68. *The Genetic Code*, Cold Spring Harbor Laboratory of Quantitative Biology, Cold Spring Harbor, New York, 1967).
69. F. H. C. Crick, in *Soc. Exp. Biol. Symp., London* (1958); F. H. C. Crick, *Structure of Nucleic Acids and Their Role in Protein Synthesis* (Cambridge University Press, London, 1957), p. 25.
70. P. Dunnell, *Nature* **210**, 1267 (1966).
71. P. Hele, *Biochem. J.* **81**, 329 (1961); *Biochim. Biophys. Acta* **87**, 449 (1964).
72. ——— and P. T. Barth, *Biochim. Biophys. Acta* **114**, 149 (1966).
73. P. Zamecnik, M. L. Stephenson, C. M. Janeway, K. Randerath, *Biochem. Biophys. Res. Commun.* **24**, 91 (1966); K. Randerath *et al.*, *ibid.*, p. 98.
74. M. D. Lane, D. L. Young, F. Lynen, *J. Biol. Chem.* **239**, 2858 (1964); M. D. Lane, K. L. Rominger, D. L. Young, F. Lynen, *ibid.*, p. 2865.; J. E. Christner, M. J. Schlesinger, M. J. Coon, *ibid.*, p. 3997; S. K. Mitra and D. P. Burma, *ibid.* **240**, 4072 (1965).
75. A. Hvidt and S. O. Nielsen, *Advances Protein Chem.* **21**, 288 (1966).
76. M. DeLuca and Mary Marsh, *Arch. Biochem. Biophys.*, in press.
77. P. Urnes and P. Doty, *Advances Protein Chem.* **16**, 402 (1961).
78. W. F. Harrington, R. Josephs, D. Segal, *Annu. Rev. Biochem.* **35**, 599 (1966).
79. J. Monod, J.-P. Changeux, F. Jacob, *J. Mol. Biol.* **6**, 306 (1963); J. Monod, J. Wyman, J.-P. Changeux, *ibid.* **12**, 88 (1965).
80. D. E. Koshland, in *Advances Enzymol.* **22**, 45 (1960).
81. J. Boyko and M. G. Fraser, *Can. J. Biochem.* **42**, 1677 (1964).
82. This work was supported in part by grants from NIH and NSF and by a contract with AEC.

Creative Tensions in the Research and Development Climate

Technical achievement of scientists and engineers was high under conditions that seemed antithetical.

Donald C. Pelz

What kinds of climate in research and development organizations are conducive to technical accomplishment? What is the optimum degree of freedom versus coordination? of pure research versus practical development? of isolation versus communication? of specialization versus diversification?

To find some answers, my colleagues and I studied 1300 scientists and engineers in 11 research and development laboratories. Since the answers in different kinds of settings might vary, we included five industrial laboratories, five government laboratories, and seven departments in a major university. Their objectives ranged from basic research to product development.

Among the findings appeared a number of apparent inconsistencies. The optimum climate was not necessarily some compromise between extremes. Rather, achievement often flourished in the presence of factors that seemed antithetical.

Some examples are given below and summarized in Table 1 (*1*). As we pondered these findings, it seemed possible to fit many of them under two broad headings. On the one hand, technical men were effective when faced with some demand from the environment—when their associates held divergent viewpoints or the laboratory climate required disruption of established patterns. These might be called conditions of challenge.

On the other hand, technical men also performed well when they had some protection from environmental demands. Factors such as freedom, influence, or specialization offer the scientist stability and continuity in his work —conditions of security.

It seemed reasonable to say that the scientists and engineers of our study were more effective when they experienced a "creative tension" between sources of stability or security on the one hand and sources of disruption or challenge on the other. The term was suggested by T. S. Kuhn in a paper entitled "The essential tension: tradition and innovation in scientific research" (*2*).

Necessity is said to be the mother of invention, but our data suggest that invention (technical achievement) has more than one parent. Necessity might better be called the father—since necessity is one form of challenge, a masculine component. The role of mother is, rather, some source of security. When both are present, the creative tension between them can generate scientific achievement.

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Methods

The findings were not obtained by polling scientists concerning what climate they preferred. Rather, we obtained measures of each man's scientific performance, including his scientific or technical contribution to his field of knowledge in the past 5 years, as judged by panels of his colleagues; his overall usefulness to the organization, through either research or administration, also as judged by his colleagues; the number of professional papers he had published in the past 5 years (or, in the case of an engineer, the number of his patents or patent applications); and the number of his unpublished reports in the same period.

