WHAT DO WE KNOW ABOUT MANAGING SCIENTISTS AND ENGINEERS: A REVIEW OF RECENT LITERATURE

George F. Farris
Graduate School of Management
Rutgers University
Newark, N. J. 07102
(973-353-5982)
gfarris@andromeda.rutgers.edu

and

Rene Cordero
School of Management
New Jersey Institute of Technology
Newark, N.J. 07102
(973-596-6417)
cordero@admin.njit.edu

The Center for Innovation Management Studies (CIMS) at North Carolina State University funded this project. George F. Farris is Professor of Management and Director of the Technology Management Research Center at the Graduate School of Management at Rutgers University. He received his Ph. D. at the University of Michigan. His research focuses on managing technical professionals. Rene Cordero is a Professor in the School of Management at New Jersey Institute of Technology. He received his Ph. D at Rutgers University. His primary research focuses on the management of technology and innovation, both at the human resources management level and the organizational level.

OVERVIEW

This paper reviews the recent literature on the management of scientists and engineers and updates the four categories of study identified by Badawy (1988) in his earlier review of this literature: human resources planning, rewarding scientists and engineers, appraising the performance of scientists and engineers, and career management. It also discusses six new developments impacting the way scientists and engineers are managed: cross-functional teams, leading scientists and engineers, knowledge management, demographic diversity, electronic and other technologies, 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.

INTRODUCTION

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 previous paper in *Research-Technology Management*, Badawy (1988) reviewed the literature and summarized what was known then about managing scientists and engineers.

While much about doing R&D has remained the same since Badawy published his review in 1988, much has 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 very important. 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* people. The diversity of the technical workforce has increased significantly. Scientists and engineers are more likely to experience tensions between work and family life.

This paper reviews the literature since 1988 on managing scientists and engineers. It covers the four areas identified by Badawy: human resources planning, rewarding scientists and engineers, appraising the performance of scientists and engineers, and career management. Moreover, it adds reviews of work on six important new topics: cross-functional teams, leading scientists and engineers, knowledge management, demographic diversity, electronic and other technologies, and outsourcing. For readers seeking quick overviews of the four areas identified by Badawy in 1988, Table 1 provides a summary. Similarly, Table 2 summarizes what the one hundred and nine studies reviewed here suggest is new in the four traditional topics and the six new topics identified here. First we shall briefly discuss our approach to reviewing the literature and the overall changes we found. Then we shall turn to reviews of the traditional topics and the six relatively new topics. We shall conclude with a discussion of the implications of the review for scientists, engineers, and their managers and recommend actions (summarized in Table 6) for leading scientists and engineers in today's business environment.

TYPES OF ARTICLES IN THE LITERATURE

We set out to conduct a comprehensive review of the literature since 1988 on managing scientists and engineers. In order to do this, we used Proquest Direct, a comprehensive computerized database of business and management journals, to search on several key words 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 over one hundred articles. We classified each article as "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-two per cent of the studies were conceptual, forty-six per cent were empirical, and twenty-two per cent were anecdotal.

We then divided the studies according to the date of publication to see if any changes were occurring 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 Figure 1. Clearly all three types of studies – conceptual, empirical, and anecdotal – increased during the 1988-2002 period. Conceptual and empirical studies increased steadily, but the number of anecdotal studies we found 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 being reported about the new developments in managing scientists and engineers. These anecdotal publications provide information on interesting new developments on management practices and issues too recent for many conceptual or empirical reports to have been published.

TRADITIONAL TOPICS

Human Resources Planning

Traditional R&D laboratories hired scientists and engineers for their specialized technical skills. In contrast, current R&D laboratories hire scientists and engineers for more varied skills (Kirchoff & Lyn, 1994; Schongerger, 1994). To work in cross-functional teams, scientists and engineers need people and leadership skills, and adequate skills in marketing and manufacturing, in addition to specialized technical skills (Cordero, 1999; Pelled & Adler, 1994, Rosenbaum, 1990). To work in geographically distributed teams, scientists and engineers need computer-mediated communication systems skills (Kayworth & Leidner, 2001-2002). To work in a demographically diverse workforce, scientists and engineers need cross-cultural interaction skills (Cordero et al., 1996). To work with recent technology, scientists and engineers need such computer skills as computer aided engineering and CAD/CAM (Braham, 1992). As an example of this need for a variety of skills, a recent industrial survey (Valenti, 1996) finds 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 scientists and engineers are needed to perform these roles. Moreover, it appears important to provide these few scientists and engineers with the kinds of assignments where they can put these talents to good use (James, 2002). 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* (Markham & Aiman-Smith, 2001; Markham & Griffin, 1998). Adequate project leadership and senior management support are critical for project success (Schilling & Hill, 1998). Thus, the champion role appears a stand-by role, because the informal project leadership provided by champions appears helpful only when formal project leadership is inadequate or when there is a lack of project support by senior management (McDonough, 2000). 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. Evidence from one organization suggests that this is not possible (Nochur & Allen, 1992). Evidence from another organization, however, suggests that this is possible (Quinn, 2000). Another role is that of *idea generator, key innovator, or rainmaker* (James, 2002). This is a critical role that can inspire whole 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 & Sashittal (2000) 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. Moreover, Kayworth & Leidner (2001-2002) find that leadership in virtual projects is particularly demanding. These are geographically dispersed cross-functional teams relying on technologically mediated communications for task 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 high technology for the hiring process over traditional approaches such as ads in professional journals and newspapers (Perry, 2002). Job openings are first posted for current company employees in the Intranet (Leibowitz et al., 1986). Unfilled job openings are then posted for all interested in the Internet (Perry, 2002). Moreover, external candidates can use the Internet to find about the company, the projects the company is working on, and to submit an application for posted job openings on-line. High technology, however, cannot be used exclusively, because knowing candidates and appealing to their interests is important for a good match (Perry, 2002). Thus, companies also rely on such people 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 high technology, most scientists and engineers believe the most effective means of finding a job is still *word of mouth* (LaVine & Cassidy, 1999).

Rewarding Scientists and Engineers

Although scientists and engineers can be motivated with extrinsic rewards, the evidence clearly suggests that intrinsic rewards are more effective motivators than extrinsic rewards (Chen et al., 1999). For example, Alpert (1992) finds that technical challenge is the chief motivator for scientists and engineers. James (2002) finds evidence that what motivates scientists and engineers is the opportunity to pursue their research interests. Katz (1988) suggests that sequences of job positions providing new challenges and demanding new skills are required to motivate scientists and engineers. McKinnon (1987) finds that many scientists and engineers are more interested in the challenge of project work than in advancement up the management or the technical career ladders. Other scientists and engineers are interested in the challenge of starting a new venture without incurring the risk of going into business for themselves (Gomez-Mejia et al., 1990).

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 scientists and engineers achieve the high levels of performance required in today's business environment (Amabile, 1998). Thus, current reward systems need to focus on motivating performance with the rewards inherent in the work itself (Despres & Hiltrop, 1996).

But current reward systems also need to motivate performance with extrinsic rewards. Because high performing scientists and engineers 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 (Depres & Hiltrop, 1996; Geraci, 1994; Gomez-Mejia et al., 1990; Triendl, 1998). Moreover, many 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 (Risher, 2000).

Because current R&D laboratories rely heavily on cross-functional teams, these laboratories also provide rewards for cross-functional and team performance (Meyer, 1993). For example, companies create pay for knowledge and skills plans, and provide bonuses based on team performance and company profitability (O'Dell, 1989). Moreover, a study of 189 companies in the U.S. and Canada (Page, 1993) found that the compensation plan of 53% of these companies involved a bonus. 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. Because projects are disrupted and because scientists and engineers are hard to replace, turnover is very costly for R&D laboratories. Interestingly, the evidence also suggests that intrinsic rewards are more important than extrinsic rewards for retaining scientists and engineers (Kochanski & Ledford, 2001). Scientists and engineers stay with laboratories that provide interesting and challenging work, and leave laboratories that offer 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 (Kochanski & Ledford, 2001). Thus, broader pay ranges, cash bonuses, stock options, and promotional opportunities also help retain high performing scientists and engineers.

