially in engineering education at the university level, is that it becomes more difficult for students and others concerned to see the phenomena directly with their own eyes. Increased invisibility coupled with lack of technological and physical contents need to be compensated for adding socio-technical specifics or contexts to systems engineering. This may be a promising compromise in introducing the discipline of systems engineering into engineering education.

SOCIAL SYSTEMS ENGINEERING INTRODUCED INTO ENGINEERING EDUCATION

An attempt is currently under way to introduce systems engineering into the engineering education of Japan. The Department of Social Systems Engineering was established in the Faculty of Engineering of Tottori

University in 1984. The adjective "social" is placed before "systems engineering," in order to stress intended amalgamation of systems engineering with socio-technical contexts. "Socio-technical contexts" refer to (i) urban and regional systems, (ii) human and social systems, (iii) engineering economics, (iv) information-processing, and (v) basic systems theory. In accordance with this, four laboratories are currently being prepared to accept students in their undergraduate courses. This idea is also reflected in the curriculum, which consists of the five socio-technical specific-related subjects plus engineering basics.

The success of such an attempt is to a large extent dependent on whether the above-stated socio-technical contexts can be adequately interwoven into the discipline of systems engineering and on the extent to which students acquire a body of social systems engineering knowledge as presented in a formal curriculum, with which to solve ever-broadening socio-engineering problems in the real world. It also depends largely on whether future industry will be attuned to proper acceptance of the graduates from this new type of discipline, in order to best utilize their expertise under proper conditions.

CONCLUSION: SOCIAL SYSTEMS ENGINEERING AS A MEANS OF CREATIVE THINKING AND TECHNOLOGICAL INNOVATION

To conclude, let us note that social systems engineering will definitely encourage creative thinking and take an effective if not essential role in the promotion of technological innovation. Since one of its objectives is to systematically codify the process of problem-solving, social systems engineering is expected to provide graduates of this discipline with "secondary creativity" - the ability to create and discover things on the basis of predecessors' achievements (Adams, 1974). It is also likely that this new discipline will ferment "primary creativity" - the ability to discover a novel idea which leaps far from the current state-of-the-art. This may sometimes be achieved in the process of problem-solving by encouraging students to view the given problem from different viewpoints (Kayano, 1973).

Notably, creativity is achieved by an exquisite combination of two complementary approaches, (i) to penetrate, and (ii) to take a quantum leap. In fact, any discipline, be it vertical or horizontal, is exclusively directed to "penetration," and not to "taking a quantum jump," since the latter is largely inconsistent with the former, and can hardly be taught or trained in educational programs. It requires some deviation from the base discipline as a first step, thus producing an inertia which in turn-may lead to such a quantum leap. Social systems engineering tends to encourage this deviation by bringing in vertical momentum, that is, some socio-technical contexts interwoven with the horizontal momentum of systems engineering.

Buddhism teaches us that enlightenment should be achieved by proceeding through three steps; (i) to master thought, (ii) to deviate (or break off) from the original concept, (iii) to take off in a new direction. This process seems very much the same with the development of creativity. It is, however, pointed out that although we may somehow manage to convey knowledge of the first and second steps, we commonly fall short of the last step. Even the proposed discipline of social systems engineering would not be an exception.

So let us conclude this paper by raising a fundamental question: Can creative thinking be achieved principally by educational programs? This question parallels another one: Can "taking off from the base discipline" be taught by a systematic method? The question has yet to be resolved; however, it is undoubtedly true that a systematic method becomes really powerful only when some appropriate software is interlinked with it, and it is man who operates the software.

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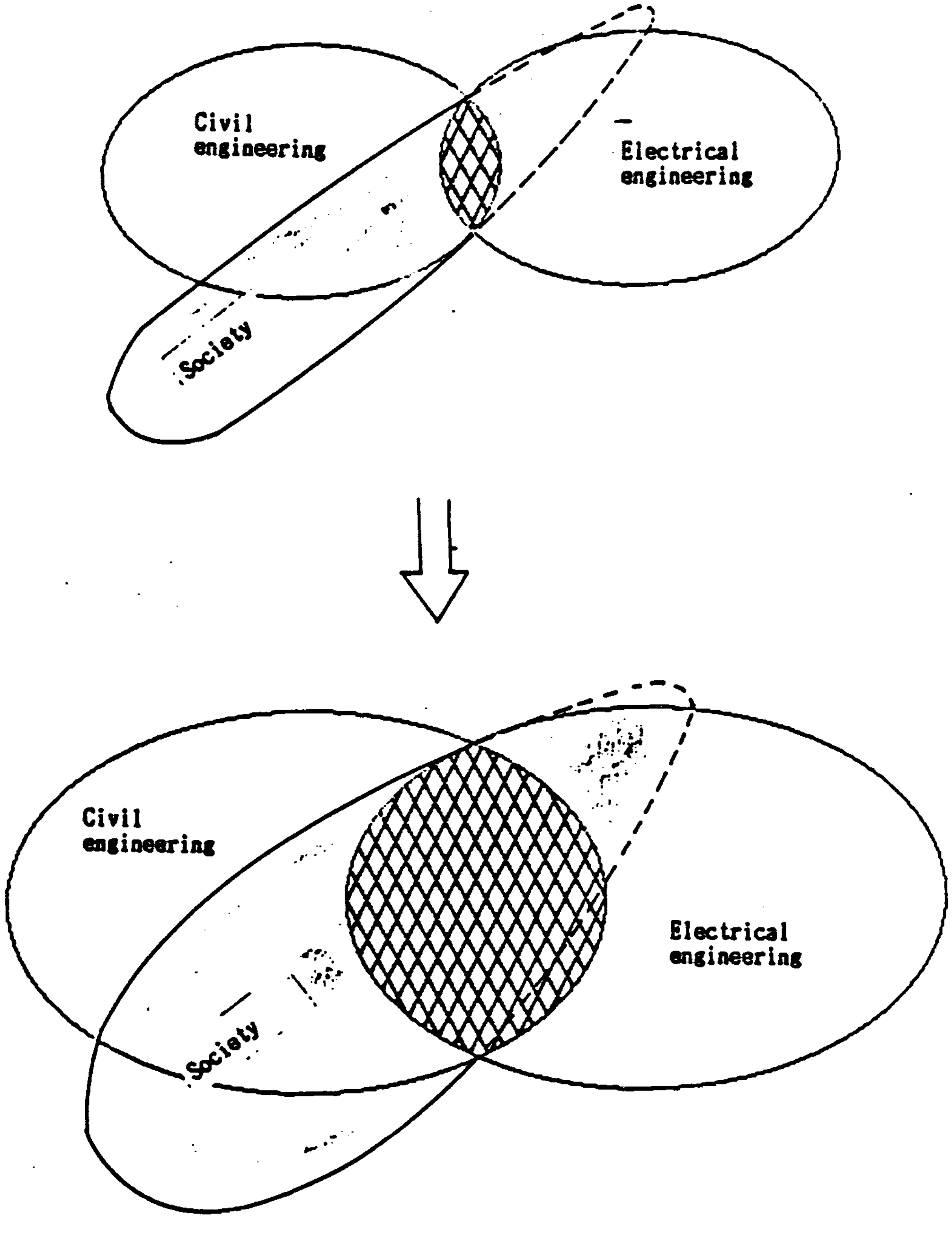

Fig.1. Example of the overlapping of two engineering disciplines.

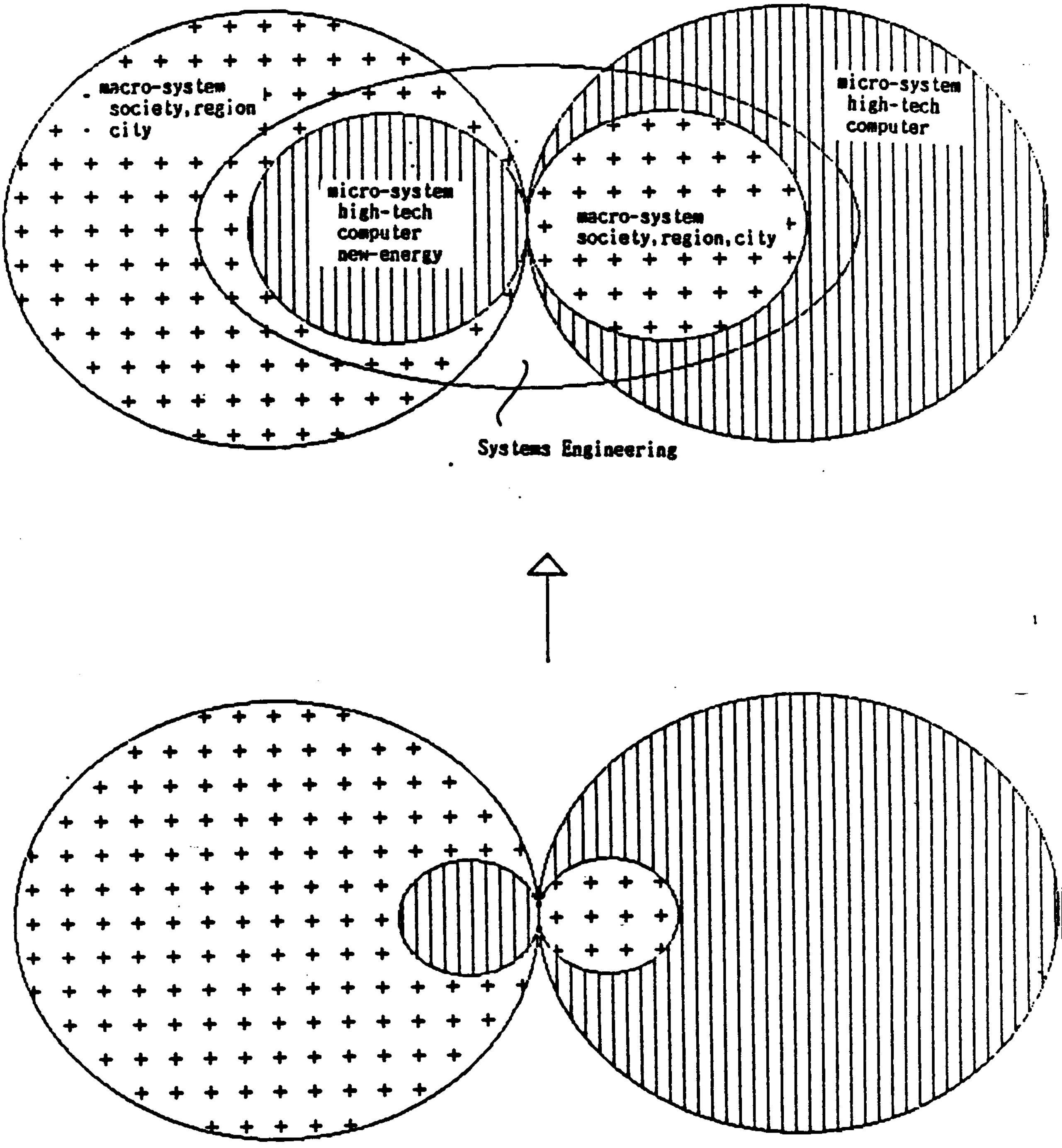

Fig.2. Changing demand for engineering to mirror the changing society.