The performance measures were modified in several ways. Since distributions of papers, patents, and reports were skewed, a logarithmic transformation was applied to normalize them. Systematic variations with level of education, length of working experience, time in the organization, and type of institution were removed by adding constants so as to equalize the means. Each scientist, that is, was scored relative to others with similar background.

Characteristics of the climate were obtained on a carefully tested questionnaire. The two sets of data (on performance and on climate) were analyzed to find those conditions under which scientists actually performed at a higher or lower level.

Since optimum conditions might differ in different settings, all analyses were replicated within five subcategories: Ph.D.'s in research-oriented laboratories; Ph.D.'s in development-oriented laboratories; non-Ph.D.'s in research-oriented and in development-oriented laboratories (for convenience the latter have been called "engineers"); and non-Ph.D.'s in laboratories where 40 percent or more of the staff members held a doctoral degree (because of the limited influence and promotional opportunity of these non-Ph.D.'s we have called them "assistant scientists").

Science versus Application

For the first illustration, consider a tension not between factors of security and challenge but rather between science-oriented and product-oriented activity. The respondent estimated the proportion of his technical time (that is, time spent on research or development, as opposed to administration or teaching) that he allocated to each of the following five "R & D functions":

Research (discovery of new knowledge, either basic or applied):
- General knowledge relevant to a broad class of problems ___%
- Specific knowledge for solving particular problems ___%

Development and invention (translating knowledge into useful form)
- Improving existing products or processes ___%
- Inventing new products or processes ___%

Technical services (either analysis by standardized techniques or consultation and trouble-shooting) ___%

Some interesting trends appeared. For instance, Ph.D.'s in both research-oriented and development-oriented laboratories were judged most effective, on the basis of several criteria, when they devoted only half their technical time to research as such (first two categories above) and the rest to activities described as development or technical services. Similarly, Ph.D.'s in development-oriented laboratories were most effective when they spent only one-quarter or one-third of their time on activities labeled "development."

Another way to summarize the same data is illustrated in Fig. 1, where technical contribution is plotted against the number of R & D functions to which the individual devoted at least a little time (6 percent or more). Similar curves (not shown) were obtained for other measures of achievement—usefulness, publications, patents, and unpublished reports. Even in laboratories devoted to pure research the best performers carried on four functions; they did not concentrate on research alone, but spent some time on development or service functions. Performance dropped if Ph.D.'s or assistant scientists tried to perform all five functions, although engineers flourished under this condition.

Effective scientists, in short, did not limit their efforts either to the world of pure science or to the world of application but were active in both (see Table 1, tension 1).

Is this involvement with both worlds a genuine tension? I am inclined to think so. As time invested in one increases, investment in the other must decrease. Demands for solution of practical problems can interfere with long-range research.

Why, then, should such a tension be creative? Several writers have proposed that a creative act occurs when a set of elements not previously associated is assembled in a new and useful combination. Diversity in technical activities may broaden the range of elements from which the scientist or engineer can draw in synthesizing new combinations.

Other findings reinforced the importance of diversity. Individuals performed better when they had two or three "areas of specialization" within their scientific discipline, rather than one. The Ph.D.'s did their best work not when they devoted full time to technical activities but when they spent about one-quarter of their time in either teaching or administration.

In the framework of challenge versus security, diversity in the task may also be viewed as a source of disruption and hence a condition of challenge. For data on specialization versus diversity, see Table 1, tension 3.

Independence versus Interaction

Scientists place high priority on freedom. To measure this need, an index of "motivation from own ideas" was constructed, from self-reported (i) stimulus by one's previous work, (ii) stimulus by one's own curiosity, and (iii) desire for freedom to follow one's own ideas. This score—the index might also be labeled intellectual independence—was analyzed in relation to the four performance measures within each category of scientific personnel. A series of positive correlations appeared. Among the 36 correlation coefficients, 25 were positive ($r = +.10$ or larger) and none were negative; this was one of the most stable trends in the analysis, and was consistent with other research. As stated by Anne Roe (*3*), "almost all studies of scientists agree that the need for autonomy, for independence of action, is something that seems to be particularly strong in this group."

In what seemed an inconsistency, however, effective scientists did not avoid other people; they and their colleagues interacted vigorously. High performers conferred with their most important colleagues several times a week or daily; they regularly conferred with several colleagues in their own section and often with ten or more elsewhere in the organization.