In today's business environment, scientists and engineers find job demands stressful and often find it difficult to balance job and family demands. Thus, 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 (Hammonds et al., 1997; Reimers, 2001).

Appraising the Performance of Scientists and Engineers

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 (Cordero, 1999; Womack & Jones, 1996).

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 (Cordero, 1990; Werner & Souder, 1997). 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 that rank individuals on one or more dimensions of performance and evaluate the extent 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 (Merton, 1957). *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 (Womack & Jones, 1996; Allen & Katz, 1992; Aryee & Leong, 1991). 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 paths (James, 2002). Locals are expected to receive promotions in the management path. Cosmopolitans are expected to receive promotions commensurate to those available in the management path in the technical 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. Promotions in the management path mean managing more scientists and engineers and coordinating their work with the work 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 (Allen & Katz, 1986). Another problem is that scientists and engineers in the technical path may become isolated from the rest of the organization (Allen & Katz, 1992; Roth, 1988).

Moreover, recent studies suggest that scientists and engineers have more than two career orientations. Scientists and engineers also have the *project* orientation—the desire to work in 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 (Allen & Katz, 1986; Bailyn, 1991; Kim & Cha, 2000; McKinnon, 1987; Petroni, 2000). Moreover, these orientations do not appear to be mutually exclusive (Baugh & Roberts, 1994).

Recent studies also suggest that doing work in cross-functional teams has frequently replaced doing work in technical groups (Cooper, 1994, 1995; Page, 1993). To formally prepare scientists and engineers to work in cross-functional teams, colleges and universities allow students to take courses in specialized fields other than their own, to pursue a management minor, and to take capstone courses where they cooperate with students from business fields such as marketing and manufacturing (Cordero, 1999). To develop scientists and engineers to work in cross-functional teams, they are cross-trained, rotated to other technical groups, and rotated to manufacturing and marketing groups (Anderson, 1993; Kusunoki & Numagami, 1998; Ransley & Rogers, 1994). Moreover, to make sure they stay technically proficient, they are rotated back and forth between technical groups and cross-functional teams (Womack & Jones, 1996).

Thompson & Dalton (1976) found that technical and other professional careers develop in four stages. 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 professional, many as technical managers. In Stage 4—the *Sponsor Stage*—professionals provide opportunities to other professionals and deal with the external environment of the organization, many as general managers. A recent major study of Thompson and Dalton's Four Career Stages model found that the model is still a generally valid way to describe career progress in technical and other professions (Younger & Sandholtz, 1997). Several differences from the early study, however, were identified. There are more professionals in Stage 2 and less 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 less 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 (Jackson, 1998).

Thus, the traditional vertical dual-career paths 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 (Igbaria et al., 1999; Petroni, 2000). These traditional vertical dual-career paths are becoming flatter multiple-career paths that provide more cross-functional and more mixed (technical/management) career development opportunities (Cordero, 1999; Levi & Slem, 1995).

Finally, there is less emphasis today on developing a career in the same organization than there was in the past. Waterman et al. (1994) suggest that the career responsibility of the individual is more to remain employable than to develop a long-term career within the current organization. Moreover, the career responsibility of the organization is more to maintain and enhance the individual's employability than to provide the individual with a long-term career opportunity. Thus, 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 are no grounds under this covenant for resentment when either individuals leave the laboratory or when they are laid off by the laboratory.

NEW DEVELOPMENTS

Cross-functional Teams

A recent study found that about 60% of R&D laboratories use a systematic stage-gate process for new product development (Cooper et al., 2002). A stage-gate process breaks product development into discrete stages where cross-functional activities are performed, each stage followed by a gate where a decision is made to either move into the next stage or terminate product development (Cooper, 1994).

The successful completion of a stage requires the close cooperation of different functions such as marketing, R&D, and manufacturing (Cordero, 1999). This cross-functional cooperation can be increased by the use of cross-functional teams, and recent studies suggest that about 75%

of R&D laboratories rely on cross-functional teams for new product development (McDonough, 2000; Page, 1993).

Cross-functional teams have gained wide acceptance with R&D management because these teams facilitate accomplishing product quality objectives, reduce the need for formal reviews (gates), and reduce the cost and time required to develop new products (Anderson, 1993; Cooper, 1995; Keller, 2001; Phillips et al., 1999; Zirger & Hartley, 1996). Moreover, scientists and engineers are expected to welcome the use of these teams, because cross-functional teams increase quality of work life (Cordero et al., 1998). See Table 3 for some advantages and disadvantages of cross-functional teams.

Traditional new product development is divided among functional groups (Cook, 1990; Cooper, 1994). Thus, scientists and engineers assume responsibility for only the technical task. In cross-functional teams, members of different functional groups work as a closely integrated cross-functional unit (Cooper, 1994; Cordero, 1999; Trygg, 1993). Thus, in addition to responsibility for the technical task, scientists and engineers share responsibility with other functions for the overall cross-functional team task (Hershock et al., 1994). Moreover, members are given enough autonomy to take ownership for the team task, have a clear understanding of the other member's interests, make decisions that take into account these diverse interests, and produce collective outcomes that add to more than their individual outcomes (Jassawalla & Sashittal, 1999; 2000).

To achieve efficiency in today's global economy, cross-functional teams may be globally distributed (Bartlett & Ghoshal, 1989). This means team members may also be cross-cultural and located far away from each other (Baba et al., 2001). These teams allow multinational companies to bring together highly qualified scientists and engineers from many parts of the world to work on a team. Fournier (2001), however, suggests that these teams are likely to fail if not managed properly, because it is difficult to make these teams work together as cohesive units. The cross-cultural nature of these teams is likely to bring different perspectives that may result in communication problems. For example, people around the world have different definitions of teamwork (Gibson & Zellmer-Bruhn, 2001), and different reasons for terminating a project (Balachandra, 1996). Moreover, having team members globally distributed makes face-to-face communications impossible on a daily basis, which means relying on impersonal and technologically mediated communication for task performance (Kayworth & Leidner, 2001-2002; Baba et al., 2001). To prevent team failure, Fournier (2001) suggests the following: make information explicit, since you 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.

Ancona & Caldwell (1992) have identified four boundary roles that scientists and engineers and other professionals can perform to help cross-functional teams become more effective. The *ambassador* role relates to helping link the team to outsiders. The *task-coordinator* role relates to helping coordinate the cross-functional task. The *scouting* role relates to helping scan the environment for relevant ideas. The *guarding* role relates to helping manage the flow of information to outsiders. The ambassador and the scouting roles appear to be boundary management roles (they help regulate external team interactions), while the task coordinator and the guarding roles appear to be information sharing roles (they help the team engage in external interactions)(Green et al., 2002).

Leading Scientists and Engineers

Traditional technical managers managed scientists and engineers through command and control systems: they provided direction, plans, procedures, and rules that defined work. Moreover, they made sure scientists and engineers followed directions and complied with these plans, procedures, and rules. In competitive R&D work, technical management is pushed down and more is done by scientists and engineers individually or in teams (Levi & Slem, 1995; Reynes, 1999; Waterman et al., 1994). Thus, technical managers lead scientists and engineers: they assign scientists and engineers broad objectives, and create a work climate that helps them define and control their work (Anderson, 1993; Cordero, 1999; Hammer & Champy, 1993; Hershock et al., 1994; James, 2002; Jassawalla & Sashittal, 2000; Petroni, 2000; Rosenbaum, 1990; Wageman, 1997).