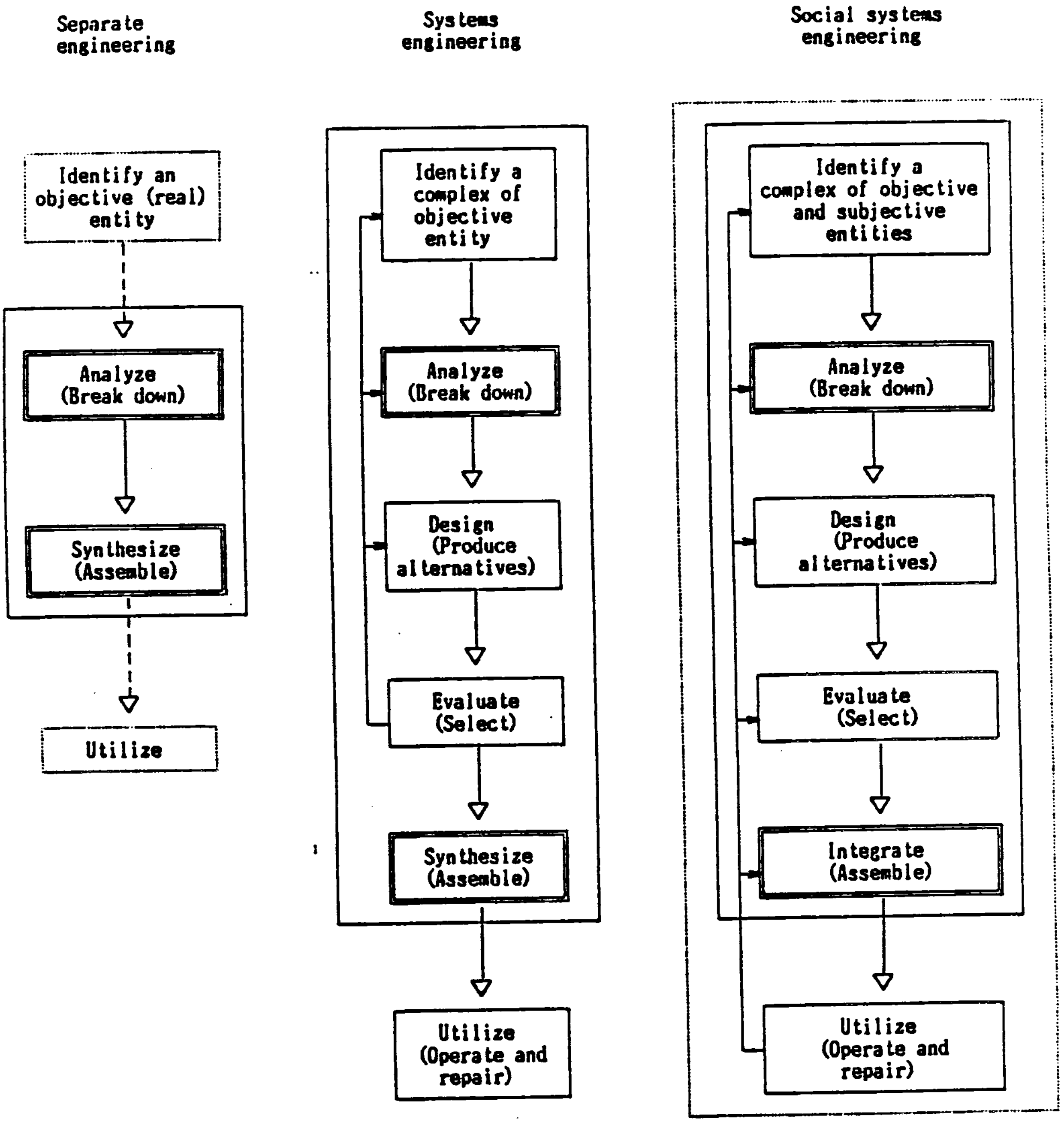

Fig.3. From product making to problem-solving

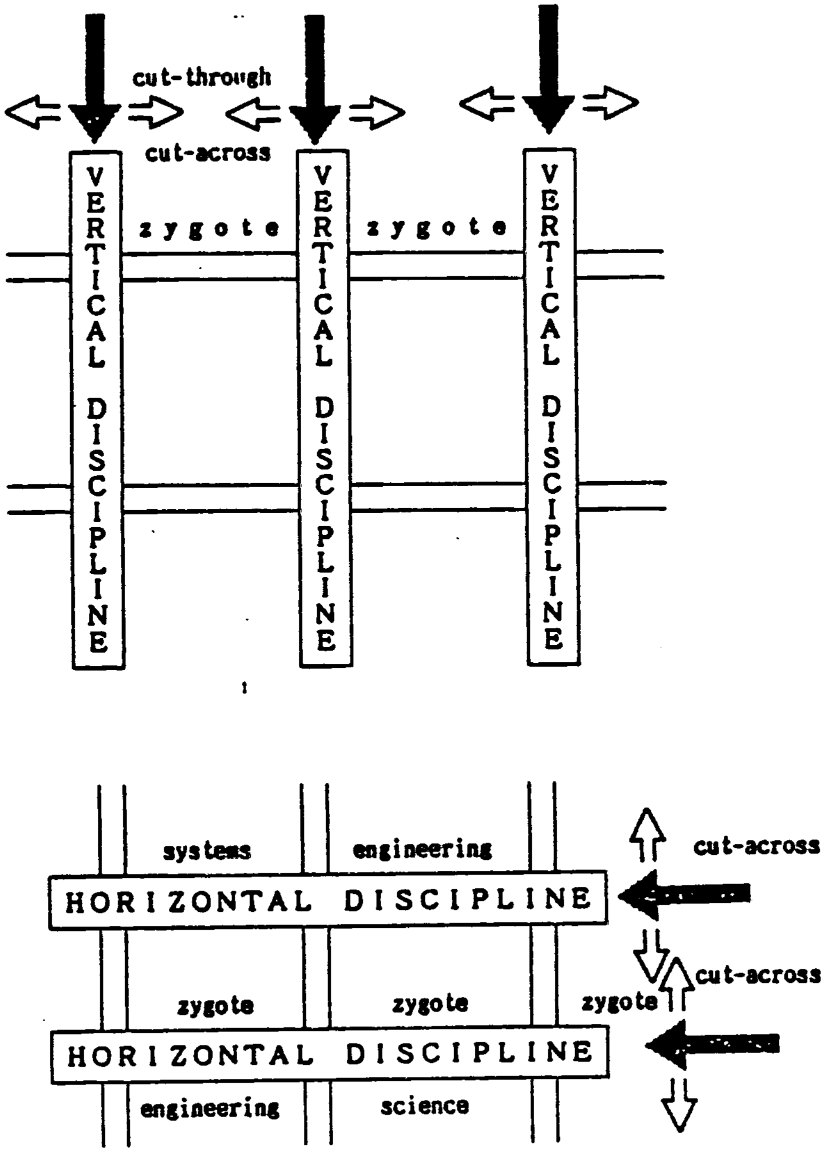

Fig.4. Vertical discipline vs. horizontal discipline

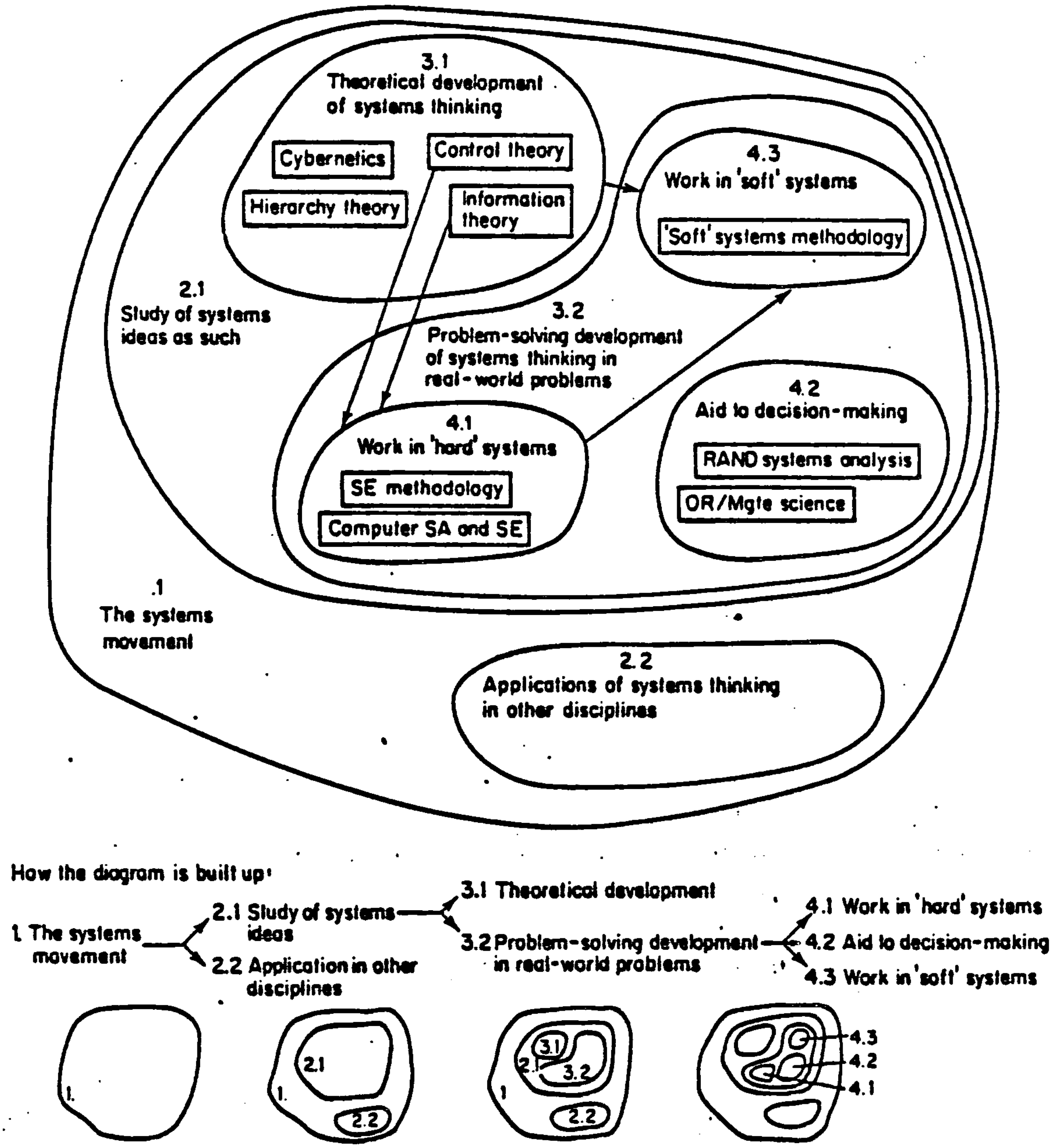

Fig. 5 The shape of the systems movement (from Checkland, 1981, pp 96)

MEETING THE CHALLENGE OF NEW TECHNOLOGIES: MANAGEMENT PRACTICES FOR ENHANCING CREATIVITY AND INNOVATION

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The rapid introduction of new products and processes is challenging the engineering work force to keep up with technological advances and be competitively innovative. It is ironic that engineers, who are most responsible for technological change, are also highly vulnerable to its consequences - obsolescence of engineering knowledge and skills (Kaufman, 1974; 1975; 1982).

With rapid advances in technology continuing unabated, more effective management practices are needed to help assure that creativity and innovation are not stifled by knowledge and skill obsolescence among engineers. This paper addresses this issue by focusing on several management methods that research has suggested are effective in helping engineers meet the challenge of changing technology. These practices are examined vis-a-vis their importance to engineers and their prevalence among engineering employers in the United States. These data were obtained from a recent national survey of 3357 engineers working in industry (Engineering Manpower Commission, 1986).

- Use job assignments of engineers to stimulate the learning of new knowledge and skills - The effective utilization of engineers in their work is a key factor affecting their motivation and technical competence (Kaufman, 1974; 1979; 1986). A lack of either motivation or competence reduces an engineer's capability to be creative or innovative. Engineers have a strong need to use their overall technical competence. However, every indicator shows that a large segment of the engineering work force in the United States remains poorly utilized (see Table 1). This problem appears to affect at least one out of every three engineers, regardless of age. Most perceive their employers as not having an adequate concern with enlarging and enriching engineering work assignments to make them more challenging. Organizations need to improve their use of job assignments to stimulate the learning of new knowledge and skills required to achieve creativity and innovation. This can be accomplished by paying closer attention to factors such as job design and the role of the supervisor in improving engineer utilization.
- Provide adequate resources to engineers in terms of support services and up-to-date equipment to achieve more rapid and effective problem solutions - The provision of

TABLE 1

UTILIZATION OF AMERICAN ENGINEERS

	IMPORTANT TO ENGINEER %	CHARACTERISTIC OF EMPLOYER %	DIFFERENCE[1]
CHALLENGING WORK ASSIGNMENTS	96	56	40
USE OF OVERALL TECHNICAL COMPETENCE	94	59	35
MATCH BETWEEN JOB REQUIREMENTS & CAPABILITIES	93	55	38
UTILIZATION OF EXPERIENCED ENGINEERS	92	55	37
UTILIZATION OF EDUCATION & TRAINING	86	52	34
AMPLE CONCERN WITH ENLARGING & ENRICHING WORK ASSIGNMENTS	81	31	50

Source: Engineering Manpower Commission, 1986

[1] The difference in all tables was computed by subtracting the percentage of engineers who indicated a job-related factor was characteristic of their employer from the percentage who said it was important to them personally. The magnitude of this difference is an indicator of the degree to which a problem exists with respect to a particular factor.

sufficient technical and clerical support as well as up-to-date computers and other equipment is necessary for the application of knowledge and skills, (see Table 1), to help achieve greater efficiency and innovation (Kaufman, 1986; 1987). Engineers recognize the importance of such resources but what many receive appear to be inadequate, especially with regard to technical support personnel (see Table 2). This is one of the major contributing factors to poor utilization of engineers' knowledge and skills. To rectify this problem, there are barriers which first need to be overcome before engineers are able to receive adequate resources, such as a technician shortage.

