LEADING YOUR SCIENTISTS AND ENGINEERS 2002

Leadership skills, business knowledge and other non-technical abilities have become increasingly important since RTM's 1988 survey. Ten areas are highlighted.

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OVERVIEW: Review of the recent literature on the management of scientists and engineers updates the four categories of study identified by M. K. Badawy in his 1988 survey (1), and identifies six new areas. Badawy's review covered human resources planning, rewarding scientists and engineers, appraising the performance of scientists and engineers, and career management. The new developments impacting the way scientists and engineers are managed comprise cross-functional teams, leading scientists and engineers, knowledge management, demographic diversity, electronic technology, and outsourcing. Based on this updated review of the literature, actions are recommended in each of these ten areas for leading scientists and engineers in today's business environment.

The management of scientists and engineers has been a subject of study for several decades. Scores of papers have been written about ways to increase their performance, satisfaction and retention. In a 1988 article in Research Technology Management, Badawy reviewed the literature and summarized what was known then about managing scientists and engineers (1).

While much about doing R&D has remained the same since then, much has also changed. Today, as then, scientists and engineers are doing work that is essentially technical. They are still asked to solve problems, find information, and discover relationships among phenomena that may lead to the development of new products, services and processes. Today, however, the R&D business environment is more competitive and complex. Strategic shifts have led to more emphasis on development and less on research. Time-to-market is more critical than before, so project cycle time reduction is critical. Structural shifts have led to relatively less effort on internal R&D and more on alliances, outsourcing and partnerships. Intellectual property is increasingly being treated as a core competency. New computer and telecommunications technologies facilitate work. Teamwork has become widespread. Emphasis has changed from commanding and controlling people to leading them. The diversity of the technical workforce has increased significantly. Scientists and engineers are more likely to experience tensions between work and family life.

This article reviews the literature since 1988 on managing scientists and engineers. After explaining our approach to reviewing that literature, we begin with the four areas identified by Badawy: human resources planning, rewarding scientists and engineers, appraising the performance of scientists and engineers, and career management. Then, we review work on the six important new topics: cross-functional teams, leading scientists...
Among 102 studies identified since 1988 on the management of engineers and scientists, there has been a dramatic increase over the past five years in anecdotal studies of such new developments as cross-functional teams, outsourcing, and knowledge management.

and engineers, knowledge management, demographic diversity, electronic technology, and outsourcing. We shall conclude with the implications of the review for scientists, engineers, and their managers, and recommend actions (summarized in Table 2) for leading scientists and engineers in today’s business environment. For readers seeking a quick overview, Table 1 summarizes what the 102 studies we identified suggest is new in the 10 topical areas.

### Trends in the Literature

We began our review of the literature by using Proquest Direct, a comprehensive computerized database of

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<th>Topical Area</th>
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<td>Human Resources Planning</td>
<td>Business, people, leadership, and other skills are required; roles are better understood; electronic technology is used in hiring.</td>
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<td>Rewarding</td>
<td>Intrinsic rewards remain most important; extrinsic rewards and team rewards are used more; quality of work-life arrangements are introduced.</td>
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<td>Appraising Performance</td>
<td>Performance is appraised more formally and systematically; multiple appraisers (i.e., managers, peers) and metrics (i.e., objective, subjective) are used.</td>
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<td>Career Management</td>
<td>Flatter, multiple-career paths that provide cross-functional and technical/management career development opportunities are used; emphasis is more on employability and less on life-employment with one company.</td>
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<td>Cross-functional Teams</td>
<td>Cross-functional teams replace functional groups in many applications; some of these teams are globally distributed.</td>
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<td>Leading</td>
<td>Technical managers shift their main role from directing work to communicating technical and business goals and providing a stimulating work environment to achieve these goals.</td>
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<td>Knowledge Management</td>
<td>Knowledge is managed for competitive advantage, and knowledge communities are developed.</td>
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<td>Demographic Diversity</td>
<td>The technical workforce is demographically diverse; diversity is managed to avoid conflicts and realize benefits.</td>
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<td>Electronic Technology</td>
<td>The Internet and other electronic technologies now supplement more traditional means of handling and processing information.</td>
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<td>Outsourcing</td>
<td>R&amp;D is increasingly being outsourced by contracting-out projects in whole or in part, or by bringing in contract staff.</td>
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business and management journals, to search on key phrases such as “managing technical professionals,” “outsourcing and R&D,” “flexible workers and R&D,” and “turnover and R&D.” In addition, we contacted several researchers active in the field for a list of their recent articles.