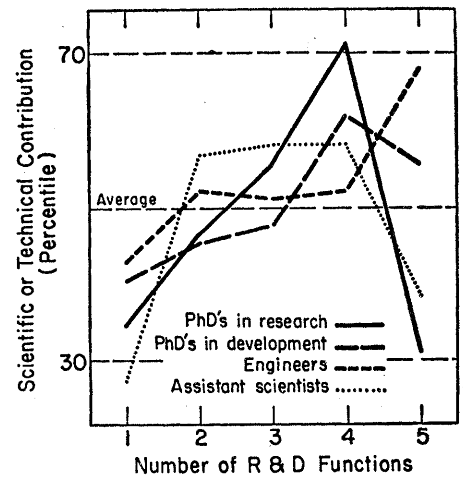

Fig. 1. Graph showing that the more numerous were the R & D functions, up to four, performed by Ph.D.'s and assistant scientists in development-oriented and research-oriented laboratories, the higher was their scientific or technical contribution as judged by colleagues; engineers did best when they had five R & D functions.

In our speculative framework, independence or self-reliance is a source of security. Interaction with colleagues is a source of challenge, for they may criticize and prod. The high contributor experienced a creative tension between independence and interaction (Table 1, tension 2).

The skeptic may ask, Are the two conditions antithetical? In terms of their occurrence in our data, not necessarily. Yet in common experience it is often difficult to maintain one's independence under social pressure. As Ralph Waldo Emerson put it over a century ago in his essay "Self-Reliance": "It is easy in the world to live after the world's opinion; it is easy in solitude to live after our own; but the great man is he who in the midst of the crowd keeps with perfect sweetness the independence of solitude." The aphorism fits our effective scientists today. In the midst of the crowd they retained—with enough sweetness to be creative—the independence of solitude.

Age, Specialization, Diversity

In one analytical study we considered the question, Under what conditions can younger or older scientists, respectively, do their best work? Andrews and I had speculated that younger scientists already face challenge because their work is new; mainly they need security. Older scientists, we thought, possess security and mainly need challenge. To test these ideas we correlated several measures of climate against performance within successive age brackets.

The findings were far from simple. The overall conclusion, however, was that, among younger and older scientists alike, *both* security and challenge were required for achievement.

In the youngest age categories (up to age 34), positive correlations appeared between technical performance and length of time the scientist or engineer had spent in his main project. Devoting 2 or 3 years to one undertaking is a source of security. It enables the young man to build contributions in which he can take pride. But, at the same time, young non-Ph.D.'s were effective when they had several areas of specialization, and young Ph.D.'s did better when they were *not* preoccupied with "digging deeply in a narrow area." A diversified task provides challenge (Table 1, tension 3*a*).

After age 40, a somewhat different set of measures accompanied high performance. Older individuals achieved only when self-confident—when motivated from their own ideas and willing to take risks. After age 50, achievement was also linked with an interest in probing deeply. These factors both suggest security. On the other hand, achievement after 50 was also linked strongly with interest in mapping broad features of new areas (Table 1, tension 3*b*). Thus, among older scientists, positive correlations appeared between performance and *both* penetrating study and wide-ranging study. The tension in this case was genuine; self-ratings of the two interests were found to be negatively correlated.

One wonders whether, in the creative tensions discussed thus far, the opposing conditions occur simultaneously or successively. Does the effective scientist pursue one narrow specialization at the same time he is exploring several new frontiers, or does he alternate between these postures? Does he retreat one month to his own ideas and engage in dialogue the next, or does he do both at the same time?

Our data contain no means of distinguishing. My hunch is that many creative scientists are flexible; they are able to alternate between contrasting roles.

Table 1. Eight creative tensions.