- Enhance access to new technical information by increasing opportunities for engineers to communicate with colleagues on new developments - Without access to new technical information, innovation is practically impossible. Much of the information needed by engineers comes from interactions with colleagues (Kaufman, 1974; 1983). Therefore open communication, both internal and external to the organization, is critical. Engineers need access to new technical information, but many report such access is inadequate, as are opportunities to communicate with colleagues (see Table 3). Encouraging more open communication can go far toward increasing the amount and quality of new technical information available to enhance the creation of new ideas and the innovation process. There are a variety of practices that can improve communication and these include paying closer attention to information dissemination systems, the structure and longevity of engineering project groups, and the role of technological gatekeepers.
- Provide opportunities and encouragement for continuing education and career development of engineers to stimulate their professional growth - The "half-life" of an engineering education in 1960 was about five years (Kaufman, 1974). It is probably even lower today, given the rapid changes in engineering knowledge and skills in recent years. While continuing education and career development activities are important to most engineers; only a minority report opportunities for participation or that their employers encourage such activities (see Table 4). This is all the more surprising given the widespread availability of employer support for courses. Commitment by top management to continuing education and career development activities is the key to encouraging participation in such activities. This commitment can be effectively translated into policies that require implementation through the engineers' immediate

TABLE 2

SUPPORT SERVICES & FACILITIES

	IMPORTANT TO ENGINEER %	CHARACTERISTIC OF EMPLOYER %	DIFFERENCE
SUFFICIENT SUPPORTING TECHNICAL PERSONNEL	86	46	40
SUFFICIENT SUPPORTING NON-TECHNICAL PERSONNEL	70	39	31
UP-TO-DATE ADVANCED EQUIPMENT AVAILABLE TO ENGINEERS	84	52	32
ADEQUATE COMPUTER FACILITIES	80	60	20

Source: Engineering Manpower Commission, 1986

TABLE 3

ACCESS TO INFORMATION

	IMPORTANT TO ENGINEER %	CHARACTERISTIC OF EMPLOYER %	DIFFERENCE
READY ACCESS TO NEW TECHNICAL INFORMATION	87	58	29
OPPORTUNITY TO COMMUNICATE INTERNALLY ON NEW DEVELOPMENTS	85	56	29
OPPORTUNITY TO COMMUNICATE EXTERNALLY ON NEW DEVELOPMENTS	62	31	31

Source: Engineering Manpower Commission, 1986

TABLE 4

OPPORTUNITIES FOR PROFESSIONAL CAREER DEVELOPMENT

	IMPORTANT TO ENGINEER %	CHARACTERISTIC OF EMPLOYER %	DIFFERENCE
OPPORTUNITIES FOR PROFESSIONAL DEVELOPMENT	85	37	48
OPPORTUNITIES TO AVOID TECHNICAL OBSOLESCENCE	88	41	47
OPPORTUNITY TO INCREASE TECHNICAL COMPETENCE	86	45	41
COMPREHENSIVE ON-THE-JOB TRAINING AVAILABLE FOR ENGINEERS	68	34	34
ENCOURAGE ENGINEERS TO PURSUE CONTINUING EDUCATION	66	45	21
ENCOURAGE ENGINEERS TO ACQUIRE ADVANCED DEGREES	44	30	14
HIGH QUALITY CAREER GUIDANCE	64	16	48

Source: Engineering Manpower Commission, 1986

supervisors, and reinforced via job assignments and performance reviews.

- Expand the engineers' responsibility and control by increasing their communication with management as well as in the decision-making process - The growing complexity of decision-making and the problem of time compression in the innovation process from idea generation through marketing requires increasing the communication and influence of engineers (Kaufman, 1987). Practically all engineers desire these practices but most report that they are not characteristic of their employers (see Table 5). This is particularly true for participation in decisions affecting the engineers' interests. By giving greater responsibility and control to engineers, management can create a climate more conducive to creativity and innovation. This may be achieved through the restructuring of engineering groups and the roles of engineers with greater emphasis on practices such as autonomous work groups and entrepreneurship.
- Utilize meaningful reward systems to motivate engineers to achieve greater creativity and innovation - One of the most difficult management problems is the development of reward systems for engineers that can foster creativity and innovation. While money is important to engineers; non-monetary rewards are at least as important in their development (Kaufman, 1974). However, it is clear that neither type of reward is adequately provided to many engineers (see Table 6). If, in fact, creativity and innovation are to be encouraged, commitment from top management to this goal must be present. This commitment can be introduced operationally through a variety of methods such as the performance review system, meaningful ladders of career advancement, and individualized rewards that recognize and reinforce creative and innovative behavior.

The effectiveness of the management practices discussed above may be dependent on a variety of societal or cultural forces. For example, the labor market in engineering can serve as a powerful force. Experience has shown that shortages of engineers can stimulate organizations to introduce and support the type of practices suggested in this paper. Another example pertains to the gradual emergence of cultural norms that view engineers as important organizational assets to be treated as part of the management team. As such norms become more prevalent, the management practices described here will become more effective in fostering creativity and innovation.

TABLE 5

PARTICIPATION IN DECISION-MAKING & MANAGEMENT COMMUNICATION

	IMPORTANT TO ENGINEER %	CHARACTERISTIC OF EMPLOYER %	DIFFERENCE
GOOD MANAGEMENT-TECHNICAL PERSONNEL COMMUNICATIONS EXIST	92	43	49
TECHNICAL PERSONNEL PARTICIPATE IN DECISION-MAKING	90	47	47
ENGINEERS PARTICIPATE IN DECISIONS AFFECTING THEIR INTERESTS	88	31	57

Source: Engineering Manpower Commission, 1986

TABLE 6

ORGANIZATIONAL REWARD SYSTEMS

	IMPORTANT TO ENGINEER %	CHARACTERISTIC OF EMPLOYER %	DIFFERENCE
ENCOURAGES INNOVATION & NEW IDEAS	92	52	40
ORGANIZATIONAL POLICIES REFLECT A HIGH CONCERN FOR EMPLOYEES	89	41	48
EXCELLENT SALARY SCALE EXISTS FOR EXPERIENCED ENGINEERS	89	46	43
RECOGNITION FOR TECHNICAL ACCOMPLISHMENTS IS COMMON	81	39	42
EXCELLENT FRINGE BENEFIT PROGRAM FOR ENGINEERS	81	59	22
PROMOTIONS ARE PRIMARILY BASED ON TECHNICAL COMPETENCE	75	35	40
ENCOURAGES CONSTRUCTIVE NONCOMFORMITY & INDIVIDUALITY	73	28	45

Source: Engineering Manpower Commission, 1986

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CREATIVITY - WESTERN AND JAPANESE STYLE

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TWO PATTERNS OF INNOVATION

The body of experience gained from case studies of past successes and failures in research and development gives us an invaluable wealth of information. Based on my view that innovation stems from the culture of the country in which such innovation comes about, I feel that we should pursue the subject of research on innovation a little further by seeing it in the context of the background of each country.

Economic growth as the source of improvement in the well-being of the human race requires ongoing innovation. But, it is not quite clear what innovation implies, what its magnitude is. It is therefore impossible to envision better planning and more purposeful management before we have made further progress in our research on innovation and achieved a better understanding of what it is all about.

This subject has in fact been extensively studied by economists, management scientists, and sociologists each from different viewpoints. The outcome of these research efforts is the realization that innovation is an extremely complex process in which many people are involved and which depends on R&D activities where the outcome is uncertain. To progress further in our understanding of this process, much more positive research will be needed.

Let me now present my own particular view of innovation. The process it entails may be divided into a number of elements such as the development of an idea, and seeing that idea through to the production stage. Figure 1 illustrates this idea. This figure may be easier to understand if we see it as a conceptual schematic rather than a chronicle of events. Each of these elements develops and progresses by taking in the required scientific-technical and marketing information. However, at this point, I would like to emphasize the interrelation between the elements. This aspect is very similar to what is sometimes referred to as technology transfer.

An overall look at this schematic diagram shows that in the 1980s the United States is becoming increasingly committed to the downstream stages of the innovation process, or "commercialization," in response to the perceived need to strengthen its competitiveness in the high-technology industrial fields. In contrast, Japan, seeing its overriding objective in the development of its own autonomous technology, has gone into the 1980s with a firm commitment to the upstream areas of creativity and basic research.

In simple terms, development has taken such a different course in the two countries because of the traditional worldwide leadership of the United States in technology; while Japan's policy has been to catch up with the industrialized countries. Before we turn to the future and try to predict what patterns of innovation the two countries will follow, let us probe a little deeper with our analysis.

Research and development in Europe and America have taken the form of a process that develops according to the following pattern. First, a problem or task is given and this is broken down into the many factors that constitute or are believed to constitute the problem. The next step is to study in-depth and analyse each of these factors. After this, the pieces are put together to form a new idea and establish the concept as a system.

The innovation pattern is totally different in Japan. Even if the constituent factors are a little vague and the relationships between these factors are blurred or obscure, research is considered worthwhile if it achieves some goal. In other words, Japanese-style research is a goal-oriented type of thought process aimed at discovering what results or what purposes may be served.

Let us visualize this in terms of the innovation flow of Figure 1 from the left to the right. The European-American, that is, "Western," thought process tries to achieve innovation from the left to the right. Let us call this type of development "science-side-push or SSP, for short (see Figure 2), which is the American or Western style of innovation. The opposite of this is the Japanese way of innovation which starts from the right and pulls toward the right. Let us call this process "demand-side-pull," or DSP for short, that is, the Japanese style of innovation.

Westerners try to understand nature in order to conquer and harness it for practical utilization. The Japanese, on the other hand, want to co-exist with nature without opposing its laws and in so doing hope to obtain practical knowledge about nature to benefit everyday life.

This may also be described in terms of the opposition between Western atomism and Japanese holism. It is frequently argued that this opposition goes back to the religious foundations of the two; Western christianity and monotheism and Japanese buddhism and polytheism. It can therefore be argued that the whole world is indebted to the development of science and technology in the West as a result of the influence of Christian culture.

Let us turn our view from the past and try to peer into the future. Let us project what kind of innovation may or will emerge as Japan goes over to basic research under the above DSP trend at the same time as the United States devotes its efforts to commercial product development (commercialization) under the SSP trend referred to above.

PROSPECTS IN JAPAN

Innovations flow from ideas on to the market and are assessed only on the basis of the economic values they create. Their evaluation at the intermediate stages is difficult to quantify. In all the to-and-fro shifting of an idea, it should always be remembered that the ultimate goal is the market. Yet, the more that knowledge possessed by the researchers is biased toward pure science, the more difficult it will be for those on the demand side to understand it, and the situation may arise where research is handled rather like a black box. Let us assume that these two trends exist and question which of these is more effective, SSP, that is, Western style innovation; or DSP, that is, Japanese style innovation.

The closer technology comes to science, the more difficult it is for those on the demand side to understand what the science side is saying. In tracing basic research in Japan, I feel there are two trends that can be discerned. One is the traditional Japanese research pattern I have mentioned earlier, that is, research which goes from the DSP-determined research field toward basic research or science orientation. With this approach, there is little opposition to this type of research, yet the risks of research are gradually increasing. The other type of research is that of the Western-type approach, that is, research that assesses the results SSP produces in the context of Japanese society. Even though it may be upheld as the ideal way of doing research, this approach will be difficult to implement because individualism and contract-mindedness have little in common with the Japanese character.

Recently, some private corporations have established centers for basic research. I will deal later with the appropriateness of looking to the private sector to actively engage in basic research, but clearly the private sector would give priority to activities which would generate future profits. However, if the basic research required is not being performed in other sectors, the private sector will have to fill the gap.

I feel it is necessary here to explain the present situation in Japan a little more so that we can consider the research approaches I have mentioned above. First, there is the organizational structure of Japan and the relationship between the public and private sectors to consider. A characteristic of Japanese society is to give priority to cooperation and harmonious coexistence. This is quite different from the strict division of tasks and collaboration among specialized employees of private companies in the United States and Europe. In the production field, Japanese-style management is considered by some to be superior in several respects. Concerning the relationship between the public and private sectors, or in similar situations, the tendency prevails to leave it up to the authorities, the general view being that "we needn't concern ourselves with the issues."

I consider it very important that Japan should be aware of the importance of basic research. The current lack of a clear commitment to ensuring the optimum interaction among the public and private sectors is regrettable. Only such a structure, exclusive to neither private industry nor public sector, can find the path toward the next generation of science and technology, with benefits to both production and society.

One of the reasons for this lies in the so-called "hic et nunc" orientation of the Japanese. Dr. Shuichi Kato coined the phrase "hic-et-nunc-ism" (or here-and-now-ism"). This attitude professes unconcern over the future, and is characterized by expressions such as "let's flush away the unpleasant past" or "let's see what tomorrow brings" or "let's wait and see which way the wind will blow tomorrow." R.J. Ballon explains in his book Research in Japanese-style Businesses (1978), the differences in management dimensions in Japan, America, and Europe (see Figure 3). Rather than adopting from a strategy which takes the future into account, the Japanese attitude looks for favorable results through flexible adaptation if the environment changes.