Technical managers perform two important roles: the catalyst role and the captain role (Farris, 1988). Technical managers perform the catalyst role by providing scientists and engineers a stimulating work environment that challenges and empowers scientists and engineers, provides clear task objectives, and allows them to grow and develop. Technical managers perform the captain role by directing the work of scientists and engineers. The more technical managers act as catalysts, however, the less they are required to act as captains, because a stimulating work environment substitutes for the need to direct the work of scientists and engineers (Cordero et al., 2002).

To succeed in today's highly competitive R&D environment, technical managers shift from the *command and control* approach to the *leadership* approach (Hammer & Champy, 1993; James, 2002; Jassawalla & Sashittal, 2000). Thus, technical managers shift from the performance of the *captain* role to the performance of the *catalyst* role.

Administrative, people, and technical skills are important for performing the catalyst role (Cordero et al., 2002) and for leading scientists and engineers. 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

Scientists and engineers are knowledge workers, and knowledge is a key source of competitive advantage (Mandel and Hof, 2001). There are two types of knowledge: explicit knowledge and tacit knowledge (Hitt et al., 2000; Nonaka & Konno, 1998). Explicit knowledge can be transmitted verbally or through the written word; tacit knowledge is personal and experiential and is better transmitted through joint activities. Moreover, both types of knowledge can reside in the individual and the organization. In today's business environment, R&D laboratories gain competitive advantage by managing both types of knowledge, but in particular, tacit knowledge (Hitt et al., 2000).

Armbrecht et al. (2001) find that the two primary factors enabling knowledge management in technical organizations are culture and structure, with information technology being the secondary factor. 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 (1999) makes several useful suggestions for successful knowledge management. A sample of these suggestions follows: help 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 sharing knowledge.

For example, Sakkab (2002) discusses how P&G has twenty chartered communities of practices (natural knowledge communities) in areas such as biotechnology/life sciences, fiber, microbiology, and robotics. Each of these communities is sponsored by an R&D vice-president, has a budget, and uses different media to share knowledge. Some of the large communities even have full time staff.

Demographic Diversity

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 (Cordero et al., 1996). This increased demographic diversity creates opportunities and challenges for R&D laboratories, particularly when one considers the increased importance of teamwork within these laboratories.

Three reasons are frequently given for the need to manage demographic diversity (Ely & Thomas, 2001). These are facilitating creativity and decision-making by using demographic diversity to bring different perspectives to the task; gaining market 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 by bringing different perspectives to the task, diversity facilitates creativity and decision-making, and, therefore, morale (Cordero et al., 1996; Ely & Thomas, 2001; Pelled & Adler, 1994). The literature, however, also provides evidence that demographic diversity can hurt creativity and decision-making, and, therefore, morale by increasing conflict (Cordero et al., 1996; Tsui et al., 1992). To minimize conflict and obtain the benefits of demographic diversity, experts provide the following advice: training and education programs, diversity-friendly organizational policies, mentoring programs, and equal opportunity career development programs (Wentling & Palma-Rivas, 1998).

Demographic diversity is sometimes the result of scientists and engineers involved in multinational R&D programs. A recent study (Ohba, 1996) suggests several strategies for facilitating the work of scientists and engineers temporarily in a foreign culture: showing signs of respect for their home culture, following home country labor regulations, and creating an environment more like the home country.

Electronic and Other Technologies

The task of scientists and engineers relies heavily on the flow and analysis of information, and electronic technology can be used to direct the flow of and to analyze information. See Table 4 for some advantages and disadvantages of electronic technology.

The Internet is a new tool that dramatically increases the speed and dramatically lowers the cost of communication (Mandel & Hof, 2001). Thus, the Internet has the potential to dramatically increase the performance of scientists and engineers. A recent study argues that scientists and engineers are already taking advantage of this tool. Scientist and engineers spend an average of 66 minutes per day using the Internet to purchase and sell lab equipment, to purchase business travel and accommodations (Rozgus, 2000; Studt, 2000), and for other purposes discussed below.

They use the Internet to facilitate the product development process. For example, they use a Web-based product development system to provide a central repository for all project-related information and to provide different applications for the different stages and gates (Dvorak, 2001; Hamilton, 2001; Howe et al., 2000). Moreover, they and other project members (which may include customers and world-wide suppliers) can continually update and access relevant 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 (Keenan, 2001). As a result, the quality of new products increases, and their development time and cost decrease (Beckert, 2000; Sweeney, 1999).

They use a Web-based database to enable knowledge management (Mandel, 2001). For example, they use an online database to search for existing technical solutions to technical problems in other areas of the organization (Echikson, 2001). Having such an on-line database, however, is not sufficient to guarantee that scientists and engineers will exchange technical knowledge successfully. Thus, 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 knowledge to the database and to those who use this knowledge (Ewing, 2001).

Scientists and engineers also use software systems such as computer-aided engineering (CAE) and computer-aided design (CAD) in the product development process. These software systems allow scientists and engineers to virtually test the performance of different designs, eliminating the need for building physical models, and, therefore, reducing product development time and cost (Schilling & Hill, 1998). Scientists and engineers, however, do not appear to use these software systems very effectively (Eisenhardt & Tabrizi, 1995). For example, Kessler & Chakrabarti (1999) found that CAD systems tended to increase product development time, especially for radical innovations that are more dependent on creativity than on mathematical solutions and old designs. In contrast, Robertson & Allen (1993) have found a positive relationship between the use of CAD systems communication facilities (i.e., to transfer files) and engineering performance.

Some very recent developments help chemists, and pharmaceutical and material scientists increase the number of compounds available and reduce development time and cost. For example, to help these scientists decide what compounds to create and evaluate, molecular modeling can be used (Holland & Mitchell, 1999). Then, combinatorial chemistry and high-throughput screening can be used to create and evaluate many different chemical and material compounds in the laboratory (Anonymous, 2000; Holland & Mitchell, 1999). Moreover, automation and robotics allow the creation and evaluation of these compounds to operate unattended, and the use of advanced data handling techniques help keep track of all the information generated by the creation and evaluation of these compounds (Jansen). These new developments, however, are not without problems. Because these developments are complex, a significant problem appears to be downtime (Jansen).

Outsourcing

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 (Anonymous, 1998; Rothstein, 1998). In this way, organizations that adequately 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 (Quinn, 2000; Studt, 2001). Moreover, outsourcing allows in-house staff to become part of a wider "invisible college" within the R&D community (Howells, 1999). Finally, Jarmon et al. (1998) have found that the performance of contract scientists and engineers rivals that of permanent staff. Outsourcing, however, prevents the experience and expertise acquired by contractors while working for the organization from entering the organization's memory (Rothstein, 1998). Table 5 shows some of the advantages and difficulties that outsourcing brings to the management of scientists and engineers.

CONCLUSIONS

We know a great deal about managing scientists and engineers to achieve high levels of performance, satisfaction and retention. Badawy's (1988) review identified many important factors, and our review of the literature since then identified several others. We found some changes in the ways scientists and engineers are currently managed in the four areas reviewed by Badawy: human resources planning, rewarding scientists and engineers, appraising the performance of scientists and engineers, and career management. Moreover, we found six new developments affecting the way scientists and engineers are managed: cross-functional teams, leading scientists and engineers, knowledge management, demographic diversity, electronic and other technologies, and outsourcing.

Our review of the literature leads us to make suggestions for the ways in which scientists and engineers *should* be managed. We have summarized these suggestions in Table 6 for each of the ten areas of our review. Some of these suggestions are quite 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 scientists and engineers. Clarke (2002) suggests that there are two obstacles preventing this from 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, and (2) even if some scientists and engineers also have the potential to develop leadership skills, they are often promoted into management before they have enough opportunities 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.

REFERENCES

Allen, T.J. & Katz, R. "Age, Education, and the Technical Ladder." *IEEE Transactions on Engineering Management*, Vol. 39, No. 3, 1992, pp. 237-245.

Allen, T.J. & Katz, R. "The Dual Ladder: Motivational Solution or Managerial Delusion?" *R&D Management*, Vol. 16, No. 2, 1986, pp. 185-197.