Security	Challenge
Tension 1	
	Effective scientists and engineers in both research and development laboratories did not limit their activities either to pure science or to application but spent some time on several kinds of R & D activities, ranging from basic research to technical services
Tension 2	
Effective scientists were intellectually independent or self-reliant; they pursued their own ideas and valued freedom . . .	. . . But they did not avoid other people; they and their colleagues interacted vigorously
Tension 3	
a) In the first decade of work, young scientists and engineers did well if they spent a few years on one main project . . .	. . . But young non-Ph.D.'s also achieved if they had several skills, and young Ph.D.'s did better when they avoided narrow specialization
b) Among mature scientists, high performers had greater self-confidence and an interest in probing deeply . . .	. . . At the same time, effective older scientists wanted to pioneer in broad new areas
Tension 4	
a) In loosest departments with minimum coordination, the most autonomous individuals, with maximum security and minimum challenge, were ineffective . . .	. . . More effective were those persons who experienced stimulation from a variety of external or internal sources
b) In departments having moderate coordination, it seems likely that individual autonomy permitted a search for the best solution . . .	. . . to important problems faced by the organization
Tension 5	
Both Ph.D.'s and engineers contributed most when they strongly influenced key decision-makers . . .	. . . but also when persons in several other positions had a voice in selecting their goals
Tension 6	
High performers named colleagues with whom they shared similar sources of stimulation (personal support) . . .	. . . but they differed from colleagues in technical style and strategy (dither or intellectual conflict)
Tension 7	
R & D teams were of greatest use to their organization at that "group age" when interest in narrow specialization had increased to a medium level . . .	. . . but interest in broad pioneering had not yet disappeared
Tension 8	
In older groups which retained vitality the members preferred each other as collaborators . . .	. . . yet their technical strategies differed and they remained intellectually combative

The Individual and the Organization

We saw previously the importance of desire for independence. But to desire independence does not mean that one *is* independent. We therefore measured the individual's freedom to choose his own research or development tasks by asking who exerted weight in deciding what his technical goals or assignments were to be. The more weight exerted by the technical man himself, relative to that exerted by his chief, his colleagues, or higher executives or clients, the greater his perceived autonomy. The measure appeared valid: it was highest for Ph.D.'s in research, and lowest for "assistant scientists."

Now the more autonomy an individual has (the more weight in selecting his own assignments), the greater should be the stability and continuity of his work—the greater his security. And we found that, as autonomy increased, so did performance—up to a point. We were puzzled, however, to observe that when Ph.D.'s in both research-oriented and development-oriented laboratories had more than half the weight in choosing their goals their performance dropped, whereas in the case of non-Ph.D.'s, as their autonomy increased their performance continued to rise. Why?

In one search for answers we examined an organizational variable: the tightness or looseness of coordination within the department, measured by nonsupervisory scientists' ratings of the coordination within their section and supervisors' ratings of coordination between sections. (Individual autonomy and departmental looseness are of course interrelated, but within a given department the freedom of individuals can vary.) A loose organization does not make demands on its members; it provides high security with little challenge.

We found first that, in the most loosely coordinated departments, highly autonomous individuals actually experienced *less* stimulation, from either external or internal sources. They withdrew from contact with colleagues; they specialized in narrow areas; they even became less interested in their work. In these settings, maximum autonomy was accompanied by minimum challenge.

Yet in the most loosely coordinated settings, we also found, it was essential that the person be challenged if he were to achieve. It was here that the strongest correlations appeared between performance and various stimulating factors: diversity in the work, communication with colleagues, competition between groups, involvement in the job.

In these loosely coordinated settings, the most autonomous individuals were able to isolate themselves from challenge. A nondemanding organization permitted them to withdraw into an ivory tower of maximum security and minimum challenge. There they atrophied (Table 1, tension 4*a*).

What about the more demanding organizations—those of moderately tight coordination? Why was autonomy an asset here and not a handicap? We found that autonomous persons here had more diversity in their work, not less. One can speculate that in these departments the technical man had to face problems important to the organization; personal freedom enabled him to find the best solutions. Again a creative tension: the organization itself presented challenges; autonomy provided security for solving them (Table 1, tension 4*b*).

Influence Given and Received

The question used to measure autonomy also indicated the weight exerted by other persons in the choice of an individual's assignments. The "decision-making sources" were grouped into four categories: The individual, his immediate supervisor, his colleagues or subordinates, and higher executives or clients. We scored for each scientist how many of the four sources were said to have had at least some weight (10 percent or more) in selecting his technical goals.

Now, to discuss one's projects with persons in several positions is to run the risk of criticism and disruption. The more sources there are involved in decisions, the greater is the likelihood of challenge.

For the scientist to allow other people some weight in his assignments does not, however, mean that he is powerless. He can *influence* the decision-shapers, and influence provides security.

We divided respondents into those who felt they exerted strong influence over key decision-makers and those who felt they exerted little. Responses on this item appeared valid; the highest influence was reported by Ph.D.'s in research laboratories, and the lowest by assistant scientists.