Professor Ballon explains decision-making and implementation in Japanese businesses by sketching the situation as shown in Figure 4. In Japan, development of any project moves from the bottom up, so that at the first stage the rank and file have the fullest knowledge of what is to be done. This smooths the process of implementation. In Europe and America, however, it is necessary to explain the matter in detail to the lower staff echelons to make them understand and sometimes even persuade them to agree with the intended policy. Coordination may be required to achieve cooperation. These differences in the business practices between Japan and the West have their particular merits and drawbacks.

I am practically in total agreement with the Japan versus America comparison table, that is, Table 1, presented by Professor Daniel Okimoto of Stanford University, because most of what the table says is verified by what I have pointed out here. However, this only refers to the past and present and it is reasonable to assume that the pattern may well change in the future. Even the Japanese may differ to some degree in their opinions about whether the practical implementation of basic research in Japan will succeed or not. Nonetheless I feel that in this context too, the typical Japanese optimism will prevail.

TRENDS AND TRAINING IN PRIVATE INDUSTRY

Let me first say a few words about the most recent trends in private industry and the way private enterprise recruits, trains, and raises their technical-engineering and research staff. Since 1980, some types of industries, especially the basic materials industries, have seen their prospects dimming. The result has been extensive re-structuring as the companies concerned move into different areas of industry. These transformations in the nature of the enterprise inevitably naturally create the need for re-assignment and re-training of staff as well as recruitment of new staff. With these conditions in mind, many surveys have been conducted on the problems of staff training in private industry. Let me bring up a few survey results and analyse the above problems with reference to them.

In Figure 5, I have tried to give a breakdown of the technical staff currently working in private industry. It can be seen that the engineering staff assigned to design and production accounts for 65 percent of the total. Yet, the future staff breakdown will look quite different. As is shown in Figure 6, the engineering staff currently considered strategically important for the company largely consists of research staff and information engineers. These trends are also clearly reflected in the predictions made by the Science Council of the Ministry of Education on the supply side of the human resources. It is estimated that by the year 2000 the number of researchers will have to increase by 50 percent. Most of these extra research scientists needed will be absorbed by the private sector. Let us now deal with the question of whether the demands of private industry will be met. Judging from the overall figures, it seems that the requirements for research experts in the leading-edge technologies will not be met, at least for particular high-technology disciplines such as the electronic, information-processing technology, and biotechnology fields. While I admit that the universities are not necessarily obliged to accommodate the demands of private industry, I get the impression that there is an unbridged gap between the aspirations of private industry and the universities. The latter ought to play a leading role in seeing into the future, but instead appear to act in a rather conservative and bureaucratic manner. Admittedly, there are many professors and associate professors who are not necessarily conservative in their individual attitudes, but as institutions, the universities find it difficult to make decisions. Nor, I feel, has the government done enough to deregulate the education system.

It cannot be denied that, in recent years, processes such as the transition from which the materials manufacturing industries have advanced into electronics, and the different manufacturing industries into the information processing and telecommunication sectors have aggravated the shortage of engineering staff in these fields.

Let us take a look at the situation in the software sector. As shown in Figure 7, we have here a desperate state of affairs known as the "software crisis." Japan is no exception. A survey on how to overcome this shortage of software engineers shows that, as indicated in Figure 8, Japanese companies put top priority on new recruits. The next most important way of filling staff requirements is by internal re-assignment and transfer of staff from other technical sections. They may then scout for staff from other companies.

My investigations of companies that have advanced into new areas of activity have shown that the number of new recruits started to increase gradually before the company concerned decided to launch out into a new field and that the extent of staff increases went up at the time of the decision. The survey also shows that the number of staff transferred from other sections within the company tends to decrease the longer they have served in the company, up to a maximum of ten years after joining the company. The re-training of these staff members in the company is arranged in conjunction with the internal training schemes already generally established, even though a few additional training courses may occasionally be added to round off the system.

Let us look at this from a slightly different angle. In Japan, the education and training provided by industry is a vital supplement to the education provided by the schools and universities. We also have observed the tendency of companies to attempt to recruit students at the earliest possible time and train them in-house. This trend seems to be growing in all companies.

As the emphasis of company research activities moves toward a greater science-orientation with a stronger commitment to basic research it will, no doubt, also be necessary to review both the contents and the system of the school and university education required. But even if the contents of the education provided by the establishment is reviewed, it will be necessary to progressively upgrade and expand the in-house training facilities offered by companies. Many companies are already setting up new facilities and systems for in-house training, a trend that is now very much in evidence. We have also seen a significant increase in the incidence of staff released on external training courses. In fields such as biotechnology, the practice of overseas studies for basic research in countries such as the United States and France is already widespread. It will be necessary, however, to examine the problems related to research and engineering staff in much greater detail.

The first problem will be how to increase the number of researchers. In Japan, there is a greater number of qualified engineers than there are science graduates. This is shown in Figure 9. While Japan was still trying to catch up with the West in the technology fields, this was appropriate, I believe. But in the future, it will be essential to increase the proportion of science graduates.

The next problem is concerned with the quality of our research and technical experts. As shown in Figure 7, industry is seen to complain quite strongly, not about the numerical shortage of software and system engineers, but about the lack of highly capable engineers. This problem has given rise to extremely serious difficulties in Japan. The most important issue is that of future industries requiring software and system engineers. The conventional Japanese management and engineering education of the past with its emphasis on hardware will no longer be appropriate.

The next point is this. Under the demand-side pull philosophy, it will be found that researchers will not be sufficiently used to, or skilled in, discovering problems, ordering them, and establishing concepts. Demand-side pull research is good at solving problems once they have been presented. It has not been sufficiently investigated as to how these problems can be dealt with. The demand-side pull system has some aspects in common with the science-side push system and in this sense it is most interesting to see the outcome of the second experiment referred to above. While much work still needs to be done before we know how to solve these problems, the science-side push system surely has an important contribution to make.

CREATIVITY AND ENGINEERING EDUCATION

We have seen that Japan and the United States have somewhat different ways of achieving innovation to attain the common goal of furthering the progress of mankind. Our purpose may thus be defined as the search for a method that ensures a faster rate of progress by learning from each other, because we have different patterns of innovation. Japan is now strongly committed to creativity and basic research, areas in which the United States has acquired a large body of experience and established results. To realize these aims in Japan, we must learn from the U.S. In the past, Japan learned quality control techniques and then further developed them into total quality control. Similarly, we will place our hopes for the future chiefly on following the lead given by the United States.

Let me continue by taking up a few more topics to be dealt with. First, there is the problem of creativity. To me, creativity essentially implies the generation of original ideas of high practical value. It is fair to say that Japan's success in producing and selling high-quality, high-reliability and low-price hardware through its manufacturing technology expresses the sum total of its creativity.

A breakthrough invention shows that in every phase of innovation, creativity is the essential pre-requisite, and where there is no creativity, there is not, nor can there be, any innovation. Therefore, the best way to think about creativity is to assume that there are many types of creativity to suit the particular circumstances or conditions in which it manifests itself. Take the examples I have referred to above. We can here see a distinction between collective and personal creativity, the creative products of a group or team versus the creativity of the individual. In Japan, it is easy to be creative in the collective context of an organization or group but not so easy on a personal, individual basis.

Yet, if we try to look into the future, there is more than one way of viewing creativity in Japan. One view is that there has been little demand for creative work in the past so that there has been little scope for developing ability and talent. Consequently, there will be every reason to expect great results if and when the demand for creativity arises in the future. Another view approaches creativity from a totally different aspect, viewing it as something that is a faculty given man immediately after birth. For this reason, the teaching of young children is accorded the greatest importance. Our traditionally regimented educational system from elementary school through university tends to inhibit the student's personal creativity. Taking this view, only a reform of the education system can achieve personal creativity.

Another, more penetrating, view holds that recent cerebrophysiological research has produced evidence to suggest that those brought up speaking Japanese as their mother tongue have stronger syncretistic or synthesizing tendencies than those brought up speaking a European language like English. The question arises whether training or education can impart creativity -- and the related question of whether a computer is capable of creativity. I personally feel it may well be possible in the future to induce creativity so that the computer will be able to emulate it.

Be that as it may, my next problem concerns the universities and national research institutions. In the previous chapter I have dealt with the training and education facilities provided by private industry, but we must not overlook the role the universities and national research institutions play in providing education and basic research. Most of the problems we have are due to the fact that the attitudes adopted during Japan's catching-up phase have remained unchanged. Since the Meiji Restoration, universities have been national educational entities designed to educate the human resources required for the national administration system. The national research laboratories were founded to act as testing laboratories and measurements and standards institutes. In Japan's catching-up period, they served their purpose. However, after Japan's achievement of parity, they may well have lost their leadership role as the educators of those with vision for the next generation and as institutes capable of carrying out richly imaginative basic scientific research. My personal hope is that the government will quickly broaden its deregulation measures and thus create the basis for greater innovation.

Finally, I wish to emphasize the primary importance of obtaining excellent human resources as the most critical pre-condition for the effective propagation of innovation. But for this, it is necessary to have a strategy for allocating resources, including human resources. In other words, the effectiveness of innovation in general is governed by the way in which we decide the field or fields in which we want to invest superior human and capital resources or by the incentives we provide. I feel somewhat envious when I see that information science and biotechnology were born and reared in America and may come to fruition there, thus assuring the U.S. as world leader. During that time, Japan put the main thrust of her efforts into the manufacture and exporting of hardware and has allocated many outstanding people to these activities. I would like to feel justified in hoping to see new, truly Japanese technology coming to life and growth and the seeds of innovation taking root also in Japan. But, to achieve this, the universities and national research laboratories must assume a leadership function.

One of the candidates for this leadership position is the Fifth Generation Computer Project. This is the brainchild of a group of research engineers working on the concept for the next-generation computer through a variety of associated computer projects carried out at the Electro-technical Laboratory, a National Research Laboratory. It is an exceptional project for Japan, and an extremely challenging one. It is my personal opinion that this project, too, may be seen as a DSP type approach. The project springs from the realization that there is a problem to be solved, the problem being to develop a next-generation computer with predicate logic and inferential intelligence capabilities. In other words, the project came into being when, after putting all the disparate pieces of the academic jigsaw puzzle together, the overall picture emerged. Doubtless many of the participants see it as primarily SSP.

Japan, is also gradually changing and moving away from her attitude of "research above goals." Professor H. Inose of Tokyo University has even proposed an Institute for Useless Research. The professor suggests that we abandon the question "What purpose does it serve?" And I would like to add my own suggestion to the Japanese: "Let's challenge the limits of our ability to further the progress of mankind."