Alpert, M. "The Care and Feeding of Engineers." *Fortune*, September 21, 1992, pp. 87-95.

Amabile, T.M. "How to Kill Creativity." *Harvard Business Review*, October 1998, pp. 77-87.

Ancona D. & Caldwell D. "Bridging the Boundary: External Activity and Performance in Organizational Teams." *Administrative Science Quarterly*, Vol. 37, 1992, pp. 634-665.

Anderson, R.E. "HRD's Role in Concurrent Engineering." *Training and Development*, June 1993, pp. 49-54.

Anonymous "Temporary R&D Employees in Unique Roles at DuPont and Henkel." *Chemical & Engineering News*, Vol. 72, No. 9, February 28, 1998, pp. 26-27.

Anonymous "Advances in Catalysts." *A Chemical Week Associates Custom Publication*, September 13, 2000, pp. 60.

Armbrecht Jr., F.M.R., Chapas, R.B., Chappelow, C.C., Farris, G.F., Friga, P.N., Hartz, C.A., McIlvaine, M.E., Postle, S.R., & Whitwell, G.E. "Knowledge Management in Research and Development." *Research-Technology Management*, Vol. 44, No. 4, July-August 2001, pp. 28-48.

Aryee, S. & Leong, C.G. "Career Orientations and Work Outcomes Among Industrial R&D Professionals." *Group and Organizational Studies*, Vol. 16, No. 2, June 1991, pp. 193-205.

Baba, M, Alcordo, T., Britt, D., Champieux, R., Gluesing, J., Harris, K., McKether, W., & Ratner, H. "The Development of Globally Distributed Teams: An Ecological Approach." *Working Paper*, July 24, 2001.

Badawy, M.K. "What We Have Learned About Managing Human Resources." *Research-Technology Management*, September-October 1988, pp. 19-35.

Balachanra, R. "A Comparison of R&D Project Termination Factors in Four Industrial Nations." *IEEE Transactions on Engineering Management*, Vol. 43, No. 1, February 1996, pp. 88-96.

Bailyn, L. "The Hybrid Career: An Exploratory Study of Career Routes in R&D." *Journal of Engineering and Technology Management*, Vol.8, 1991, pp. 1-14.

Bartlett, C.A., & Ghoshal, S. *Managing Across Borders*. 1989, Harvard Business School Press, Boston, MA.

Baugh, S.G. & Roberts, R.M. "Professional and Organizational Commitment Among Engineers: Conflicting or Complementary?" *IEEE Transactions on Engineering Management*, Vol. 41, No. 2, May 1994, pp. 108-114.

Beckert, B.A. "Collaborative Product Development: What's in it for You?" *Computer-Aided Engineering*, Vol. 19, No. 11, November 2000, pp. 32.

Braham, J. "Employers Demand New Skills." *Machine Design*, September 24, 1992, pp. 42-47.

Chen, C.C., Ford, C.M., & Farris, G.F. "Do Rewards Benefit the Organization? The Effects of Reward Types and the Perceptions of Diverse R&D Professionals." *IEEE Transactions on Engineering Management*, Vol. 46, No. 1, 1999, pp. 47-55.

Clarke, T.E. "Why Do We Still Not Apply What We Know About Managing R&D Personnel?" *Research-Technology Management*. March-April 2002, pp. 9-11.

Cook, W.J. "Ringing in Saturn." *U.S. News & World Report*, October 22, 1990, pp. 51-54.

Cooper, R.G. "Third Generation New Product Processes." *Journal of Product Innovation Management*, Vol. 11, 1994, pp. 3-14.

Cooper, R.G. "Developing New Products on Time, in Time." *Research-Technology Management*, September-October, 1995, pp. 49-57.

Cooper, R.G., Edgett, S.J., & Kleinschmidt, E.J. "Optimizing the Stage-Gate Process: What Best-Practice Companies Do." *Research-Technology Management*, September-October 2002, pp. 21-27.

Cordero, R., Farris, G., & DiTomaso, N. "The Technical Supervisor as Captain and Catalyst." *Proceedings of the 2002 International Engineering Management Conference*, Cambridge, U.K., August 2002.

Cordero, R. "Developing the Knowledge and Skills of R&D Professionals to Achieve Process Outcomes in Cross-functional Teams." *The Journal of High Technology Management Research*, Vol. 10, No. 1, 1999, pp. 61-78.

Cordero, R., Farris, G.F., & Ditomaso, N. "Technical Professionals in Cross-Functional Teams: Their Quality of Work Life." *Journal of Product Innovation Management*, Vol. 15, 1998, pp. 550-563.

Cordero, R., DiTomaso, N. & Farris, G.F. "Gender and Race/Ethnic Composition of Technical Work Groups: Relationship to Creative Productivity and Morale." *Journal of Engineering and Technology Management*, Vol. 13, 1996, pp. 205-221.

Cordero, R. "The Measurement of Innovation Performance in the Firm: An Overview." *Research Policy*, Vol. 19, No. 2, 1990, pp. 185-192.

Despres, C. & Hiltrop, J.M. "Compensation for Technical Professionals in the Knowledge Age." *Research-Technology Management*, September-October 1996, pp. 48-56.

Dvorak, P. "How to Conduct Projects on Line." *Machine Design*,
Vol. 73, No. 14, July 26, 2001, pp. 106-108.

Echikson, W. "When Oil Gets Connected." *Business Week*, December 3, 2001, pp. EB28-EB30.

Eisenhardt, K.M. & Tabrizi, B.N. "Accelerating Adaptive Processes: Product Innovation in the Global Computer Industry." *Administrative Science Quarterly*, Vol. 40, 1995, pp. 84-110.

Ely, R.J. & Thomas, D. A. "Cultural Diversity at Work: The Effects of Diversity Perspectives on Work Group Processes and Outcomes." *Administrative Science Quarterly*, Vol. 46, 2001, pp. 229-273.

Ewing J. "Sharing the Net." *Business Week*, March 19, 2001, pp. EB36-EB38.

Farris, G.F. "Technical Leadership: Much Discussed but Little Understood." *Research-Technology Management*, March-April 1988, pp. 12-16.

Fournier, R. "Teamwork is the Key to Remote Development." *Info World*, March 5, 2001, pp. 48-50.

Geraci, J. "Real Managers Don't Boss." *Research-Technology Management*, November-December 1994, pp. 12-13.

Gibson, C.B. & Zellmer-Bruhn M.E. "Metaphors and Meaning: An Intercultural Analysis of the Concept of Teamwork." *Administrative Science Quarterly*, Vol. 46, 2001, pp. 274-303.

Gomez-Mejia, L.R., Balkin, D.B., & Milkovich, G.T. "Rethinking Rewards for Technical Employees." *Organizational Dynamics*, Vol. 18, No. 4, 1990, pp. 62-75.

Green, S.G, McComb, S.A., & Compton, W.D. "Context & Boundary Interactions in Cross-Functional Teams." Working Paper, Purdue University, 2002.

Hamilton, S. "A Better Way to Manage Product Development." *Machine Design*, Vol. 73, No. 16, August 23, 2001, pp. 80-86.

Hammer M. & Champy, J. *Reengineering The Corporation*. 1993, HarperCollins: New York.

Hammonds, K.H., Furchgott, R., Hamm, S., & Judge, P.C. "Work and Family." *Business Week*, September 15, 1997, pp. 96-99.

Hershock, R., Cowman, C.D., & Peters, D. "FROM EXPERIENCE: Action Teams that Work." *Journal of Product Innovation Management*, Vol. 11, 1994, pp. 95-104.

Hitt, M.A., Ireland, R.D., & H. Lee, "Technological Learning, Knowledge Management, Firm Growth and Performance: An Introductory Essay." *Journal of Engineering and Technology Management*, Vol. 17, 2000, pp. 231-246.

Holland, J. & Mitchell, T. "Chemists Harness IT to Organize Data and Optimize Leads." *R&D Magazine*, September 1999, pp. 23-24.