The results were clear: both Ph.D.'s and engineers performed well when all four sources had some voice in shaping their goals but when, at the same time, the individual could influence the main decision-makers. From this arose creative tension 5 (Table 1): influence received from several others (challenge) combined with influence exerted on others (security).

The reader may ask, To what extent are the receiving and giving of influence antithetical? In conventional views of bureaucracy, each is seen as restricting the other; the size of the "influence pie" is considered a constant, so that if superiors have more, subordinates have less. Likert (*4*) argues, however, in a fashion compatible with our results, that the total amount of influence is not fixed. When everyone exerts more —when total control rises—performance is likely to improve.

But why should participation enhance the scientist's performance? Mainly, I suspect, because it helps him to avoid the narrow or trivial, to select tasks of *significance*, either to the organization or to science. Diverse contacts may also turn up unrecognized problems, or suggest new approaches to old ones. Finally, the interest of others in the scientist's work will enhance his own involvement in it.

"Dither"

Another way in which a man's colleagues can provide challenge is through questioning his ideas. An apt label was borrowed by Warren Weaver (*5*) from British colleagues who built into antiaircraft computing devices a "small eccentric or vibrating member which kept the whole mechanism in a constant state of minor but rapid vibration. This they called the 'dither.' . . . We need a certain amount of dither in our mental mechanisms. We need to have our ideas jostled about a bit so that we do not become intellectually sluggish."

A scientist's colleagues may jostle his ideas if they and he approach a problem differently. To test this hypothesis, we measured similarity or dissimilarity between the scientist and his colleagues in several ways. One method was subjective—the respondent's perception of how his own technical strategy resembled that of his co-workers. Other measures were objective, in the sense that we examined the approaches reported by the respondent and by each of his colleagues and numerically scored the similarity among them.

How much dither or disagreement is healthy? In our data the answer depended on the kind of dither. One objective measure concerned the source of motivation—whether one's superior, the technical literature, or some other source. Scientists who responded to the same sources were somewhat more effective—perhaps because they had similar interests.

On three other measures we found the opposite to be true. Scientists and engineers did somewhat better when

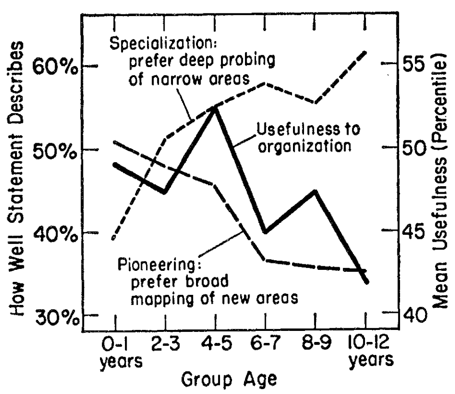

Fig. 2. Graph showing that R & D teams were most useful at that group age when the members wanted both to specialize and to pioneer.

they saw themselves as different from colleagues in technical strategy, and when, as scored objectively, they differed from colleagues in style of approach (when, for example, the individual stressed the abstract, his colleagues the concrete) or differed in career orientation.

How to reconcile this paradox? In some preliminary data obtained by Evan (*6*) for industrial R & D groups, the teams he found most effective reported personal harmony or liking among members, but intellectual conflict. Colleagues who report the same sources of motivation as the scientist's own probably provide personal harmony and support—a form of security. When they argue about technical strategy or approach, they provide dither or challenge (Table 1, tension 6).

Group Age

Another portion of our analysis concerned the age of groups—the average tenure of membership in a given section or team. A reasonable hunch is that, as a group gets "older," security is likely to rise and challenge is likely to diminish. If this is so, what conditions are needed to maintain vitality as the group ages?

To study this question, Wallace P. Wells identified 83 sections or teams in industrial or government laboratories (ranging in number of members from 2 to 25, with a median of 6). He averaged the measures for scientific contribution and usefulness of members in each group and adjusted the averages to rule out the effects of individual age, percentage of Ph.D.'s, and type of setting.

When he plotted the adjusted measures against group age, Wells found that group performance generally declined as group age increased, although usefulness was highest for groups with an average tenure of 4 to 5 years.