This effort identified 102 articles, which we classified as either “conceptual” (focusing on a presentation of ideas relevant to the management of scientists and engineers), “empirical” (reporting a statistical study in which data were collected to test hypotheses or answer research questions), or “anecdotal” (describing case examples of efforts in individual companies related to the management of scientists and engineers). Thirty-four percent of the studies were conceptual, 47 percent were empirical, and 19 percent were anecdotal.

We then divided the studies according to the date of publication to see if there were any trends in the types of studies over time. We created three time periods: 1988–1992, 1993–1997, and 1998–2002 and charted the number of each kind of study published during that period. Results are shown in the graph, page 14. While the conceptual and empirical studies increased steadily during the 1988–2002 period, the number of anecdotal studies was relatively low through 1997 and then increased dramatically during the last five years. We attribute this increase to a relatively large number of anecdotal studies about the new developments in managing scientists and engineers. These publications provide information on new developments in management practices and issues too recent for many conceptual or empirical reports to have been published.

Human Resources Planning

Traditional R&D laboratories hired scientists and engineers for their specialized technical skills. In contrast, today’s R&D laboratories hire scientists and engineers for more varied skills (2,3). To work in cross-functional teams, scientists and engineers need leadership, marketing and manufacturing skills in addition to their specialized technical skills (4,5,6); to work in geographically distributed teams, they need computer-mediated communication systems skills (7); to work in a demographically diverse workforce, they need cross-cultural interaction skills (8); to work with recent technology, they need such computer skills as computer-aided engineering and CAD/CAM (9). As an example of this need for a variety of skills, a 1996 industrial survey (10) found respondents ranking the following skills as somewhat important to very important for mechanical engineers: teamwork (94%), communication (89%) and design for manufacturing (88%).

When selecting and hiring, it also appears important to staff for critical work roles for effective performance in R&D organizations, even if few engineers and scientists are needed to perform these roles. Moreover, it appears important to provide these few technical professionals with the kinds of assignments in which they can put these talents to good use (11). One such informal role for projects is the champion role, defined by the PDMA Handbook as “a person who takes an inordinate interest in seeing that a particular process or product is fully developed and marketed” (12,13).

Adequate project leadership and senior management support are critical for project success (14). Thus, the champion role appears to be a stand-by role, because the informal project leadership champions provide appears helpful only when formal project leadership is inadequate or when there is a lack of project support by senior management (15).

Another such informal role is the gatekeeper role. Some gatekeepers keep up with external technological developments and communicate these developments to the organization; others span boundaries within the organization and help integrate different functional units. Whether gatekeeping roles can be successfully formalized, however, is not clear. While evidence from one organization suggests that this is not possible (16), evidence from another suggests that it is (17).

Another role is that of idea generator, key innovator or rainmaker (11). This is a critical role that can inspire entire units of scientists and engineers to top performance and that needs to be recognized and rewarded accordingly.

A more formal role is the project leader or team leader role. Although this role is not well understood, project leaders can influence project outcomes in many different ways. For example, Jassawalla and Sasihithal find that project leaders can positively influence project outcomes by allowing team members to participate, facilitating communications, leading rather than commanding and controlling, selecting the right mix of team members, and providing team members with the right training (18). Moreover, Kayworth and Leidner find that leadership in virtual projects is particularly demanding (7). These are geographically dispersed cross-functional teams relying on technologically-mediated communications for task

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Table 2.—Recommended Actions

Human Resources Planning
Hire scientists and engineers (S&Es) for a variety of skills in addition to their technical qualifications, e.g., people skills, leadership potential, business understanding, and cross-cultural interaction skills. Training can help develop these skills. In staffing projects and teams, it is also important to place S&E partly on the basis of their potential for performing roles which may be critical for success, such as champion, gatekeeper, idea generator, project leader, and entrepreneur. The Internet can be useful in hiring, but it is best employed as a supplement to more traditional techniques: college recruiting, professional associations, internship programs, and word-of-mouth.

Rewarding Scientists and Engineers
We cannot overemphasize the importance of task assignment in motivating S&E for performance and retention. Good performance is best rewarded by a good assignment. Extrinsic rewards are important also, but here the critical factor is equity in comparison to the perceived quality of performance and rewards received by colleagues in the company and outside. Recognition programs and bonuses can be effective in rewarding individuals and teams, but they are not a substitute for intrinsic rewards and permanent salary increases or promotion. Quality-of-life initiatives such as telecommuting policies, flex-time, on-site child care, and on-site health clubs can help retain S&E.