Howe, V., Mathieu, R.G., & Parker, J. "Supporting New Product Development with the Internet." *Industrial Management + Data Systems*, Vol. 100, No. 6, 2000, pp. 277-284.

Howells, J. "Research and Technology Outsourcing." *Technology Analysis and Strategic Management*, Vol. 11, No. 1, 1999, pp. 17-29.

Igbaria, M., Kassicich, S.K., & Silver, M. "Career Orientations and Career Success Among Research, and Development and Engineering professionals." *Journal of Engineering and Technology Management*, Vol. 16, 1999, pp. 29-54.

Jackson, L. "Flexible Career Development and Lifetime Learning." *Control Engineering*, December 1998, pp. 19.

James, W.M. "Best HR Practices for Today's Innovation Management." *Research-Technology Management*, January-February 2002, pp. 57-60.

Jansen, W.P. "Network Science." *http://www.netsci.org/science/screening/feature08.html.*

Jarmon, R., Paulson, A.S., & Rebne, D. "Contractor Performance: How Good are Contingent Workers at the Professional Level?" *IEEE Transactions on Engineering Management*, Vol. 45, No. 1, February 1998, pp. 11-19.

Jassawally, A.R. & Sashittal, H.C. "Building Collaborative Cross-functional New Product Teams." *Academy of Management Executive*, Vol. 13, No. 3, 1999, pp. 50-63.

Jassawalla, A.R. & Sahittal, H.C. "Cross-functional Dynamics in New Product Development." *Research-Technology Management*, January-February 2000, pp. 46-49.

Jassawalla, A.R. & Sashittal, H.C. "Strategies of Effective New Product Team Leaders." *California Management Review*, Vol. 42, No. 2, Winter 2000, pp. 34-51.

Katz, R. "Managing Careers: The Influence of Job and Group Longevities." In M.L. Tushman & W.L. Moore, eds., *Readings in the Management of Innovation*, 2nd Edition, 1988, Harper Business, N.Y.

Kayworth, T.R. & Leidner, D.E. "Leadership Effectiveness in Global Virtual Teams." *Journal of Management Information Systems*, Vol. 18, No. 3, Winter 2001-2002, pp. 7-40.

Keenan, F. "Opening the Spigot." *Business Week*, June 4, 2001,
pp. EB17-EB20.

Keller, R.T. "Cross-functional Project Groups in Research and New Product Development: Diversity, Communications, Job Stress, and Outcomes." *Academy of Management Journal*, Vol. 44, No. 3, 2001, pp. 549-555.

Kessler, E.H. & Chakrabarti, A.K. "Speeding Up the Pace of New Product Development, *Journal of Product Innovation Management*, Vol. 16, 1999, pp. 231-247.

Kim, Y. & Cha, J. "Career Orientations of R&D Professionals in Korea." *R&D Management*, Vol. 30, No. 2, April 2000, pp.121-137.

Kirchhoff, B.A. & Lyn, J.D. "Technological Entrepreneurship Education: Promise for the Future." Paper presented at *The 21st International Small Business Congress*, Jakarta, Indonesia, September 18-21 1994.

Kochanski, J. & Ledford, G. "How to Keep Me—Retaining Technical Professionals." *Research-Technology Management*, May-June 2001, pp. 31-38.

Kusunoki, K. & Numagami, T. "Inter-functional Transfer of Engineers in Japan: Empirical Findings and Implications for Cross-functional Integration." *IEEE Transactions on Engineering Management*, Vol. 45, No. 3, 1998, pp. 250-262.

LaVine, J.M. & Cassidy, "The One Sure Way to Land Your Dream Job." R. *R&D Magazine*, September 1999, pp. 14SE – 16SE.

Leibowitz, Z.B., Farren C., & Kaye, B.L. *Designing Career Development Systems*. 1986, Jossey-Bass, San Francisco.

Levi, D. & Slem, C. "Teamwork in Research and Development Organizations: The Characteristics of Successful Teams." *International Journal of Industrial Ergonomics*, Vol 16, 1995, pp. 29-42.

Mandel, M.J. & Hof, R.D. "Rethinking the Internet." *Business Week*, March 26, 2001, pp. 118-122.

Markham, S.K. & Aiman-Smith, L. "Product Champions: Truths, Myths, and Management." *Research-Technology Management*, May-June 2001, pp. 44-50.

Markham, S.K. & Griffin, A. "The Breakfast of Champions: Associations between Champions and Product Development Environments, Practices, and Performace." *Journal of Product Innovation Management*, Vol. 15, 1998, pp. 436-454.

McDermott, R. "Why Information Technology Inspired but Cannot Deliver Knowledge Management." *California Management Review*, Vol. 41, No. 4, Summer 1999, pp. 103-117.

McDonough III, E.F. "Investigating the Factors Contributing to the Success of Cross-functional Teams." *Journal of Product Innovation Management*, Vol. 17, 2000, pp. 221-235.

McKinnon, P.D. "Steady-State People: A Third Career Orientation." *Research Management*, January-February 1987, pp. 26-32.

Merton, R.K. *Social theory and Social Structure*. 1957, The Free Press, Glencoe Il.

Meyer, C. *Fast Cycle Time: How to Align Purpose, Strategy, and Structure for Speed*. 1993, The Free Press, N.Y.

Nochur, K.S. & Allen, T.J. "Do Nominated Boundary Spanners Become Effective Technological Gatekeepers?" *IEEE Transactions on Engineering Management*, Vol. 39, No. 3, August 1992, pp. 265-269.

Nonaka, I. & Konno, N. "The Concept of Ba; Building a Foundation for Knowledge Creation." *California Management Review*, Vol. 40, No. 3, Spring 1998, pp. 40-54.

O'Dell, C. "Team Play, Team Pay: New Ways of Keeping Scores."
Across the Board, November 1989, pp. 38-44.

Ohba, S. "Critical Issues Related to International R&D Programs." *IEEE Transactions on Engineering Management*, Vol 43, No. 1, February 1996, pp. 78-87.

Page, A.L. "Assessing New Product Development Practices and Performance." *Journal of Product Innovation Management*, Vol. 10, 1993, pp. 273-290.

Pelled, L.H. & Adler, P.S. "Antecedents of Intergroup Confict in Multifunctional Product Development Teams: A Conceptual Approach." *IEEE Transactions on Engineering Management*, Vol. 41, No. 1, 1994, pp. 21-28.

Perry, P.M. "Battle for the Best." *Research-Technology Management*, March-April 2002, pp. 1-5.

Petroni, A. "Myths and Misconceptions in Current Engineers' Management Practices." *Team Performance Management*, Vol. 6, 2000, pp.15-24.

Phillips, R., Nearley, K., & Broughton, T. "A Comparative Study of Six Stage-Gate Approaches to Product Development." *Integrated Manufacturing Systems*, Vol. 10, No. 5, 1999, pp. 289-297.

Quinn, J.B. "Outsourcing Innovation: The New Engine of Growth." *Sloan Management Review*, Summer 2000, pp. 13-28.

Ransley, D.L. & Rogers, J.L. "A Consensus of Best R&D Practices." *Research-Technology Management*, March-April 1994,
pp. 19-26.

Reimers, B.D. "Keep Talent from Taking Flight." *Network Computing*, August 6, 2001, pp. 42-45.

Reynes, R. "Training to Manage Across Silos." *Research-Technology Management*, September-October 1999, pp. 20-24.

Risher, H. "Compensating Today's Technical Professionals." *Research-Technology Management*, January-February 2000, pp. 50-56.

Robertson, D. & Allen, T.J. "CAD Systems Use and Engineering Performance." *IEEE Transactions on Engineering Management*, Vol. 40, No. 3, August 1993, pp. 274-281.

Rosenbaum, B.I. "How Successful Technical Professionals Achieve Results," *Research-Technology Management*, January-February 1990, pp. 24-26.