Why the decline after 5 years? In a search for clues, Wells examined several measures of the group's climate in relation to its age. Two of these measures are plotted in Fig. 2. The average preference for "deep probing of narrow areas" (a source of security) rose steadily as group age increased, while the interest in "broad mapping of new areas" (a source of challenge) dropped. Note in Fig. 2 that usefulness was highest shortly beyond the point where the two curves cross, where both interests were present in some degree (Table 1, tension 7). The finding is similar to that for tension 3*b* and may partly overlap it, since older groups tend to contain older individuals.

Not all older sections declined in vitality; some continued to be both useful and technically creative. Why? Wells examined other measures of group climate. One he called "cohesiveness"; a group scored high on this measure if its members listed other members of the team as their main colleagues. If group members prefer one another as collaborators, they are undoubtedly secure.

Wells found that in older groups (average group age, 4 years or more), cohesiveness was correlated strongly with usefulness and technical contribution. That is, if an older team continued to be cohesive, it stayed effective. Also, those older groups whose members communicated freely with one another performed better than younger ones did.

Yet the climate in effective older groups could hardly be called relaxed. On the measure of felt similarity to colleagues in technical strategies, Wells found that, in older groups, the more dissimilar the approach was, the higher was the performance.

One other measure proved surprising. Scientists rated the "hesitance to share ideas" within their section (for convenience we have called it "secretiveness"). Usually such hesitance was absent or mild. When some of this feeling was present in new groups, it was a handicap; it hindered their work. But this feeling *enhanced* the performance of older groups.

On reflection, this contrast makes sense. A new, insecure group must suspend criticism while it searches for new ideas. An old, secure group, on the other hand, will profit from criticism. If it stays effective it is not a club where one can lower his intellectual guard. On the contrary, there is competition in ideas; members sharpen their wits and marshal their evidence before speaking. Such a climate indicates challenge rather than insecurity.

Creative tension 8 (Table 1)—intellectual combativeness among colleagues who value each other—resembles tension 6. To prefer one's section members as collaborators is a sign of personal support, while the atmosphere of combativeness indicates intellectual conflict.

Practical Implications

Before considering practical implications I should raise the question, What is cause and what is effect? Does a combination of security and challenge help to generate achievement? Or do scientists who achieve experience more security and sense of challenge?

My own speculation is that a feedback loop exists. Usually a high performer has not only ability but also personality traits of curiosity and confidence. He is attracted to diverse problems and to contact with colleagues (a source of challenge) and at the same time insists on freedom and a voice in decisions (conditions of security). He thus exposes himself to conditions which in turn stimulate him to achieve. If this is the case, might lower achievers surround themselves with a similar climate and so enhance their own performance? Can R & D managers help to create such environments? I believe they can, and offer the following suggestions.

Conditions of Security

An important quality (see Table 1, tension 2) is self-reliance and pursuit of one's own ideas. But in a development-oriented laboratory the manager cannot give each man a free hand; how then can he build an individual's pride in his own work? One way perhaps is to insure that once or twice a year each man produces a product which bears his own name—even if this requires that a jointly prepared document be broken into parts. It was disturbing to find in our sample that two out of five non-Ph.D.'s in research had not published a single paper in 5 years; among engineers the figure was four out of five. Half the engineers had not a single patent to their credit in the past 5 years, and one out of five had not authored even an unpublished report. How can a scientist feel confident of his own ideas if he has no output in which to take a fatherly pride?

Consider how the method of rewarding performance may affect self-reliance. Typically a single chief assigns tasks, judges results, evaluates performance, and recommends promotions. What better way to stamp out independent thought? To build self-reliance there must be multiple channels for recognizing achievement. Make sure that each subordinate has a chance once or twice a year to explain his work to colleagues *outside* his group. In review sessions with executives or clients, include the engineer who is doing the work and let him do some of the talking.

Another security factor is autonomy —substantial weight exerted by the individual in choice of assignment (see Table 1, tension 4). Such weight does not mean, however, that the individual should be completely on his own. From a further analysis (not reported above) it appeared that a technical worker in a development-oriented laboratory performed best when he and his supervisor *jointly* determined assignments. For Ph.D.'s in research laboratories, an effective condition was joint determination by the scientist and his colleagues. Assignment by the supervisor alone was the worst condition in all settings.

Security can be provided by the opportunity to influence others who decide one's assignments (Table 1, tension 5). Organizational structure plays a part here. Such influence is probably weaker in a many-leveled impersonal organization where each level has a veto. The individual's voice counts more in an organization of flat structure with fewer levels, where there is a chance for face-to-face contact with the people who shape his assignments.