NOTES

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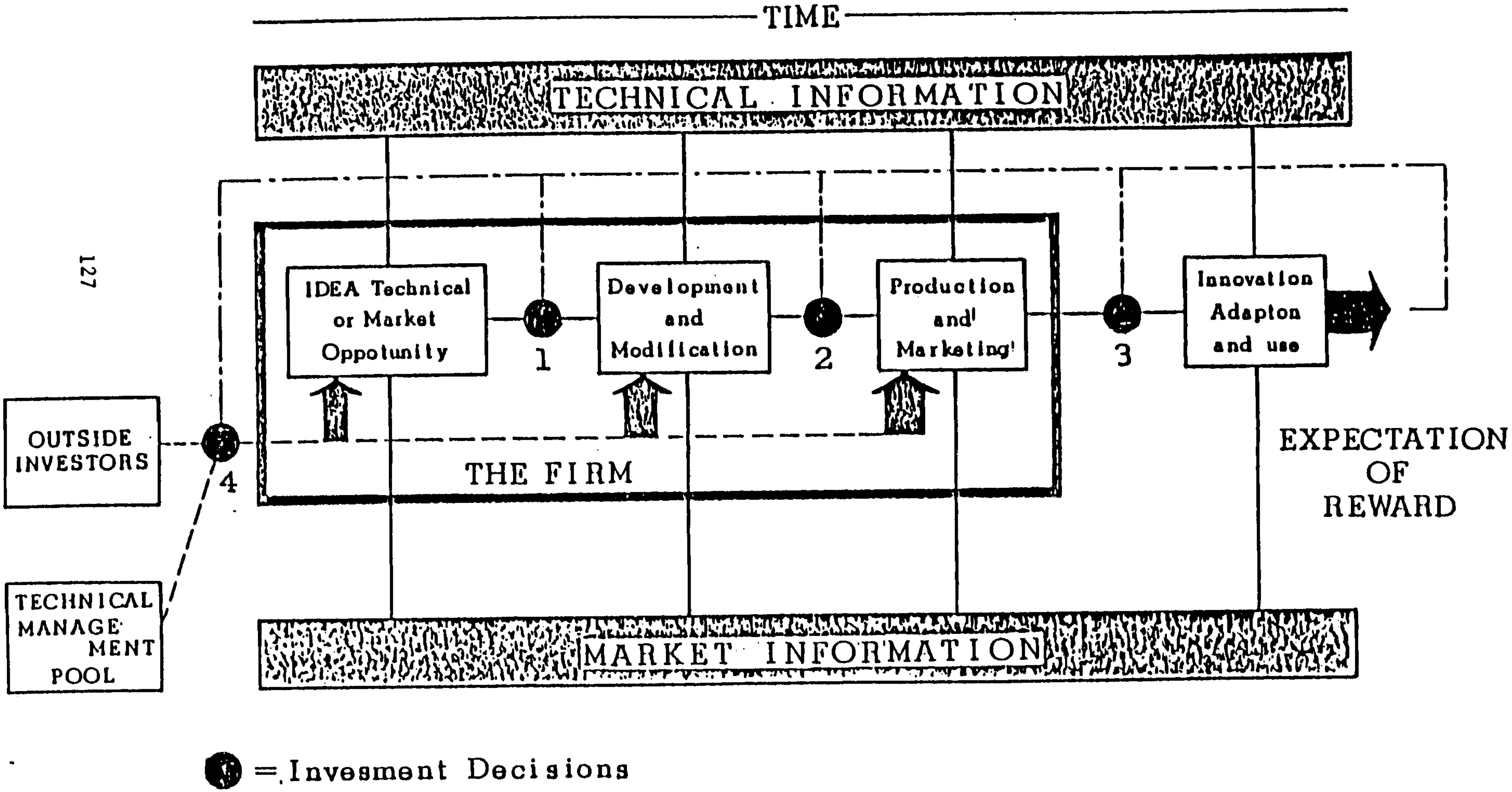
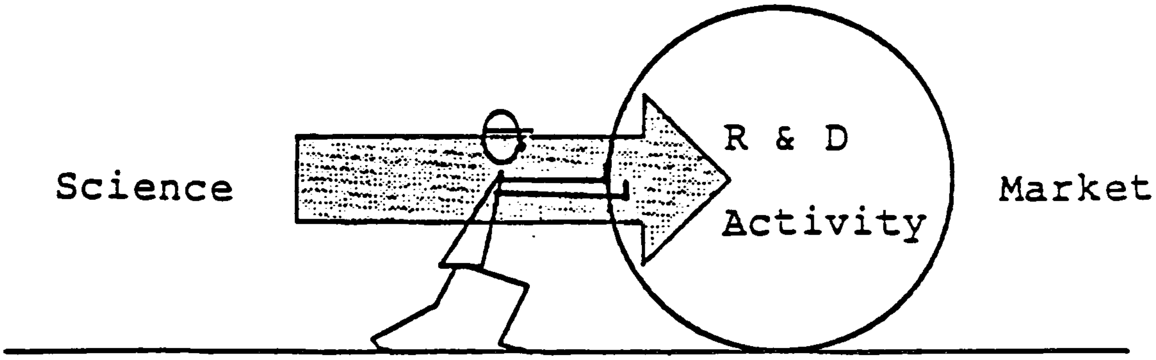
Fig.1. THE INNOVATION PROCESS
(A Simplified Decision Model)



Source: Message to Congress on Industrial Innovation Initiative, made by President Carter,1979.

Fig. 2 HOW TO PROCESS INNOVATION

Science-Side-Push



Demand-Side-Pull

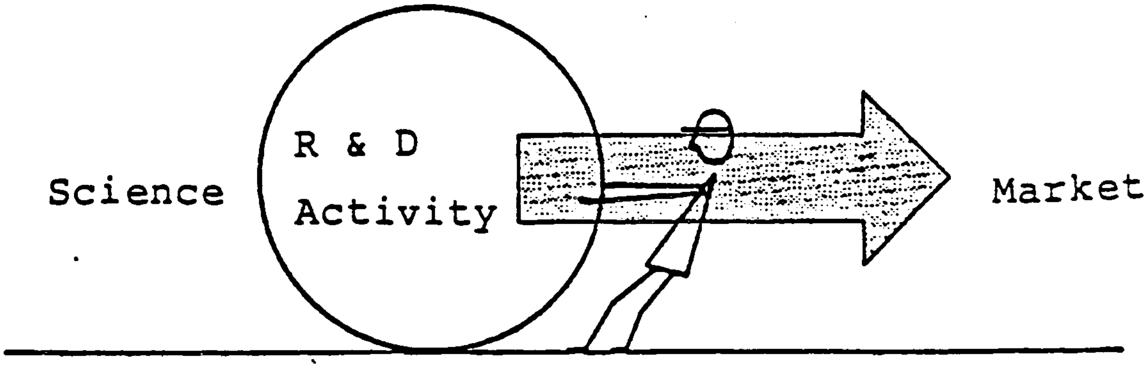


Fig. 3 DIFFERENCES IN MANAGEMENT DIMENSIONS

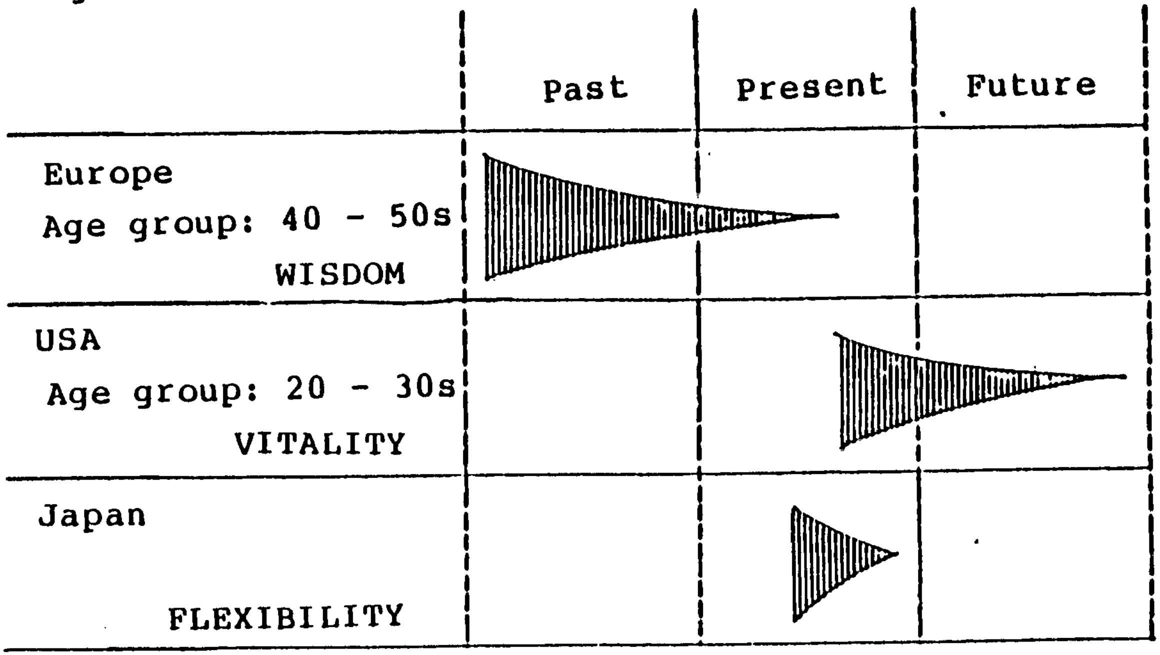


Fig.4 DECISION-MAKING AND START OF EXECUTION

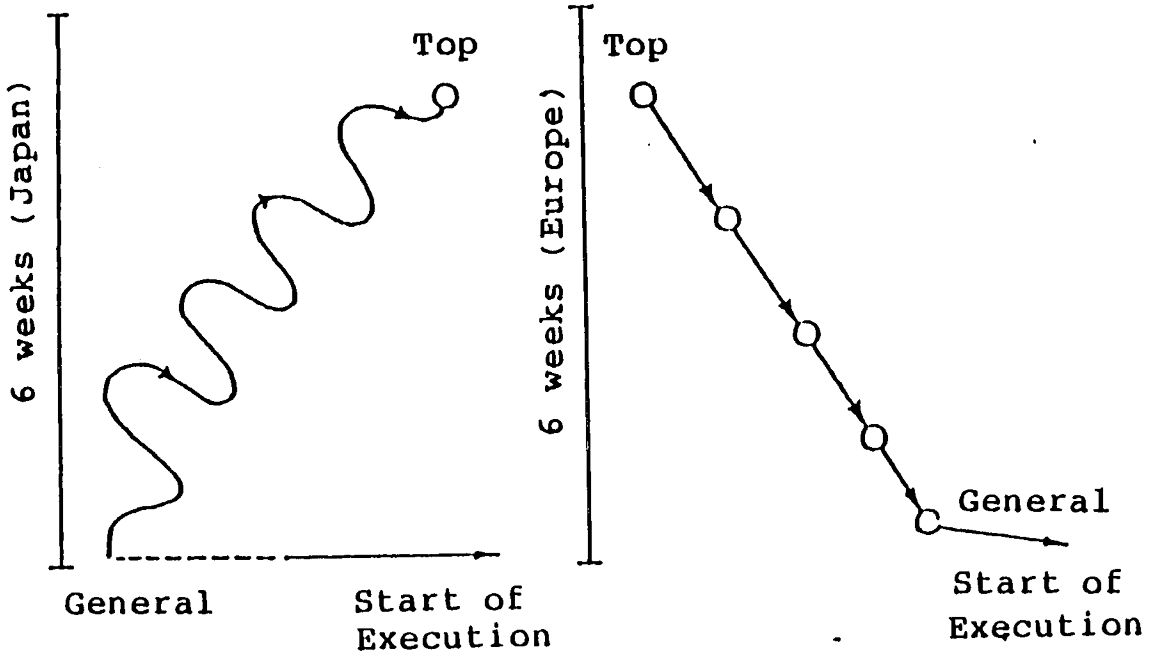
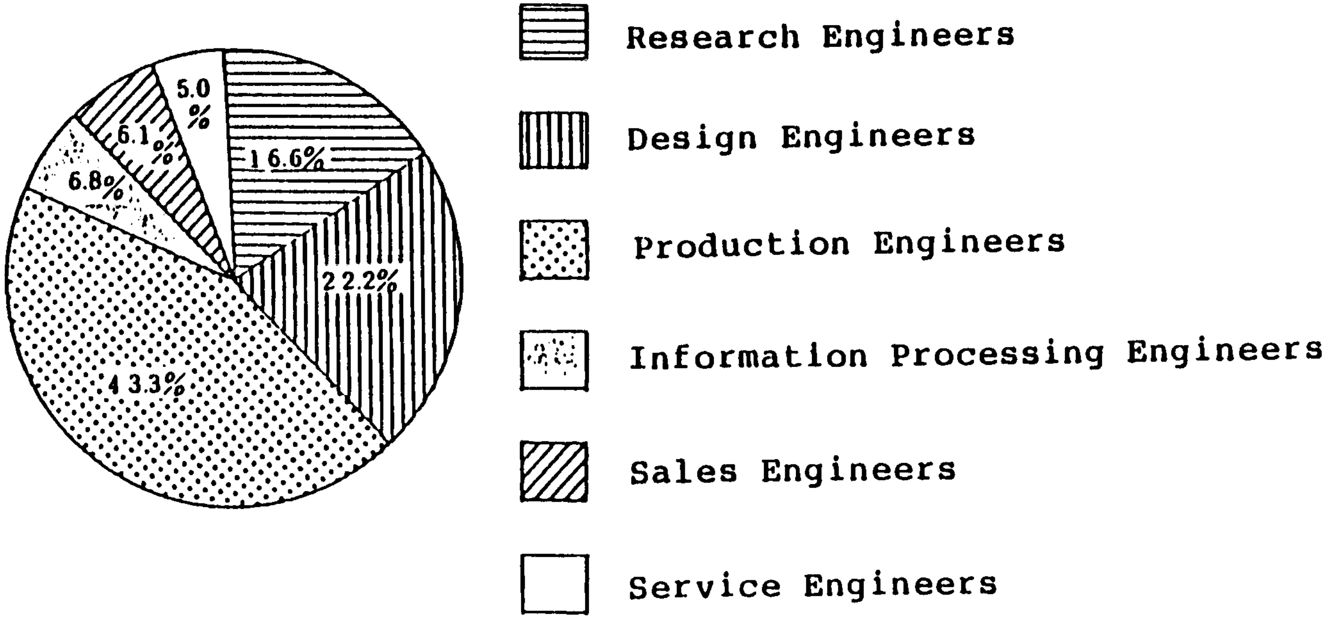
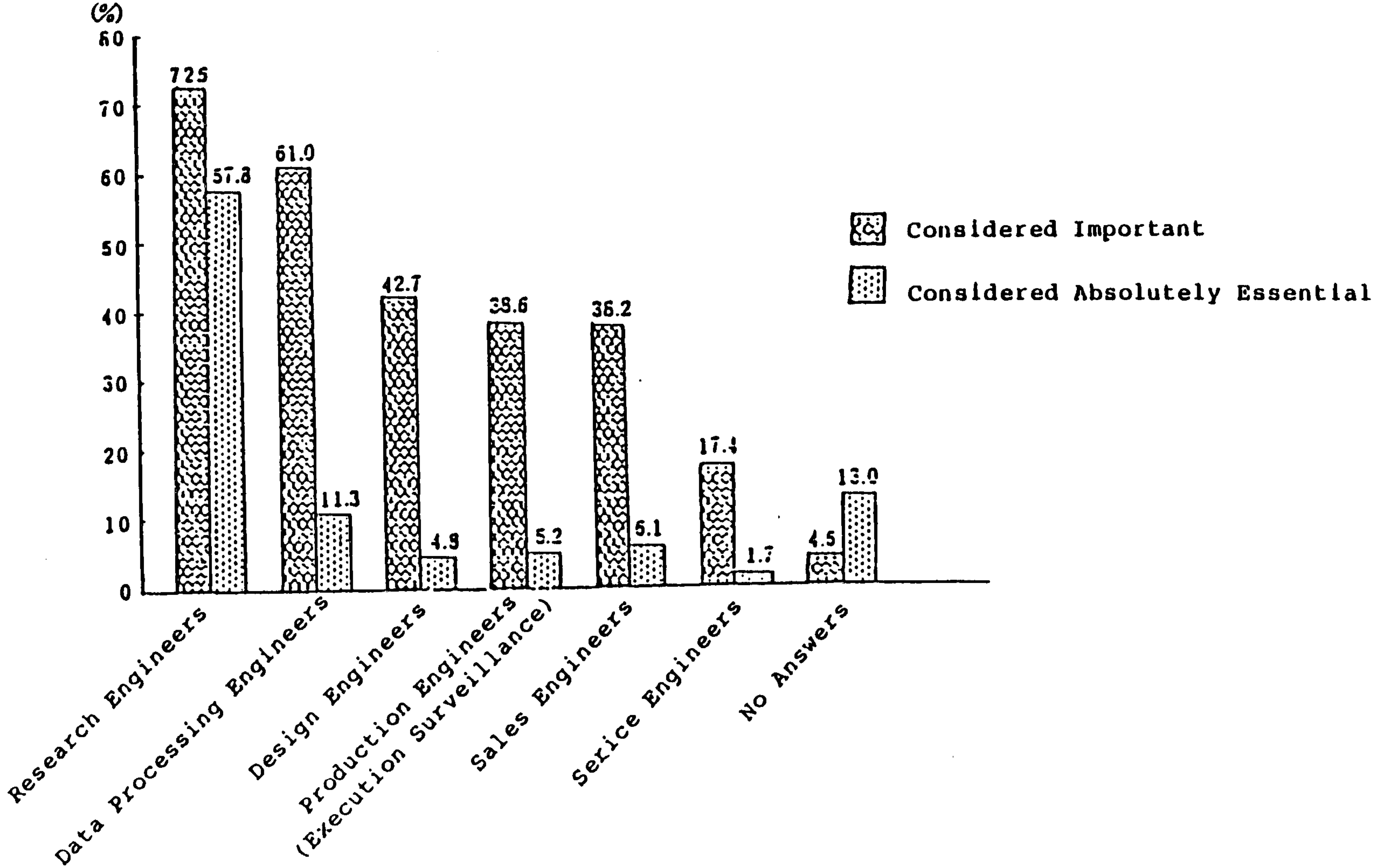