Roth, L.M. "A Critical Examination of the Dual Ladder Approach to Career Development." In M.L. Tushman & W.L. Moore eds., *Readings in the Management of Innovation*, 1988, 2nd ed., Harper Business, N.Y.

Rothstein, A.J. "Outsourcing: An Accelerating Global Trend in Engineering." *Engineering Management Journal*, Vol. 10, No. 1, March 1998, pp. 7-14.

Rozgus, A. "The Joys and Sorrows of Buying Online." *E-Business*, April 2000, pp. E4-E5.

Sakkab, N.Y. "Connect & Develop Complements Research & Develop at P&G." *Research-Technology Management*, March-April 2002, pp. 38-45.

Schilling, M.A. & Hill, C.W.L. "Managing the New Product Development Process: Strategic Imperatives." *Academy of Management Executive*, Vol. 12, No. 3, August 1998, pp. 67-81.

Schonberger, R.J. "Human Resource Management Lessons from a Decade of Total Quality Management and Reengineering." *California Management Review*, Summer 1994, pp. 109-123.

Studt, T. "R&D Outsourcing Ups and Downs." *R&D Magazine*, September 2001, p. 9.

Studt, T. "Researchers Integrate Internet Tools Into Their Work." *R&D Magazine*, June 2000, pp. E13-E14.

Sweeney, T. "R&D—Net Helps Ford, Bechtel to Innovate." *Internetweek*, October 25, 1999, pp. pg69-pg71.

Thompson, P.H. & Dalton, G.W. "Are R&D Organizations Obsolete?" *Harvard Business Review*, November-December 1976, pp. 105-116.

Triendl, R. "Rewarding Innovators." *Research-Technology Management*, November-December 1998, p. 4.

Trygg, L. "Concurrent Engineering Practices in Selected Swedish Companies: A Movement or an Activity of the Few?" *Journal of Product Innovation Management*, Vol. 10, 1993, pp. 403-415.

Tsui, A.S., Egan, T.D., & O'Reilly III, C.A. "Being Different: Relational Demography and Organizational Attachment." *Administrative Science Quarterly*, Vol. 37, 1992, pp. 549-579.

Valenti, M. "Teaching Tomorrow's Engineers." *Mechanical Engineering*, July 1996, pp. 64-69.

Wageman, R. "Critical Success Factors for Creating Superb Self-Managing Teams." *Organizational Dynamics*, Summer 1997, pp. 49-61.

Waterman, Jr. R.H., Waterman, J.A., & Collard, B.A. "Toward a Career Resilient Workforce." *Harvard Business Review*, July-August 1994, pp.87-95.

Wentling, R.M. & Palma-Rivas, N. "Current Status and Future Trends of Diversity Initiatives in the Workplace: Diversity Experts' Perspective." *Human Resource Development Quarterly*, Vol. 9, No. 3, Fall 1998, pp. 235-253.

Werner, B.M. & Souder, W.E. "Measuring R&D Performance—State of the Art." *Research-Technology Management*, March-April 1997, pp. 34-42.

Womack, J.P. & Jones, D.T. "From Lean Production to the Lean Enterprise." *IEEE Management Review*, Winter 1996, pp. 38-48.

Younger, J. & Sandholtz, K. "Helping R&D Professionals Build Successful Careers." *Research-Technology Management*, November-December 1997, pp. 23-28.

Zirger, B.J. & Hartley, J.L. "The Effects of Acceleration Techniques on Product Development Time." *IEEE Transactions of Engineering Management*, Vol. 43, 1996, pp. 143-152.

TABLE 1. WHAT BADAWY FOUND IN 1988

Topical Area	What he found
Human Resources Planning	Five different work roles are critical to the innovation process, each requiring different skills; different techniques are useful in hiring
Rewarding	Different extrinsic rewards are available, but intrinsic rewards appear more effective; motivating is not the same as manipulating; the needs of scientists are not the same as the needs of engineers
Appraising Performance	There are criteria for effective performance appraisals; there are many evaluation tools; appraising performance is difficult
Career Management	Thompson and Dalton (1976) have identified how careers develop in four stages; staff frequently faces a choice between two (technical and managerial) career paths

TABLE 2. CHANGES SINCE 1988

Topical Area	What we found
Human Resources Planning	Business, people, leadership, and other skills are required; roles are better understood; electronic technology is used in hiring
Rewarding	Intrinsic rewards remain most important; extrinsic rewards and team rewards are used more; quality of work life arrangements are introduced
Appraising Performance	Performance is appraised more formally and systematically; multiple appraisers (i.e., managers, peers) and metrics (i.e., objective, subjective) are used
Career Management	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
Cross-functional Teams	Cross-functional teams replace functional groups in many applications, some of these teams are globally distributed
Leading	Technical managers shift their main role from directing work to communicating and viding a stimulating work environment to achieve goals
Knowledge Management	Knowledge is managed for competitive advantage and knowledge communities are developed
Demographic Diversity	The technical workforce is demographically diverse; diversity is managed to avoid conflicts and obtain benefits
Electronic and Other Technologies	The Internet and other electronic technology now supplement more traditional means of handling and processing information and doing work
Outsourcing	R&D is increasingly being outsourced by contracting out projects in whole or in part, or by bringing in contract staff

TABLE 3. CROSS-FUNCTIONAL TEAMS

Advantages	Disadvantages
Facilitate accomplishing technical and business objectives, reduce project cost and time, increase quality of work life, provide cross-training	Difficult to implement and lead, increase required team member effort and cross-functional conflict, may lead team members to technical obsolescence

TABLE 4. ELECTRONIC AND OTHER TECHNOLOGIES

Advantages	Disadvantages
Facilitates accomplishing technical and business objectives, reduces project cost and time	Difficult to implement, limitations of current search tools to select usable information, security concerns, programmed analysis and design less suitable for radical innovations, increased downtime

TABLE 5. OUTSOURCING

Advantages	Disadvantages
Allows firms to subcontract routine and low value-added work, and to procure lacking technical skills not necessary to retain because of insufficient steady demand	Firms may weaken their core technical skills and may experience problems with secrecy, trust, and technical proprietorship Outsourcing relationship may fail if there is a lack of common interests, performance targets, and control systems between firm and contractors; if their cultures and product development data systems are incompatible; and if the firm attempts to micro-manage contractor and fails to share benefits contractor may bring by exceeding performance targets

TABLE 6. RECOMMENDED ACTIONS

Human Resources Planning

Scientists and engineers (S&E) should be hired 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 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 affecting S&E motivation 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 no 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 the Performance of Scientists and Engineers

As in 1988, performance appraisal continues to be a difficult and sensitive topic. Recent innovations such as broadbanding and 360 degree feedback have met with mixed success. Generally those S&E who did well under their previous systems have not welcomed the changes, while many others prefer the newer approaches to the traditional. 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 metrics of performance 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

Today's business environment is leading to reevaluation of the traditional assumption that all S&E will have lifetime careers with a single company. Layoffs by companies have been accompanied by 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 to make concerted efforts 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 their S&E who are oriented toward 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

Cross-functional teams offer several advantages, but 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. Cross-functional team 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 various technologies to facilitate communications among team members when they are not meeting face-to-face. Setting clear goals for team performance, especially moderate goals which 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

Today's 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. In most cases this can best be done by leading as a catalyst: creating a working environment which includes 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 skills and leadership skills as well as technical skills to equip S&E to work effectively in today's technical and business environments.