Appraising Performance
As in 1988, performance appraisal continues to be a difficult and sensitive task. Recent innovations such as broadbanding and 360 degree feedback have met with mixed success. Generally, those S&E who did well under their previous appraisal systems have not welcomed the changes, while many others prefer the newer approaches. Of course, it is the top performers especially who must be motivated and retained. Given the complexity of technical work and the increased involvement of S&E in teams, multiple performance metrics from multiple sources make sense. The trick is to implement these metrics consistently in a manner perceived as fair by the S&E whose work is being appraised.

Career Management
No longer can S&E expect lifetime careers with a single company. Layoffs by companies have fostered free-agent attitudes by individual S&E. The reduced commitment between companies and their employees has led many companies to counsel their S&E on the realities of their new employment “contracts” and endeavor to provide satisfactory career paths for their most valued S&E. They have added multiple career paths to the traditional dual ladder to accommodate multiple career orientations of S&E who prefer working on increasingly challenging projects, transferring technology, or developing new ventures. These developments make good sense to us, given the increased use of cross-functional teams, the trend toward flatter organizational structures, and the mixed technical and business responsibilities of many S&E.

Cross-Functional Teams
Although cross-functional teams offer advantages, their complexity produces management challenges. They can facilitate higher quality, lower costs, faster development times, and a higher quality of work-life for their members. Globally distributed cross-functional teams allow collaboration among highly qualified S&E from around the world, but they are particularly difficult to manage due to their limited face-to-face communications. Effectiveness can be facilitated by selecting and training members for team skills as well as technical skills, using face-to-face communications as much as possible (especially in globally distributed teams), and employing new technologies to facilitate communications among team members when they are not meeting face-to-face. Setting clear goals for team performance, especially moderate goals that allow small successes to be achieved early, can go a long way toward building trust among members of cross-functional teams.

Leading Scientists and Engineers
A highly competitive business environment requires effective leadership as well as good management. Priority must be placed on integrating technical goals with business and financial goals and then empowering S&E to achieve them. Most cases, this can be best done by leading as a catalyst: creating a working environment with clear objectives, challenging work, collaboration in teams, full communication opportunities, opportunities to grow and develop new skills, and a fair reward system linked to performance. Training can be very helpful. It should emphasize financial and leadership skills as well as technical skills, to equip S&E for today's technical and business challenges.

Knowledge Management
R&D laboratories can gain competitive advantage by managing knowledge effectively. This requires a culture that not only values creating, but also sharing knowledge. Companies can facilitate knowledge management by rewarding S&E for sharing knowledge, emphasizing team as well as individual rewards, creating common areas to facilitate sharing tacit knowledge, establishing communities of practice on special topics, using cross-functional teams, and creating full-time knowledge management positions. The use of information technology and other media can also be helpful, especially in making tacit knowledge explicit and in sharing explicit knowledge.

Demographic Diversity
The technical workforce is increasingly diverse. This can either facilitate performance and satisfaction by bringing different perspectives to the task, or reduce performance and satisfaction by increasing misunderstandings and conflict. Helpful actions include diversity training programs, diversity-friendly organizational policies, mentoring programs, equal-opportunity career development programs, conflict management programs, and leadership programs. A key factor in determining the success of these actions is whether they are part of an overall organizational culture that values diversity.

Electronic Technology
The Internet and corporate intranets can dramatically increase the speed and lower the cost of communications, and several specialized software technologies can facilitate problem solving in specific technical specialities. Effective use of technology depends on using it appropriately—for the right tasks. CAD systems, for example, may facilitate work on routine design improvements but increase development time for new designs. Databases are useful only to the extent that they are updated to contain information needed for the tasks at hand. Some systems do contain useful information but make it difficult to find, so the user interface is important if system benefits are to exceed the cost of search. Thus, our chief recommendation regarding new technology is to carefully consider its potential uses and costs and to involve its future users in its design and development.