Fig.5 Breakdown of Present Technical Staff



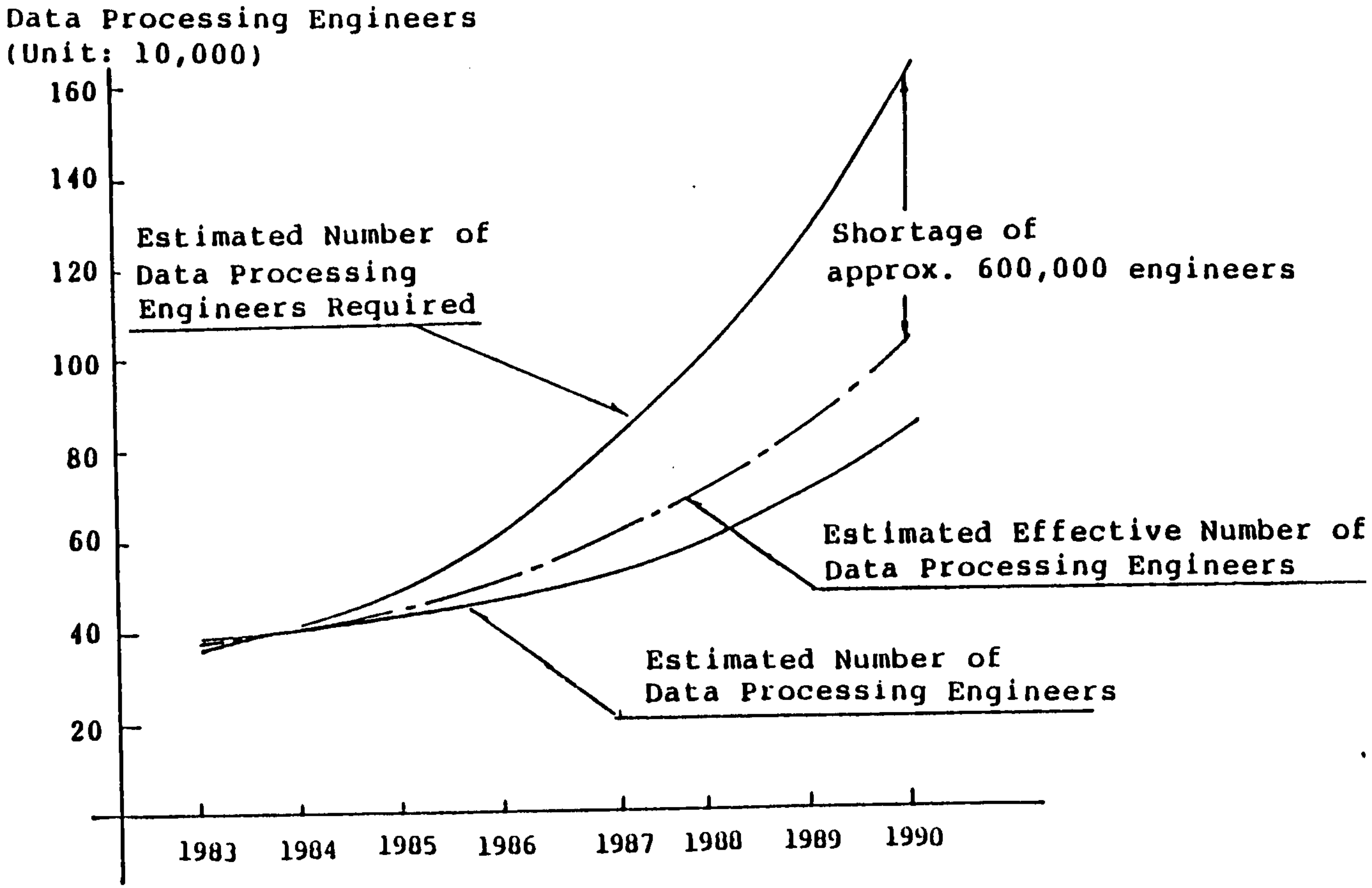
Source: Survey and Study Report on In-House Education and Training Provided by Companies - All Japan Federation of Management Organizations, March 1985

Fig.6. Engineering Staff Considered Strategically Vital for the Future



Source: Survey and Study Report on In-House Education and Training Provided by Companies - All Japan Federation of Management Organizations, March 1985

Fig.7 Forecast Demand Gap for Data Processing Engineers in Japan



Source: Survey and Study Report on In-House Education and Training Provided by Companies - All Japan Federation of Management Organizations, March 1985

Fig.8.Ways Seen as Important Means of Meeting the the Demand for Engineers by Additional Recruitment of Human Resources.

(Several Answers Permitted)

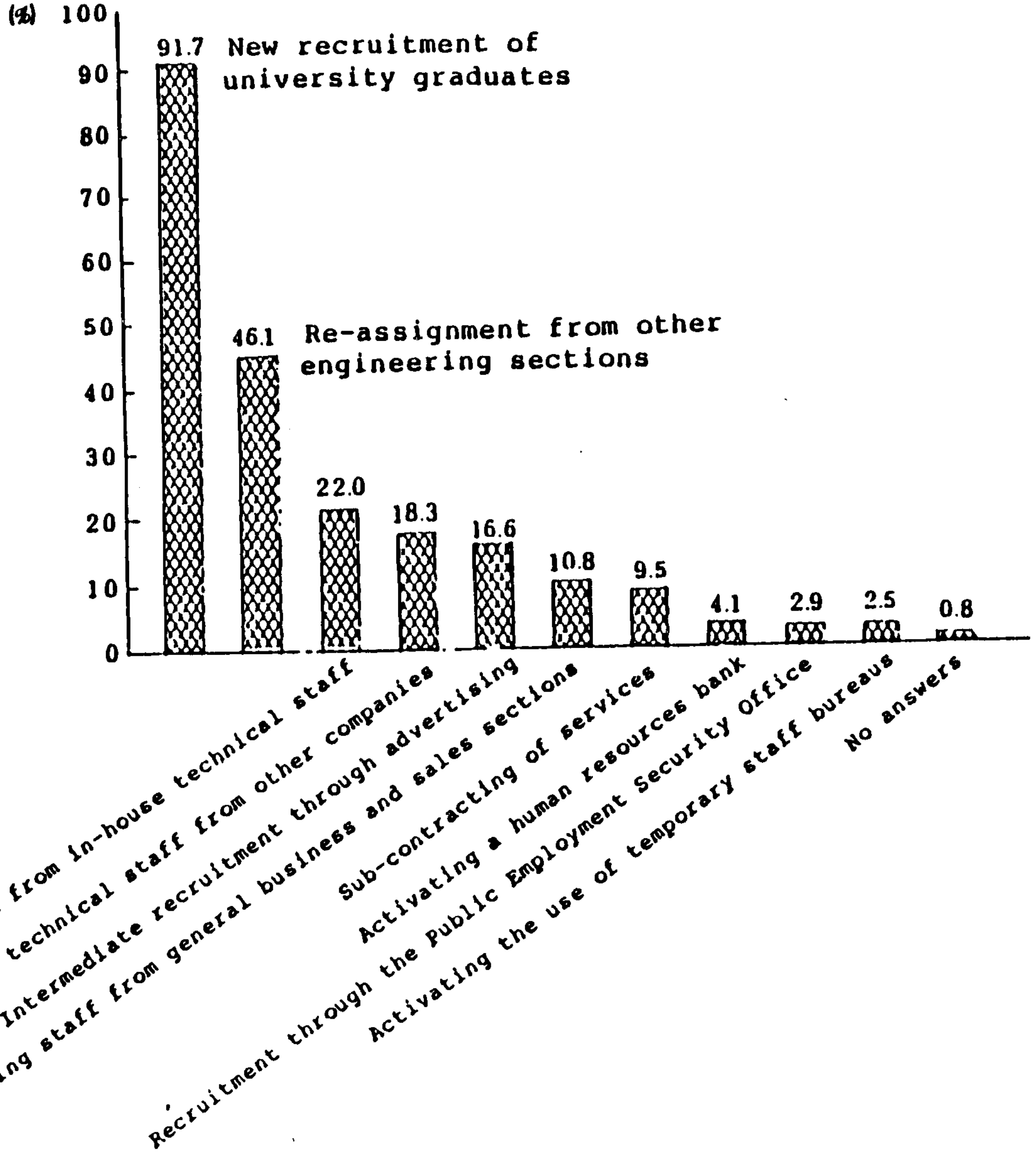
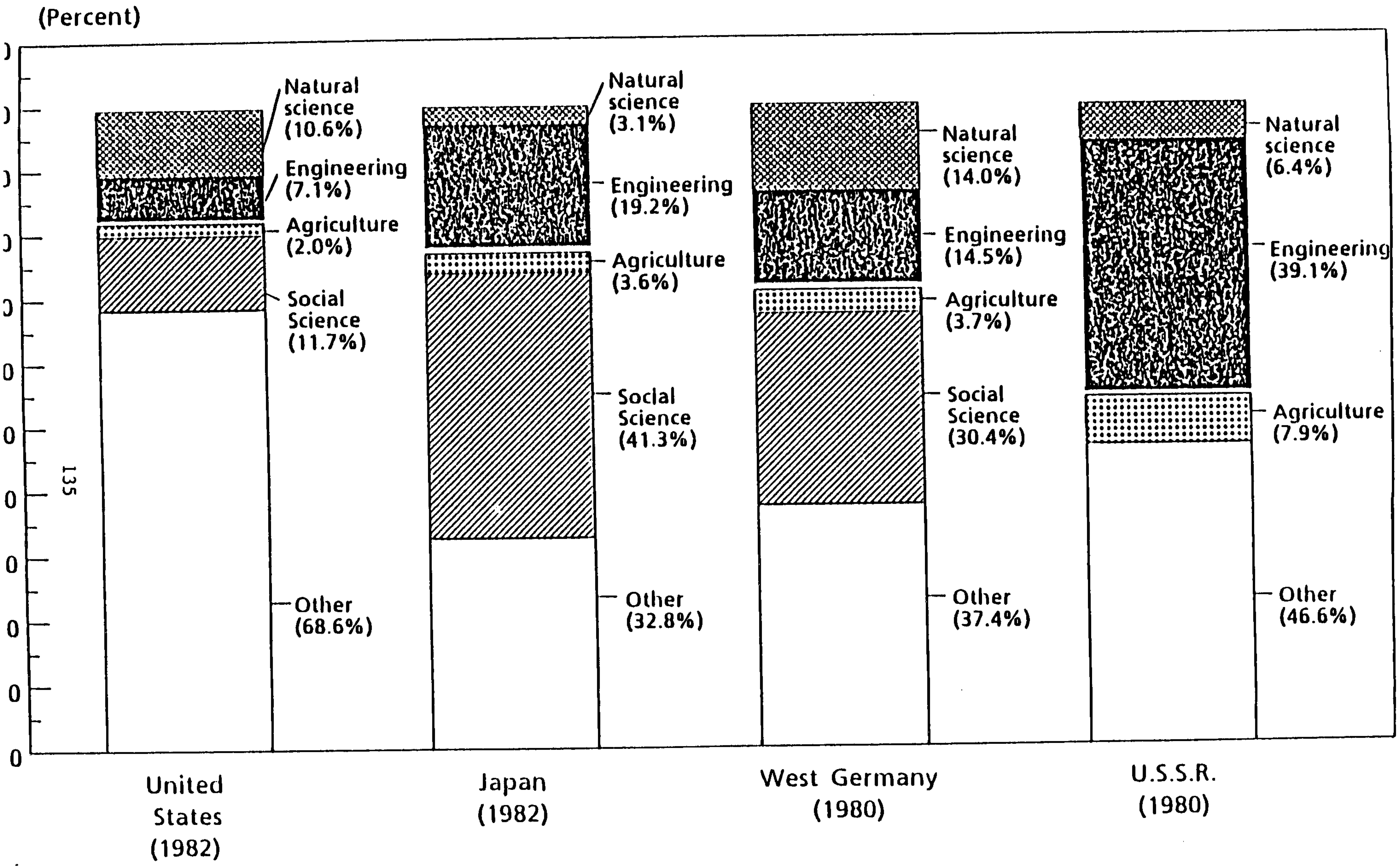