Security increases with the length of time an individual spends on a given project (tension 3), particularly in the case of the younger man. Give him a year or two to dig into his main project, instead of shifting him every 3 months. He must have time to build a solid contribution.

One's colleagues can also be a source of security. In forming teams, managers can put together individuals who have similar sources of motivation—who are interested in the same kinds of problems (tension 6).

As R & D teams get older they can remain productive if they stay cohesive (tension 8). The supervisor can encourage cohesion by giving credit to the group rather than to himself. He can build mutual respect by publicizing the contribution of each member. He can strengthen teamwork through promoting competition with other groups in the solution of technical problems.

Conditions of Challenge

Scientists and engineers performed well not only when they had continuity and stability but also when they were challenged by demands from their environment. Frequent contact with one's colleagues (tensions 2 and 5) can be an important source of challenge. Such contacts can stimulate the individual in many ways. They can point to significant problems, suggest new approaches, or correct errors in a present approach.

How can the R & D manager encourage fruitful interaction? Often simply by knowing who in the organization or the field is doing what; he can steer the scientist to others who can give or use help. He can invite the individual to talk to a seminar, set up study teams and evaluation groups, pose problems which require consultation for their solution.

To encourage friendly disagreement, the R & D manager can invite members of an older group to look for flaws in each other's presentations (tension 8). When forming a new project committee he can include individuals who like each other but who use different strategies (tension 6). Periodic regrouping of teams—always with the consent of the persons involved—may help in maintaining a vital atmosphere.

Specialization lends security but diminishes challenge; some degree of diversity is required (tensions 1, 3, and 4). The manager should beware of letting some individuals focus exclusively on research, others exclusively on development. He should encourage his staff to tackle some jobs in both areas.

A younger scientist needs more than one area of specialization (tension 3*a*). In addition to a main continuing assignment, give him each year a second, shorter assignment which demands that he learn a new skill. Keep the older man's interest in broad areas strong by tempting him with problems on the pioneering edges of his field (tension 3*b*). Set up refresher courses; arrange sabbatical exchanges with a university.

Teams as well as individuals can become too specialized and lose interest in pioneering (tension 7). The R & D manager should not assume that one group has become *the* expert group in a specific area. As problems in this area arise, occasionally he will give one of them to a different team. He will challenge the expert group now and then with a task outside its specialty.

In the short run, such a policy may not be the most efficient way to manage a laboratory. It may cost more and take more time. But in the long run it will make for breadth and flexibility, and these will continue to open doors for creative advances.

Summary

As Andrews and I examined the conditions under which scientists and engineers did effective work, we observed a number of apparent paradoxes. Achievement was high under conditions that seemed inconsistent, including on the one hand sources of stability or confidence (what I have called "security") and on the other hand sources of disruption or intellectual conflict (that is, "challenge"). It appears that, if both are present, the creative tension between them can promote technical achievement.

References and Notes

1. A full report appears in D. C. Pelz and F. M. Andrews, *Scientists in Organizations: Productive Climates for Research and Development* (Wiley, New York, 1966). Data concerning the various tensions of Table 1 appear in the following chapters: tension 1, chap. 4; tension 2, chaps. 3 and 6; tension 3, chap. 11; tension 4, chap. 12; tension 5, chap. 2; tension 6, chap. 8; tensions 7 and 8, chap. 13; the performance measures are described in appendices A–C.
2. T. S. Kuhn, in *Scientific Creativity: Its Recognition and Development*, C. W. Taylor and F. Barron, Eds. (Wiley, New York, 1963), pp. 341–54.
3. A. Roe, *ibid.*, p. 135.
4. R. Likert, *New Patterns of Management* (McGraw-Hill, New York, 1961), especially chap. 4.
5. W. Weaver, *Science* **130**, 301 (1959).
6. W. Evan, *Ind. Management Rev.* **7**, 37 (1965).

7. Collaborating in this research were W. P. Wells, S. S. West, A. M. Krebs, and G. R. Farris. The work has been supported by grants from the Carnegie Corporation of New York, the National Science Foundation, the U.S. Army Research Office (Durham), the Foundation for Research on Human Behavior, the U.S. Public Health Service, the National Aeronautics and Space Administration, and industrial laboratories. This article is based on a lecture presented in Miami in August 1966 before a meeting of the American Sociological Association.