Outsourcing
R&D tasks are being outsourced with increasing frequency because outsourcing offers cost advantages in certain situations. R&D is outsourced by contracting out projects in whole or in part, or by bringing contract S&E to the company to work with in-house staff. While outsourcing allows in-house S&E to interact with other S&E, it can prevent the experience that contract S&E gain from working for the organization from entering the organization's memory. It can also create two classes of employees working side by side, making effective collaboration more difficult. Effective management of outsourcing requires careful choice of the tasks for which it will be used, clear definitions of the roles of the contract and regular employees, and careful consideration of the effects of outsourcing policies on knowledge sharing and retention.—G.F. and R.C.
performance. For example, it appears very important for these project leaders to coordinate the communications process and to help create a cohesive project team environment.

Competitive R&D laboratories prefer to use advanced technology for the hiring process over traditional approaches such as ads in professional journals and newspapers (19). Job openings are first posted for current company employees on an intranet (20). Unfilled job openings are then posted for all interested on the Internet (19). Moreover, external candidates can use the Internet to learn about the company, the projects the company is working on, and to submit an application for posted job openings on-line. Technology cannot be used exclusively, however, because knowing candidates and appealing to their interests is important for a good match (19). Thus, companies also rely on such interpersonal techniques as networks at colleges, universities and professional associations, internship programs, and sending demographically diverse recruiters to colleges and universities. Moreover, a recent survey confirms that in spite of new technology, most scientists and engineers believe that word-of-mouth remains the most effective means of finding a job (21).

**Rewarding Scientists and Engineers**

Although engineers and scientists can be motivated with extrinsic rewards, the evidence clearly suggests that intrinsic rewards are more effective motivators than extrinsic rewards (22). For example, Alpert finds that technical challenge is the chief motivator for scientists and engineers (23); James finds evidence that what motivates scientists and engineers is opportunity to pursue their research interests (11); Katz suggests that sequences of job positions providing new challenges and demanding new skills are required (24); McKinnon finds that many technical professionals are more interested in the challenge of project work than in advancement up the management or the technical career ladders (25). Others welcome the challenge of starting a new venture without incurring the risk of going into business for themselves (26).

Money is the most common extrinsic reward. A significant problem with money is that it does not make scientists and engineers passionate about their jobs. Intrinsic rewards, however, can generate the kind of passion required to make them achieve the high levels of performance required in today’s business environment (27). Thus, current reward systems need to focus on motivating performance with the rewards inherent in the work itself (28).

But reward systems also need to motivate performance with extrinsic rewards. Because high performers can make substantial financial contributions to the company, current reward systems need to be flexible enough to reward scientists and engineers commensurately with their contributions. For example, many companies create special policies to pay for outstanding performers, provide cash or equity awards and recognition by managers and colleagues for significant contributions, and calculate bonuses on the basis of revenues generated by patents (26,28,29,30). Moreover, these companies are replacing the traditional narrow salary ranges with broad salary bands that facilitate adequately rewarding substantially different levels of performance and the traditional emphasis on internal equity with a new emphasis on market alignment (31).

Because current R&D laboratories rely heavily on cross-functional teams, these laboratories also reward cross-functional and team performance (32). For example, companies create pay for knowledge and skills plans, and provide bonuses based on team performance and company profitability (33). Moreover, a 1993 study of 189 companies in the U.S. and Canada found that the compensation plan of 53 percent of these companies involved a bonus (34). The major bases for giving this bonus were: company profitability (20.1%), individual performance (20.1%), successful accomplishment of the new product project (15.9%), performance of the new product (7.4%), and others (13.2%).

Adequately rewarding scientists and engineers also helps retain them. Interestingly, the evidence also suggests that intrinsic rewards are more important than extrinsic rewards for retention (35). Technical professionals stay with laboratories that provide interesting and challenging work, and leave laboratories that offer only routine work and little individual discretion.

Extrinsic rewards, however, also need to be provided. The evidence suggests that high performers leave if they are not treated better than low performers (35). Thus, broader pay ranges, cash bonuses, stock options, and promotional opportunities also help retain high-performing scientists and engineers.

In addition, quality-of-life arrangements such as telecommuting, flex time, on-site child care, and on-site health clubs and gyms not only help retain but also attract scientists and engineers (36,37).
Appraising Performance

Traditionally, functional managers and senior R&D professionals appraise the performance of scientists and engineers. When these scientists and engineers are assigned to project teams, however, 360-degree feedback often occurs. Team members, team leaders, project managers and team customers appraise their performance (4, 38).