Knowledge Management

R&D laboratories can gain competitive advantage by managing knowledge effectively. This requires a culture that values not only creating, but also sharing knowledge. Companies can facilitate knowledge management by rewarding S&E for sharing knowledge, emphasizing team rewards as well as individual, 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

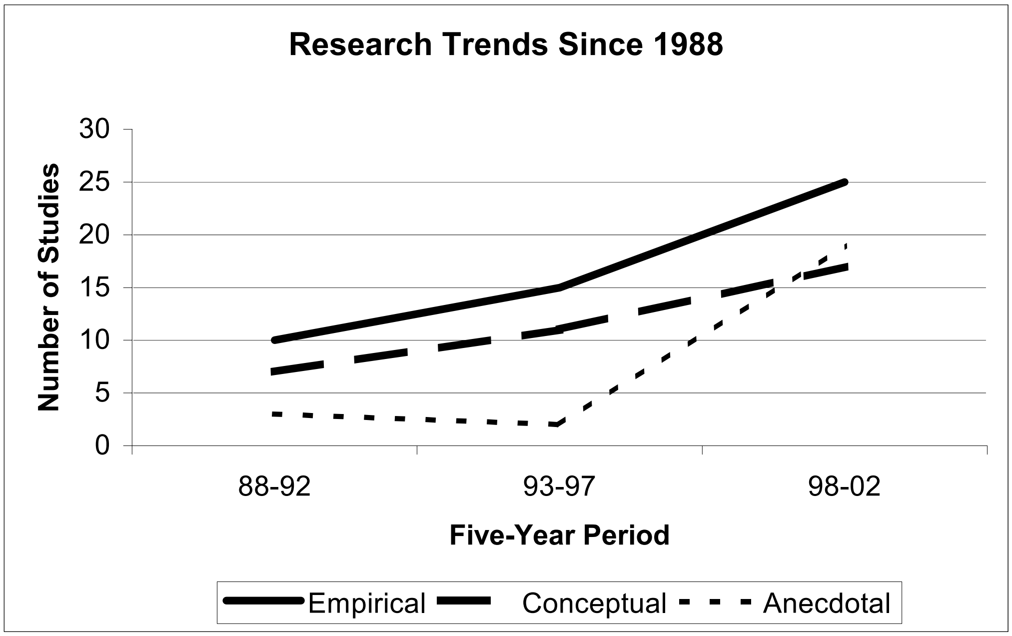
The technical workforce is increasingly diverse. Demographic diversity can facilitate performance and satisfaction by bringing different perspectives to the task or reduce performance and satisfaction by increasing misunderstandings and conflict. Actions which can be helpful include diversity training 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 which values diversity.

Electronic and Other Technologies

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 specialties. 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 today, since outsourcing offers cost advantages in certain situations. R&D is being 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. Outsourcing allows in-house S&E to interact with other S&E, but it can prevent the experience gained by contract S&E while 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.


Research Trends Since 1988
30
25
20
15
10
5
0
Number of Studies
88-92
93-97
98-02
Five-Year Period
Empirical
Conceptual
Anecdotal

ANNOTATED BIBLIOGRAPHY

Allen & Katz, 1992; 2199 technical staff; empirical. Ph.D.'s prefer the technical ladder more than those with less education and are less interested in commercial success. Those in the technical ladder are likely to become decoupled from the rest of the organization.

Allen & Katz, 1986; 2157 technical staff; empirical. 32.6% preferred the managerial ladder, 21.6% preferred the technical ladder, and 45.8% preferred to work in technically challenging projects irrespective of promotion. Preference for projects increases with age.

Alpert, 1992; anecdotal. The chief reward of engineers is the work itself. Brainstorming allows brilliant ideas to come forth. Concurrent engineering puts a premium on communication skills. Many companies have created parallel dual ladders in recent years.

Amabile, 1998; conceptual. 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.

Ancona & Caldwell, 1992; empirical. Study indicates that teams engage in vertical communications aimed at molding the views of top management; and horizontal communications aimed at coordinating work, obtaining feedback, and scanning the technical and market environments.

Anderson, 1993; anecdotal; HRM can help cross-functional team members cope with teamwork and diversity-related issues through training.

Anonymous, 1998; anecdotal. To lower costs and increase flexibility Dupont has put together R&D teams that rely heavily on both temporary and full-time employees. At times the number of contract or temporary workers has been 1/3 or more of the team.

Anonymous, 2000; anecdotal. High throughput screening techniques allow testing of large number of catalysts for a given reaction, reducing valuable development time and cost. The aim is to identify which catalysts should be further developed.

Armbrecht et al., 2001; 19 companies; empirical. Paper proposes a model of how knowledge flows in technical organizations. Model focuses on three principal enables of knowledge flow: culture, infrastructure, and technology. Culture and infrastructure are often linked.

Aryee & Leong, 1991; 165 technical staff; empirical. Subjects are either managerial or technical in their career aspirations. Managerials were more useful to company and found more job satisfaction. Technicals produced more scientific quality.

Baba et al., 2001; conceptual. Globally distributed teams not only require members from different national cultures to work together closely, but also require technologically-mediated communication for task accomplishment.

Badawy, 1988; conceptual. Summary of what is known about managing scientists and engineers. Identifies four categories of research: human resources planning, rewarding scientists and engineers, appraising the performance of scientists and engineers, and career management.

Balachandra, 1996; projects in four countries; empirical. Although there are common factors in the R&D project termination decision, there are some which are highly specific to the countries. Some of the differences are due to cultural differences.

Bailyn, 1991; empirical. Study examined 4 career routes in the R&D lab: the managerial route, the technical route, the route from project to project, and the technical transfer route. The study proposes the idea of a hybrid career for technical staff.

Bartlett & Ghoshal, 1989, Book. Identifies the types of organizations found in a global economy. The most effective type of organization combines global efficiency with local attention.

Baugh & Roberts, 1994; 114 technical staff; empirical. The relationship between organizational and professional commitment may be complementary rather than conflicting. High performance for individuals high in both commitments has been previously found.

Beckert, 2000; anecdotal. The increasing use of technological tools—including engineering software, even faster hardware, and now the Internet—adds another dimension to the product design process. This added dimension gets quality products to market faster and cheaper.

Braham, 1992; anecdotal. Engineers need more varied education and skills. For example, they need technical, cross-functional, teamwork, change management, and computer skills. Moreover, they need greater creativity and entrepreneurship, and a more global perspective.

Chen et al., 1999; 1000+ technical staff; empirical. Intrinsic rewards and salary increases provide benefits to an organization. Individual cash rewards provide the least benefits. Findings, however, vary for members of different ethnic groups and genders.

Clarke, 2002; conceptual. There is a gap between what we know and how we manage technical staff. Main reasons are: technical managers are selected mainly because of their technical competence, technical managers lack management training, and academics rather than technical managers write most articles in R&D management journals.

Cook, 1990; anecdotal. Concurrent engineering is difficult and time consuming at the start of the new product development process. Once the product reaches manufacturing, start-up is much faster because most problems have already been resolved.

Cooper, 1995; 103 product development projects; empirical. Projects that were both on time and fast-to-market were characterized by cross-functional teams, solid up-front homework before development, strong market orientation, quality of execution, and early product definition.

Cooper, 1994; conceptual. The third generation product development process represents a precarious balance between the need for thoroughness of action and complete information versus the need to move quickly. It is fluid, uses fuzzy gates, and is focused and flexible.

Cooper et al., 2002; 500+ companies; empirical. Article reports on some of the new practices companies have incorporated into their new product development process. Some of these are stage-gate practices.

Cordero et al., 2002; 2172 technical staff; empirical. Technical, people, and administrative skills help supervisors act as catalysts. People skills help, technical skills help marginally, and administrative skills mainly detract them from acting as captains.

Cordero, 1999; conceptual. For the technical staff to achieve outcomes that add value to the customer they need to work on cross-functional teams and develop process knowledge and skills by taking advantage of process-oriented career opportunities.

Cordero et al., 1998; 1714 technical staff; empirical. Technical staff working on project teams face greater job demands than positive job outcomes than those who don't. However, working on cross-functional teams seems to increase positive job outcomes more than job demands.

Cordero et al., 1996; 2331 technical staff; empirical. Creative productivity and morale appear higher in gender homogeneous work groups. The relationship of ethnic composition to creative productivity and morale, however, differs by ethnic subgroup.