Fig. 9 Comparison of university graduates



ource : JETRO技術情報 Sept. 1984, Original N S F

Table 1 , Balance of forces

Japanese strengths	American strengths
Applied research and development	Basic research
Incremental improvements	Breakthroughs and inventions
Commercial applications	Military applications
Process and production technology	New product design
Components	Systems integration
Hardware	Software
Predictable technologies	Less predictable technologies
Quality control	New functionalities
Miniaturisation	New architectural designs
Standardised, mass volume	Customisation

Source: "The Positive Sum Strategy", National Academy Press, Washington DC, 1986

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FOSTERING CREATIVITY AND INNOVATION IN AN INDUSTRIAL R&D LAB

A. R. C. Westwood and Y. Sekine
Martin Marietta Laboratories

INTRODUCTION

The creative act and the innovative process can be regarded as the fuel and the motor of the industrial enterprise. Marketing largely determines where the enterprise shall go; and management when; and in what style. But creativity and innovativeness are the crucial factors in determining whether the enterprise will arrive at its preferred destination in a timely and profitable manner.

The term creativity, as used in this paper, relates to the act by which new insight occurs regarding the solution to some intellectual challenge. In our context, the challenge is scientific or technical in nature; but equivalent challenges occur in art, music, or the humanities. Usually, the act is the product of an individual, and can occur in an instant, for example, during the course of a spirited debate...or even while taking a shower. Typically, it requires that the problem be precharged into the brain along with sufficient data base of assumedly relevant "facts" acquired through study or experience. The creative person's mind then takes some time to permutate the various cause-and effect relationships until it arrives at the most reasonable solution, given the data base. If the person is then able, through natural skill or training, to bring this solution into the conscious mind and enunciate it for others to use, the outcome is regarded as an act of creativity.

Creative people produce many ideas, not all of which are useful. But if the product is potentially useful, then following further study and successful proof-of-concept experimentation, the consequence is an invention.

In our view, creativity is an intrinsic skill, like the ability to compose a symphony or to solve non-linear differential equations. A person either possesses it, or does not. It can be stimulated or suppressed by a superior, or by the local or national culture, but not generated where it does not pre-exist.*

Now, if this view is correct, it follows that if an organization values and needs a creative staff, it must seek out, hire and nurture at

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* We limit this argument to mature individuals only. Whether the capability for creativity is influenced by early interactions with parents or teachers we shall not debate. However, we submit that by the time one's formal education is complete, it is probably too late for external influences...such as R&D managers...to have much of an impact on this capability.

least a nucleus of creative people. This is not easy to do. Truly creative people, i.e., people whose natural penchant is for upsetting the status quo, are not easy to identify, attract, or live with once hired. However, such people are critical to the vitality of an R&D organization.

Innovation, in our context, is defined as the process by which inventions are sometimes transformed into profitable products or systems. This process usually involves many people, various skills, and substantial amounts of time and money. The success of an innovation can be markedly impacted by the difficult-to-control confluence of events known as "luck," which may involve market timing, public perception, politics, and the state of the investment market. Innovation is a team activity, because to bring a new product to market requires the diverse skills of a number of people, plus persistence, flexibility, compromise, and the dedicated support of a high-level "champion."

Unlike creativity, the capability to innovate successfully and repeatedly can be developed in an organization just as, by analogy, a good coach can produce a winning team from a more or less average group of players, whereas a less skilled coach cannot. In other words, innovativeness is not an intrinsic factor; nor is culture, though it can affect both creativity and innovation. For example, the Japanese, known for their emphasis on consensus, harmony, and teamwork, have expressed concern recently over their apparently limited ability to create original concepts [1]. The Americans, on the other hand, known for their emphasis on individuality, and viewed as a significant source of new ideas, are concerned nowadays with the capability of their management and workers to function as efficient teams. Conversely, Japanese scientists working in the United States have proved to be every bit as creative as their American colleagues, vide Nobel Laureate Leo Esaki, Dean Hisashi Kobayashi and, in his earlier years in the United States, Dr. Michiyuki Uenohara. By the same token, U.S. auto workers in a Japanese-style management environment have proved to be as effective and quality conscious team players as are their Japanese counterparts in Nagoya. Thus, it seems that the culture of a nation can foster creativity by encouraging individualism, and enhance innovativeness by encouraging consensus and teamwork.

We now examine some of the ways in which management can influence creativity and innovativeness in and R&D organization.

FOSTERING CREATIVITY

(a) Hire Creative People: If creativity is an intrinsic skill, then the first and probably most difficult challenge of an R&D manager is to seek out and hire a nucleus of creative people. Indeed, Augustine [2] has noted that "a distinguishing feature of effective managers seems to be their ability to recognize talent." Sarett [3], on the other hand, has commented that a batting average of around 0.200 might be typical for most managers in this regard! There are, however, some behavioral clues of which one can make use. For example, creative people tend to exhibit the following characteristics: a diversity of interests, with skills and contributions in several areas; a high level of enthusiasm and mental least a nucleus of creative people. This is not easy to do. Truly creative people, i.e., people whose natural penchant is for upsetting the status quo, are not easy to identify, attract, or live with once hired. However, such people are critical to the vitality of an R&D organization.

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(b) Establishing a Creative Environment: There are a variety of laboratory environmental factors that can facilitate creativity. They include: (i) a stable working environment, i.e., sustained, steady financial support and a low rate of turnover of staff and management; (ii) the personal interest of management, as evidenced by visibility and the occurrence of one-on-one conversations about the state of technical progress, and whether or not management's help is needed to overcome administrative roadblocks; (iii) the establishment of high expectations for performance, together with a feeling of confidence in meeting them; and (iv) most importantly, a clear mutual understanding of the general area in which the staff is supposed to be creative. This point is critical because, as mentioned earlier, truly creative people have a tendency to be creative in many areas. Therefore, it is important that management gently focus their abilities into areas of most interest to the company, and specifically orient them toward problems the solutions to which are likely to generate a novel basis for innovative endeavor. Achieving the solution to such problems should require an intellectual stretch, for trivial problems will be treated trivially by creative people.

The challenge for the R&D manager is to resist the temptation to tell the creative scientist exactly what he thinks the problem is that must be solved. It is better that he place the scientist in an environment where, given time for reflection, the scientist can identify for himself the missing element of understanding. This might be done by arranging for the scientist to spend a few days at a production operation. Usually the important technical problem(s) there will soon become evident to the scientist, whereupon it becomes his problem, not that of the manager. This can have a marked impact on the rate at which the creative person will address its solution.

With further regard to establishing an atmosphere of confidence, it is important to recognize that failure, not success, is the norm for truly creative work. This important insight, and its significance with respect to managerial attitudes, has been addressed recently by Backus [4], the inventor of Fortran. Backus noted further that within one's mental "junkyard" of past failures often lies the resource to solve some future problem. It might also be added that what appears to be a problem in one context can be the solution to a problem in another. For example, a liquid that causes the premature fracture of a stressed metal component might prove to be an effective additive to the fluid used to machine that metal. In other words, where a scientist might see a problem, an inventor is likely to see a product. Changing one's perspective on a problem can be profitable.

(c) Fund Ideas Promptly: Once a good idea on solving a problem is generated, it is important to fund its evaluation without delay. Asking too many questions is not recommended at this stage, because the creative person's concepts are likely to be fuzzy, ill-formed, and not easily defended. Control can be maintained by ensuring that funding is adequate for only a few weeks' or months' work, and for just the few critical experiments necessary to establish the merits or otherwise of the basic idea. The availability of too much funding is likely to lead to the premature establishment of a full-blown investigation. Such a study may be appropriate at a later stage, but early on it is better to sustain an element of adventure associated with time and financial pressures, i.e., a spirit of entrepreneurial endeavor. Many creative people seem to work best under such conditions, provided they are limited to the proof-of-principle stage.

In our company, and in others, "discretionary" funds are provided to the research manager to support the quick evaluation of good ideas. Typically, they amount to only 1 to 3 percent of the R&D budget, but the return on this investment can be impressive.

(d) Encourage Cross-Disciplinary Activities: It is not unusual for a difficult problem to yield quickly to a nontraditional approach, having resisted for some time the best efforts of the discipline to which it apparently belongs. This may be because certain preconceived assumptions are not considered as absolute or relevant as they were in the home discipline. More likely, however, it is because a scientist from some other discipline has in his portfolio of knowledge some increment of information or insight not common to the field in which the problem has routinely been considered. In any event, our experience is that creativity is much enhanced when management delicately, yet deliberately, causes scientists from different disciplines to get together to discuss their problems. This can be done by establishing interdisciplinary groups to brainstorm solutions to a problem; by suggesting to individual scientists that they could profitably get together on an issue (in industry, as perhaps opposed to academe, such a managerial suggestion stands a fair chance of being taken seriously); or by creating an environment in which such cross-disciplinary interactions occur naturally, for instance, by providing a pleasant cafeteria that dispenses good tea or coffee continuously, has pencils and notepaper on every table, and blackboards nearby.

(e) Encourage the Acquisition of Knowledge: Scientists should be encouraged to acquire and exchange knowledge via travel to company operations and to other labs at home and abroad, and by attending conferences. One can not predict where the next good idea will come from, but its generation is likely to be stimulated by a non-routine situation. An up-to-date library, with computer search capability and access to the major data bases, plus a skillful and helpful staff, also are mandatory... as are frequent seminars by visiting scientists, both distinguished experts and promising beginners. Presentations by scientists known for their unconventional views should also be encouraged. They can help the young scientist learn how to distinguish good ideas from wild ideas, and also cause them to revisit their assumptions, sometimes to good purpose.

It is also important to ensure that the staff takes seriously its professional responsibilities to contribute to the fund of common knowledge via publications and presentations, to explain its results and their significance to both management and plant personnel in a language that they can understand, and to preserve the investment of the company via the generation of robust portfolios of patents.