Successful organizations approach the evaluation of performance in a formal and systematic way. There are several metrics useful for helping appraise the performance of scientists and engineers (39, 40). Some of these metrics are quantitative: a publication is a sign of innovation; the number of times a publication is cited is a measure of the quality of the publication; a patent is a sign that innovation has market potential; the number of times a patent is cited and the revenues generated by a patent are a measure of the importance of the patent. Some of these metrics are qualitative: self-evaluations and evaluations by experts, managers, peers, and customers who rank individuals on one or more dimensions of performance and evaluate the extent to which individuals accomplish previously agreed-upon objectives. Because individual metrics are imperfect (i.e., they are inaccurate, they are partial metrics), multiple measures are typically used.

Career Management

The traditional assumption is that scientists and engineers have two career orientations: the technical orientation and the management orientation (41). Cosmopolitans—those with the technical orientation—are more likely to have a Ph.D., to value freedom of research, to value technical performance, and to identify with their profession (38, 42, 43). In contrast, locals—those with the management orientation—are more likely to be less technically educated, to value commercial success, to value organizational performance, and to identify with their organization.

To accommodate these career orientations, R&D laboratories have created the dual-career path (11). Locals are expected to receive promotions in the management path; cosmopolitans are expected to receive promotions in the technical path commensurate with those available in the management path. The dual-career paths also accommodate the traditional approach to doing work in a technical group. Promotions in the technical path mean doing more advanced technical work, while promotions in the management path mean managing more scientists and engineers and coordinating their work with that of other technical and non-technical professionals.

One problem with the traditional technical path is that it may become a dumping ground for failed managers (44). Another problem is that people on the technical path may become isolated from the rest of the organization (42, 45).

Moreover, recent studies suggest that scientists and engineers have more than two career orientations: they have the project orientation (the desire to work on challenging projects), the technical transfer orientation (the desire to move with the technology to other organizational units) and the entrepreneurial orientation (the desire to develop a new venture) (25, 44, 46, 47, 48). Moreover, these orientations do not appear to be mutually exclusive (49).

Recent studies also suggest that doing work in cross-functional teams has frequently replaced working in technical groups (34, 50, 51). To work in cross-functional teams, scientists and engineers are cross-trained, rotated to other technical groups, and rotated to manufacturing and marketing groups (52, 53, 54). Moreover, to make sure they remain technically proficient, they are rotated back and forth between technical groups and cross-functional teams (38).

Thompson and Dalton found that technical and other professional careers develop in four stages (55). In Stage 1—the Apprenticeship Stage—professionals learn necessary technical skills and work under close supervision. In Stage 2—the Independent Contributor Stage—professionals master technical skills and become independent technical contributors. In Stage 3—the Mentor Stage—professionals develop junior professionals, many as technical managers. In Stage 4—the Sponsor Stage—professionals provide opportunities to other professionals and deal with the organization’s external environment, many as general managers.

A recent major study of Thompson and Dalton’s Four Career Stages model found that it is still a generally valid way to describe career progress in technical and other professions (56). Several differences from the early study, however, were identified. There are more professionals in Stage 2 and fewer in Stage 4, suggesting a reduction of professionals in the more advanced career stage. There are more Stage 2 professionals in formal
management roles and fewer Stage 3 and Stage 4 professionals in formal non-management roles, suggesting more professionals are developing their careers by simultaneously assuming both technical and management responsibilities (57).

Thus, the traditional vertical dual-career path appears too restrictive to accommodate the many career orientations of scientists and engineers, the use of cross-functional teams in R&D laboratories, the trend towards flatter structures, and the mixed responsibilities of scientists and engineers (48, 58). These traditional career paths are becoming flatter, multiple-career paths that provide more cross-functional and more mixed (technical/management) career development opportunities (4, 59).

Finally, there is less emphasis today on pursuing a career within the same organization than there was in the past. Waterman et al. suggest that an individual’s career responsibility is more to remain employable than to develop a long-term career at one company (60). Moreover, the organization’s career responsibility is more to maintain and enhance the individual’s employability than to provide him or her with a long-term career opportunity. Consequently, under this new covenant, R&D laboratories provide scientists and engineers with opportunities to develop greater competitive skills and to temporarily develop a career in exchange for greater performance and commitment to organizational goals for as long as the individual remains in the laboratory. Moreover, there can be no justification under this covenant for resentment when individuals either leave the laboratory voluntarily or are laid off.

Cross-functional Teams

Successful development of new products today requires close cooperation between marketing, R&D, manufacturing, and other functions (4). This cooperation can be strengthened with cross-functional teams, and recent studies suggest that about 75 percent of R&D laboratories rely on such teams for new product development (15, 34).

Cross-functional teams have gained wide acceptance among R&D management because these teams facilitate accomplishing product quality objectives, and because they reduce the cost and time required to develop new products (51, 52, 61, 62). Moreover, engineers and scientists are expected to welcome the use of these teams because they increase quality of work life (63).

Traditional new product development is divided among functional groups (50, 64), with scientists and engineers assuming responsibility for only the technical task. In cross-functional teams, members of different functional groups work as a tightly integrated unit (4, 50, 65). Thus, in addition to responsibility for the technical task, technical professionals share responsibility with other functions for the overall cross-functional team task (66).

Some of these teams are dispersed globally, so that team members are cross-cultural as well as far apart (67). While these teams allow multinational companies to assemble highly qualified scientists and engineers from many parts of the world, Fournier cautions that they are likely to fail unless managed properly because it is difficult to make them function as cohesive units (68). The cross-cultural nature of these teams is likely to bring different perspectives that may result in communication problems. For example, people from different countries have different definitions of teamwork (69), and different reasons for terminating a project (70). With face-to-face communications impossible on a daily basis, teams must rely on impersonal and technologically-mediated communication (7, 67). Thus, Fournier suggests the following: make information explicit, since one cannot rely on a shared sense of understanding; increase opportunities for face-to-face contacts; build trust among team members; and continually work on improving communications among distributed team members (68).

Ancona and Caldwell have identified four boundary roles that technical and other professionals can perform to help cross-functional teams become more effective (71): the ambassador role helps link the team to outsiders; the task-coordinator role helps coordinate the cross-functional task; the scouting role scans the envi-

**Cross-functional teams**

**Advantages**

- Facilitate accomplishing technical and business objectives, reduce project cost and time, increase quality of work life, provide cross-training (4, 51, 52, 63).

**Disadvantages**

- Difficult to implement and lead, increase team member effort and cross-functional conflict, may lead team members to technical obsolescence (5, 13, 38, 63, 66).

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ronment for relevant ideas: the guarding role manages the flow of information to outsiders. The ambassador and the scouting roles help regulate external team interactions, while the task coordinator and the guarding roles appear to be information-sharing roles in that they help the team engage in external interactions (72).

Leading Scientists and Engineers

Traditional technical managers operated through command and control systems: they provided direction, plans, procedures, and rules that defined the work. Moreover, they made sure scientists and engineers followed directions and complied with these plans, procedures, and rules. Today, in competitive R&D work, technical management is pushed down and more is done by scientists and engineers individually or in teams (59, 60, 73). Thus, technical managers shift from the command-and-control role to the leadership role: they assign broad objectives, and create a work climate that helps scientists and engineers to define and control their work (4, 6, 11, 18, 48, 52, 66, 74, 75).

Today’s technical managers perform two important roles: the catalyst role and the captain role (76). They perform the catalyst role by providing scientists and engineers with a stimulating work environment that challenges and empowers, presents clear task objectives, and allows them to grow and develop. They perform the captain role by directing the work of scientists and engineers. The more they act as catalysts, however, the less they are required to act as captains, because a stimulating work environment negates the need to direct the work of scientists and engineers (77).

Administrative, people and technical skills are important for performing the catalyst role and for leading scientists and engineers (77). For example, financial skills are important to prioritize technical activities and to communicate these priorities to other managers in a language that they can easily understand. Indeed, finance is the language used to communicate across the entire business organization.

Knowledge Management

Engineers and scientists are knowledge workers, and R&D laboratories gain competitive advantage today by managing knowledge (78). Ambrecht et al. find that the two primary factors enabling knowledge management in technical organizations are culture and structure, with information technology being the secondary factor (79). These authors make several recommendations for harnessing culture and structure, the most significant ones in our opinion being: the development of a culture that values sharing and creating knowledge; top management support for knowledge management; and the development of measures that support knowledge management in conjunction with tying incentives to high scores in these measures. They also recommend flat organizational structures, large common areas that facilitate interactions, the use of cross-functional teams, and the creation of full-time knowledge management positions.

Similarly, McDermott makes several useful suggestions for successful knowledge management (80). These include: develop natural knowledge communities that avoid operating as bureaucracies; allow these communities to determine what information they need to share and the media they will use; allow them to use different media such as on-line, face-to-face, telephone, regular mail, etc.; integrate these communities into the natural flow of work; and create an organizational culture that supports the sharing of knowledge.