FOSTERING INNOVATION

Regarding industry's need for innovation, Maddock [5] has commented that "to cherish traditions, old buildings, ancient cultures and graceful lifestyles is a worthy thing...but in the world of technology, to cling to outmoded methods of manufacture, old product lines, old markets, or old attitudes among managers and workers, is a prescription for suicide." On innovation itself, Quinn [6] has remarked that "one should recognize and manage innovation as it really is -- a tumultuous, somewhat random, interactive learning process, linking a worldwide network of knowledge sources to the subtle unpredictability of customers end uses." In other words, innovation, like creativity is complex and not easy to manage. Nevertheless, again there are some things that R&D managers can do to facilitate the process, for example:

(a) Establish a Climate for Change: Because innovations upset the status quo and disturb the smooth running of a company, managers who desire to innovate must have a high tolerance for change and uncertainty [7]. Establishing an encouraging atmosphere for innovation is thus best begun at the top. It probably helps if the leader is himself a successful entrepreneur (e.g., Land of Polaroid), but this is more likely to be the exception than the rule. It certainly helps if the leader has a technical or marketing background. Studies by the McKinsey organization [8] indicate that companies so led outperform those led by financial people by a substantial margin. Interestingly, their report notes that in 1978 only 25 percent of new U.S. CEO's were promoted from technical or marketing functions, but by 1982 the ratio was 50 percent. We believe this is a hopeful sign for the future of U.S. industry.

The next best thing to the CEO being himself visionary and technically capable is an R&D director who has these attributes, and who also is a close advisor to the president. In Japan, according to Ohmae [9], this is true in about 80 percent of the cases. In the United States, we suspect that it is much less. In this case, the R&D director must endeavor to see that his message reaches the CEO through someone on whom he relies for solid, down-to-earth advice. Often this is his chief financial officer.

(b) Establish the Innovation Team: The team should involve not only scientists and engineers from the labs, but also decision-makers from planning, finance, marketing and manufacturing and, in the best of all worlds, they should agree upon product and market goals, timetables, cost, etc., at the very beginning of the project.

We understand that such an integrated approach is standard practice in certain leading Japanese electronic products companies. Thus, before any R&D program is initiated, all the major corporate functions get together to define and agree on their customers' expectations for the company's next product. What should this product be; of what quality; what price; and... most importanrly, what improvements over the current state-of-the-art will be expected? From this dialog falls out what R&D is needed; what improvements in manufacturing technology will be required to meet cost and performance goals; what shall be the marketing niche and pricing strategies, etc. The results of the planning team's deliberations are presented to the CEO for approval before any work begins, and when it does it begins essentially simultaneously, though obviously at different rates, in all segments of the operation. This planned approach to innovation involves the conduct of each of the components of the effort essentially in parallel, with strong and regular interactive feedbacks between the various activities.

This approach may be distinguished from that traditionally used by U.S. companies, namely the sequential undertaking of basic research, applied research, product development, process development, market research, etc...with its inevitable problems of persuading each successive function to accept the results of its predecessor in the chain, i.e., a perfect environment for the not-invented-here syndrome.

On the other hand, the parallel approach is reminiscent of that adopted of necessity by small entrepreneurial companies, and the use of variations on this approach, as appropriate for the particular company, is strongly recommended.

(c) Ensure Focus: The consensus approach to deciding on product and market goals brings up the issue of focus, because one of the greatest obstacles to success in innovation is the availability of choice, and the consequent tendency towards indecision. In discussing this issue, the successful Danish inventor/entrepreneur Karl Kroyer [10] stressed the need for mental flexibility when dreaming up a new product..."gather as many ideas as you can, from everyone willing to offer them, even the janitor!." However, to paraphrase Kroyer further, "after you have decided which product to pursue, you must be absolutely single-minded in your dedication to the profitable introduction of this one product, and this one only. That is the key to success in innovation." Changing one's mind in midstream, changing specifications (unless the product doesn't work), or trying to produce several products at once, is usually fatal in Kroyer's view.

(d) Organizational Factors: Paolillo and Brown [11] found that the work environment (climate) is more important than organization structure in influencing innovativeness in an R&D laboratory. However, given a supportive climate, the fewer the number of supervisory levels and the greater the autonomy of the staff, the greater is likely to be their innovativeness. Accordingly, management should eliminate superfluous hierarchical levels and operate with as horizontal or "lower-archical" a structure as possible.

Flexibility in managerial attitude, and a willingness to operate on the basis of applied common sense rather than written policies, also helps.

However, this approach becomes increasingly difficult as the size of the organization increases. Therefore, there may be some merit in breaking down larger R&D organizations into relatively autonomous groups of perhaps 100 persons or so...just as multi-billion dollar corporations nowadays are beginning to perceive the benefits of decentralizing into smaller relatively autonomous companies with annual sales of, say, $1 billion or so.

(e) Staff Mobility and the Value of Alumni: In contrast to Japan, the United States is a heterogeneous and mobile society. In Martin Marietta's central laboratories, for example, the 300 or so staff is comprised of people from more than 20 different nations, including immigrants from Japan, China, Cyprus, Egypt, Turkey, Nigeria and most European countries. It seems that most of our scientists change jobs at least once in their careers, usually in the early years. Mobility becomes much reduced after the age of 35, however, usually because of family responsibilities that increasingly include a spouse who also has a professional career.

We believe job mobility early in one's career to be a good thing, because it permits an individual to find the most congenial and productive environment, and because it exposes his new organization to ideas and attitudes from other companies, permitting the organization to incorporate the best of these into its own operation. Later in one's career, reduced mobility provides advantages, because the development of a network of friendly connections throughout the company, and a sensitivity to its "culture" (or cultures...since these may vary across a large corporation) are important factors in technology transfer, a significant component of the innovation process.

Incidentally, senior alumni from the R&D laboratory can be valuable champions and facilitators of the technology transfer process. Accordingly, the transfer of appropriately motivated technical people from the laboratories to management positions in the operating companies is a recommended long-term strategy. However, it should be remarked that, in our experience alumni are not useful in the short run. This may be because they must first establish their credentials in their new environment, and this requires that they develop an evident detachment from their former colleagues. Given time and appropriate cultivation, however, they can become strong supporters of the R&D organization, serving as reliable sources of information on pending product and technology needs, and enthusiastic receptors for the laboratories' developments.

(f) Experience and Education: The skills required to innovate successfully are different from those called for in the creative act, and usually are acquired by on-the-job training and a broadening education.

As a general observation, we have noted that it takes about five years to transform a freshly graduated Ph.D. into an effective scientist (i.e., one with the skills and perspective to both select and solve a variety of technical problems); a further five years to become an effective industrial scientist (i.e., one with a knowledge of production operations, economics, market niches, etc.); and a further five years to become an effective R&D manager (i.e., one having gained skills in interpersonal relations and the creation and control of budgets, who has developed a network of useful connections around the company and country, and who also is capable of transmitting information in an understandable and usable fashion to both senior management and plan operating personnel). Thus, though there will certainly be exceptions, effective innovators are rarely under 40 years of age.

It follows that education and training of the future leaders of innovation in a major company is an important responsibility of management, and should be seen as a long-term task. In addition to participation in company strategy and problem-solving meetings, and the development of personal relationships with managers in other functions, progression through a series of formal educational courses is recommended to familiarize the future innovator with the terminology and standard procedures of the ancillary components of the innovative process. At Martin Marietta Laboratories, for example, over a period of a few years we conduct potential innovators through a sequence of courses in project management, communication, personnel management, and the principles of finance and marketing. Close participation in the patent process provides insights into business law.

Given such a background, the prospective innovator should know enough to realize that he will never know enough. However, he should know where and how to get the help he will surely need to be successful.

(g) Recognition and Reward: Gellman [12] has noted that the personal incentives that stimulate innovation can be different in different countries. In the United States, financial reward is an important factor; in Japan, increased prestige and responsibility are rated more highly. Even in the United States, however, rewards do not necessarily have to be financial. Psychological rewards also are effective. For example, simply to see one's own ideas brought to practice can be a real stimulus, and to participate in this process a significant reward. This may not necessarily be true for the creative individual, however. It was mentioned earlier that such persons are likely to have a limited attention span, and tend to lose interest in a project once the outcome is evident (at least, to them). The inevitably lengthy innovation process can be boring and demotivating to such people. Generally, therefore, it is better to set them to new challenges, and hand over the exploitation of their ideas to others who have more patience and a greater capability to handle the numerous and diverse interferences that arise between the moments of invention and positive return on investment.

In all cases, however, the timeliness of a reward is an important factor in determining its impact. In our laboratories, the award of a dinner for two and a show, delivered personally by the manager at the moment of triumph along with his congratulations and thanks, is much appreciated. The cost is small, but the personal nature of the award, and the opportunity to share it with a spouse or close friend, makes it most effective. Appropriate publicity in both company and local news media also is an appreciated form of recognition, as are opportunities to present accounts of one's work and its significance to executive management.

So far, we have addressed the functioning of the R&D scientist or engineer in today's world. But it seems likely that the practice of R&D will be somewhat different in the future as a consequence of the existence of high speed and parallel processing computers with enormous memories, of the development of algorithms that match human inference capability, and of the ready availability of much of the world's knowledge from huge data banks. We conclude, therefore, with some thoughts on technical education and practice in the future.

FUTURE

It has been said that prediction is difficult, especially about the future. However, one thing is reasonably certain. Our society and world will become more and more technological, and irreversibly so [13]. Whether or not computers will ever become "creative" is debatable. One view is that there is no reason why the computers of the future should not be able to search out and interact all the dependent variables of a problem, and then derive a novel solution that is correct within given practical constraints. Presumably, this is just what the creative brain does.*

Another view is that computers will remain essentially passive, responding only to programmed inputs and so producing essentially predictable outputs. In this view, since creativity is not precisely definable, and therefore not programmable, it will not become a computer capability...nor will intuition, or emotion. Nevertheless, computers should be able to produce good solutions to incredibly complex problems, even given inexact or "fuzzy" inputs. An interesting question then is, will humans accept the solutions, given that the route by which they were derived may be too complex for us to understand? Or will a massive not-invented-here syndrome set in? Who will get credit for some new insight that is computer-derived? Is there a Nobel Prize in the computer's future? Conversely, can a computer be held liable for an incorrect answer that leads, for instance, to a structural failure?

In any event, creative or not, computers will dramatically influence and reduce the degree to which experimentation is involved in innovation. For example, the property and performance databases traditionally developed by testing will be increasingly generated via computer simulation studies. And much of the optimization of product and process design will be handled by the interaction of pre-programmed fundamental scientific principles with engineer-introduced experimental variables.

One consequence of all of this is that the educational requirements of future researchers will be different. Given that all fundamental

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* The Nobel Laureate Ilya Prigogine has proposed that, in contrast to what might be expected from entropy arguments, in massive systems order can arise out of chaos via the occurrence and amplification of fluctuations [14]. In this view, one might speculate that, given time and a sufficiently massive computing system, seemingly unrelated observations might be organized by the computer to reveal some unpredicted but important relationship, e.g., a new scientific "law". Would this be considered a creative act?

scientific relationships and the physical, chemical and mechanical properties of all important materials will be accessible in a few seconds, what will the future researcher need to be able to do in order to be useful? Well, good judgement will remain an important skill, because he will be required to select from the mass of available data that which is relevant and sufficiently precise. He will then have to evaluate the solutions generated by the computer and decide how to apply them. Thus, judgement born of intuition and experience is likely to be a valuable human input to technical practice for some time to come.

Software specification skills will also become more useful to the future researcher than programming talents, because he will interact with his computer via a natural language interface, and the computer itself will handle the programming. Then, when his work is done, he will identify its key findings, select a format, and the computer will generate his report automatically. It will then file it in an appropriate data bank.

The advent of parallel processing computers will require researchers to begin to think differently about how they set up a problem. Today, most problems are addressed sequentially, perhaps because most people think as they speak, in a one-dimensional sequence of words or images. However, the enhanced speed of parallel processing is of use only if one can set up the problem in such a way that its various components can be addressed simultaneously and, perhaps, interactively. Learning how to do this will be a substantial intellectual challenge.

The future scientist or engineer should also be prepared to change his basic area of expertise several times during his career. As new technologies emerge, his skills in a particular field are likely to become obsolete, or replaced by intelligent systems. Consequently, universities will be called upon to educate not only 18-24 year olds, but also 35-55 year olds. The latter group will need both refresher courses in the fundamentals, and new knowledge and skills in emerging areas of science and technology. Members of this group also are likely to have time and economic constraints that will not permit them to take extended periods away from work. A solution may be the availability of concentrated courses lasting perhaps a month or so, taken every other year. Passing such courses probably will become a requirement for continued certification as a professional engineer, as recently they have for medical specialists.

In closing, we express the hope that future researchers will take more seriously than do those of our generation the challenge of interpreting the significance of their findings to intelligentsia in the fields of humanities, law, finance and politics. The perspectives and actions of informed thinkers from these fields will do much to determine whether the quality of life will improve or otherwise, as a consequence of future technological developments.

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