Diversity in the Workforce

In the past, R&D laboratories were staffed mainly with white males. Recently, however, there has been an influx of women and nonwhites, especially Asian, in the technical workforce (8). This greater demographic diversity creates opportunities and challenges for R&D laboratories, particularly when one considers the increased importance of teamwork.

Three reasons are frequently given for the need to manage demographic diversity (81): facilitating creativity and decision-making by using demographic diversity to bring different perspectives to the task; gaining market

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**Electronic Technology**

**Advantages**

Facilitates accomplishing technical and business objectives, reduces project cost and time (14, 78, 91).

**Disadvantages**

Difficult to implement, limitations of current search tools to select usable information, security concerns, programmed analysis and design less suitable for radical innovations (86, 87, 92, 95, 96).
access and legitimacy by staffing to reflect diverse markets and constituents; and being morally and legally responsible by being fair and avoiding discrimination. The literature provides evidence that diversity facilitates creativity and decision-making and, therefore, morale by bringing different perspectives to the task (5, 8, 81). However, it also provides evidence that demographic diversity can hurt creativity and decision-making and, therefore, morale by increasing conflict (8, 82). To minimize conflict and obtain the benefits of demographic diversity, experts recommend: training and education programs, diversity-friendly organizational policies, mentoring programs, and equal-opportunity career development programs (83).

Demographic diversity sometimes arises from multinational R&D programs. A recent study suggests several strategies for facilitating the work of scientists and engineers temporarily in a foreign culture: show signs of respect for their home culture, follow home-country labor regulations, and create an environment more like the home country (84).

Leveraging Electronic Technology

The Internet has the potential to dramatically increase the performance of scientists and engineers (78) and a recent study argues that they are already taking advantage of this tool: they spend an average of 66 minutes per day using the Internet to purchase and sell lab equipment, to purchase business travel and accommodations (85, 86), and for other purposes discussed below.

- They use the Internet to facilitate product development by, for example, using a Web-based system to provide a central repository for all project-related information (87, 88). Moreover, they and other project members (which may include customers and worldwide suppliers) can continually update and access this information on a secure project extranet. Thus, a Web-based system allows for quickly discovering and solving design problems with a minimum of travel before the final design is completed (89). As a result, the quality of new products increases, and their development time and cost decrease (90, 91).

- They use a Web-based database to facilitate knowledge management by, for example, searching for existing solutions to technical problems in other areas of the organization (78, 92). Having such a database, however, is no guarantee that technical knowledge will be exchanged successfully—an on-line database needs to be managed effectively. For example, to promote posting solutions to technical problems in this database and to promote searching and using these solutions, some organizations assign individuals to promote the database and offer incentives to those who contribute or use the knowledge (93).

- Computer-aided engineering (CAE) and computer-aided design (CAD) software systems allow scientists and engineers to test the performance of different designs, virtually eliminating the need for building physical models, and thereby reducing product development time and cost (14). Scientists and engineers, however, do not appear to use these software systems very effectively (94). For example, Kessler and Chakrabarti found that CAD systems tend to increase product development time, especially for radical innovations that are more dependent on creativity than on mathematical solutions and old designs (95). In contrast, Robertson and Allen have found a positive relationship between the use of CAD systems communication capabilities (i.e., to transfer files) and engineering performance (96).

Outsourcing R&D

R&D is increasingly being outsourced by contracting out projects in whole or in part, or by bringing in contract scientists and engineers to work in teams with in-house staff (97, 98). In this way, organizations that adequately

| Outsourcing R&D
| **Advantages**
| Allows firms to subcontract routine and low value-added work, and to procure technical skills not necessary to retain because of variable demand (100).
| **Disadvantages**
| Firms may weaken their core technical skills and experience problems with secrecy, trust and technical proprietorship (100).
| Outsourcing relationship may fail if there is a lack of common interests, performance targets, or control systems between firm and contractors; if their cultures and product development data systems are incompatible; if the firm attempts to micro-manage the contractor and fails to share benefits contractor may bring by exceeding performance targets (17).
develop their core technical competencies and outsourcing management practices are able to innovate faster and less expensively, particularly in those areas where they lack internal expertise (17, 99). Moreover, outsourcing allows in-house staff to become part of a wider “invisible college” within the R&D community (100). Finally, Jarmont et al. (101) have found that the performance of contract scientists and engineers rivals that of permanent staff. However, outsourcing also prevents the experience and expertise acquired by contractors while working for the organization from entering the organization’s memory (98).

Apply What We’ve Learned

We know a great deal about managing scientists and engineers to achieve high levels of performance, satisfaction and retention. Badawy’s review (1) identified many important factors, and our review of the literature since then identified several others.

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**Recommended Readings**

**Human Resources Planning**

James (11). Presents four bases for sound technical human resource management practices: It’s the work that motivates; several criteria roles are essential for performance; ensure peer and organizational recognition; provide stimulating work environment.

**Rewarding Scientists and Engineers**

Amabile (27). Intrinsic motivation is more essential to creativity than extrinsic motivation. People will be most creative when they feel motivated primarily by the interest, satisfaction and challenge of the work itself and not by external pressures.

Despres et al. (28). Rewards to technical staff should be attached to performance targets rather than activity cycles, and these targets should include team performance. Moreover, these rewards should include challenges inherent in the nature of the work.

**Appraising Performance**

Werner and Souder (40). Discusses different metrics for measuring R&D performance.

**Career Management**

Bailyn (46). Study examined four career routes in the R&D lab: the managerial route, the technical route, the route from project to project, and the technical transfer route. Proposes the idea of a hybrid career for technical staff.

Womack and Jones (38). In order to use and expand the knowledge of employees, companies must organize this knowledge into functions. But focusing on processes, which is the means of making organizations lean, requires a high degree of cross-functional cooperation.

**Cross-Functional Teams**

Hershock et al. (66). Functional managers often influence subordinates to attach high priority to the functional aspects of their jobs. A major hindrance to teamwork, however, is team members who do not attach high priority to teamwork.

**Leading Scientists and Engineers**

Hammer and Champy (74). This best-seller makes a strong point for organizing around processes rather than around functions. In contrast to TQM, reengineering is a radical redesign of organizational processes.

Cordero, Farris and DiTomaso (77). Technical supervisors can act as captains, leading technical work directly, or catalysts, creating a stimulating working environment that empowers S&E to do innovative work. Technical, people, and administrative skills help supervisors act as catalysts. People skills help, technical skills help marginally, and administrative skills mainly hinder managers from acting as captains.

**Knowledge Management**

Armbricht et al. (79). Proposes a model of how knowledge flows in technical organizations. Model focuses on three principal enablers of knowledge flow: culture, infrastructure and technology. Culture and infrastructure are often linked.

**Demographic Diversity**

Cordero, DiTomaso and Farris (8). Innovative work and satisfaction appear higher in gender-homogeneous work groups. The relationship of ethnic composition to creative productivity and morale, however, differs by ethnic subgroup.

Ely and Thomas (81). Three diversity perspectives are compared: a diversity of approaches is valuable; mirroring diverse customers is valuable; managing diversity is a moral imperative. Only the first perspective is associated with performance.

**Electronic Technology**

Kessler and Chakrabarti (95). More frequent use of CAD systems tends to slow down innovation. This result is consistent with those who caution against the “technology fix” to execute the same old process.

Mandel and Hof (78). The Internet is a tool that dramatically lowers the cost of communications. Thus, it can radically alter any industry or activity that depends heavily on the flow of information and can boost the rate of innovation.

**Outsourcing**

Quinn (17). Outsourcing offers increased opportunities for much faster and lower-cost innovation to companies that develop their core competencies and outsourcing management practices properly. In fact, suppliers have become the major source of high-tech jobs. —G.F. and R.C.
Our review also leads us to make suggestions for the ways in which engineers and scientists should be managed, and we have summarized these suggestions in Table 2 for each of the ten areas. Some of these suggestions are firmly grounded in empirical research; others, particularly some of those in the six new areas, are more speculative, being based more on conceptual and anecdotal reports. Most of these suggestions involve leading rather than managing.

All we know about managing scientists and engineers, however, is of little use unless technical managers use this knowledge to lead. Clarke (102) suggests that there are two obstacles to this happening: (1) managerial potential is still determined much more by an individual’s technical skills than by his or her potential to develop leadership skills; (2) even if some scientists and engineers have the potential to develop leadership skills, they are often promoted into management before they have enough opportunity to develop these skills adequately.

Leadership skills, business knowledge and other non-technical skills are increasingly important in today’s business environment. If scientists and engineers are provided opportunities to develop both technical and leadership skills and relevant knowledge of the business, we will increase the chances of making full use of what is known about leading scientists and engineers today.

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References


What We’ve Learned


69. Gibson, C. B. and Zellmer-Bruhn, M. E. “Metaphors and
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