Cordero, 1990; conceptual. The evaluation of innovation performance can bring benefits to technical firms. To obtain these benefits, managers need to approach this evaluation in a formal and systematic way. A model of innovation performance evaluation is proposed.

Despres et al., 1996; conceptual. 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.

Dvorak, 2001; anecdotal. It's not hard to imagine that entire design projects will eventually be conducted on line. The advantages of doing so include faster communications, transmissions, and minimal travel. Security, however, is a big concern.

Echikson, 2001; anecdotal. An example of how the intranet was used to post a technical solution to a technical problem in one area of an oil company, and how this solution was found and used successfully in another area of the company.

Eisenhardt & Tabrizi, 1995; 72 projects; empirical. Multiple design iterations, extensive testing, frequent project milestones, a powerful project leader, and a cross-functional team accelerate product development (PD). In contrast, supplier involvement, CAD, and overlapping project steps accelerate PD only in mature industries.

Ely & Thomas, 2001; non-technical staff; empirical. 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 was associated with performance.

Ewing, 2001; anecdotal. Share Net, an online database lets employees find expert advise within Siemens instantly. Advocates preach that the collective expertise of workers is a company's most precious resource, so managers need to tear down walls between departments and employees.

Farris, 1988; conceptual. Studies of technical leadership fall into three categories: those which studied leadership directly, those which studied characteristics of the organizational climate, and those which studied informal leadership functions critical for project success.

Fournier, 2001; anecdotal. Virtual projects allow companies to quickly assemble multitalented teams of professionals from anywhere in the world. To make these projects successful, it appears important to develop mutual trust and a common language to smooth communications.

Geraci, 1994; conceptual. A meaningful reward for a technical professional is specific recognition for specific achievements from their colleagues and managers.

Gibson & Zellmer-Bruhn, 2001; 107 individuals representing 52 teams; empirical. The study finds that people around the globe hold different definitions of teamwork. Thus, they are likely to have different expectations of how the team will be managed.

Gomez-Mejia et al., 1990; conceptual. Traditional pay systems aim to achieve internal equity and consistency across different employee groups. These systems fail to motivate the technical staff. Flexible pay systems, however, are based on the individual's contribution.

Green et al., 2002. empirical. Authors find two boundary activities in cross-functional teams. Boundary management activities—regulating external interactions and information management activities—engaging in external interactions.

Hamilton, 2001; anecdotal. A project Web site can provide a common workspace for team members. It's a central repository and access point for all project-related information. The secure site also provides an easy way (little training required) to manage and share information.

Hammer & Champy, 1993; Book. This is a best-seller that makes a strong point for organizing around processes rather than around functions. In contrast to TQM, reengineering is a radical redesign of organizational processes.

Hammonds et al., 1997; 1200 individuals at 55 companies; empirical.
In some companies, culture and strategy are designed to ease work-family tensions. In other companies, work has a negative impact on family life. Many see a conflict between family life and getting ahead.

Hershock et al., 1994; conceptual. 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.

Hitt et al., 2000; conceptual. This article explores the importance for firm competitiveness of technological learning and knowledge management.

Holland & Mitchell, 1999; Anecdotal. This article discusses two technologies useful for increasing the number of new drugs discovered and developed: combinatorial chemistry and high-throughput screening. It also discusses the contributions of robotic and molecular modeling.

Howe et al., 2000; Anecdotal. This paper discusses how the Internet can be used to help increase the effectiveness of each stage-gate during new product development.

Howells, 1999; conceptual. There has been significant growth in the amount of contracted out research in the advanced industrialized economies since the 1970's. Some would argue that a *core* and a *periphery* workforce is now appearing in the R&D workforce.

Igbaria et al., 1999; 78 technical staff; empirical. The dual career ladder is very limited and is not an effective device for managing R&D professionals. Security, service, and lifestyle career orientations are the most prevalent orientations among the R&D professionals surveyed.

Jackson, 1998; conceptual. Technical supervisors can revitalize their technical depth by moving back to the technical side instead of remaining in management. Flexible development is also needed because there are fewer managerial positions available now.

James, 2002; conceptual. There are four basis for sound technical human resource management practices: It's the work that motivates; several critical roles are essential for performance; ensure peer and organizational recognition; provide stimulating work environment.

Jansen; Anecdotal. Web page describing how to automate combinatorial chemistry and high throughput screening.

Jarmon R. et al., 1998; empirical. Managers in 6 high technology settings were surveyed about their overall perceptions of contractor performance. Respondents perceived contractors to rival comparable employees.

Jassawalla & Sashittal, 1999; 10 high technology companies; empirical. This article discusses characteristics of collaborative and successful teams: high level stakeness, high level transparency, high level mindfulness, and high level of synergy.

Jassawalla & Sashittal, January-February 2000; 10 high technology companies; empirical. To achieve collaborativeness and success, the cooperation of senior level management, cross-functional team (CFT) leaders, and CFT members is required.

Jassawalla & Sashittal, Winter 2000; conceptual. Effective new product development leaders: ensure commitment by team members; build information intensive environments; become facilitators, not directors; foster human interactions in teams; and focus on learning.

Katz, 1988; conceptual. To maintain adaptability and to keep technical staff responsive, what might be needed are career histories containing sequences of job positions involving new challenges and requiring new skills.

Kayworth & Leidner, 2001; 13 virtual teams; empirical. Findings suggest that the leadership roles of communications processor and social facilitator may be vitally important when groups are dispersed and linked through computer-mediated communication systems.

Keenan, 2001; anecdotal. Some manufacturing companies share digital designs simultaneously with suppliers worldwide. Every supplier can make changes immediately. All changes can be consolidated into a master Web file, and design problems discovered and corrected quickly.

Keller, 2001; 93 R&D groups; empirical. Functional diversity works its beneficial effects on project performance due to having members with diverse backgrounds and areas of expertise, and diverse contacts with important external networks of information. Functional diversity, however, reduces group cohesiveness.

Kessler & Chakrabarti, 1999; 75 new product development projects; empirical. More frequent use of CAD systems tended to slow down innovations. This result is consistent with those who caution against the "technology fix" to execute the same old process.

Kim & Cha, 2000; 1240 technical staff; empirical. Findings revealed five distinctive and independent career orientations: technical, manager, project, technical transfer, and entrepreneurial orientations.

Kirchhoff & Lyn, 1994; conceptual. The demands on the engineering profession today far exceeds the educational content of the typical specialized engineering undergraduate education that contains few components of marketing, finance, management, and business strategy.

Kochanski & Ledford, 2001; conceptual. Turnover is very costly for R&D laboratories. The *employee value proposition*—the total set of rewards that the company offers in exchange for employment and effort—is key to understanding turnover.

Kusunoki & Numagami, 1998; 213 technical staff; empirical. Inter-functional transfers are relatively frequent at Japanese companies (sample mean frequency = 2.67). These transfers are likely to create critical organizational capabilities for cross-functional integration.

LaVine & Cassidy, 1999; R&D satisfaction and salary survey; empirical. Some 29% of respondents found their jobs through word of mouth, 77% said they would use word of mouth if looking for a job. Of those involved in hiring, 54% use word of mouth to find candidates.

Leibowitz et al., 1986; book. Using combined consulting experience and case studies, authors provide a model for designing and implementing a robust organizational career development system.

Levi & Slem, 1995; 378 technical staff; empirical. Teams were viewed as effective and increasing in use, members enjoyed working in teams, and teams were seen as developing professional skills. Only about 1/3 of the employees viewed working on teams as helping their careers.

Mandel & Hof, 2001; anecdotal. 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.

Markham & Aiman-Smith, 2001; conceptual. The champion role is informal. The champion's critical contribution is generating needed project support form other people throughout the organization. Several myths and truths about champions are discussed.

Markham & Griffin, 1998; 381 technical staff; empirical. Forty percent of respondents indicate firm uses champions to lead projects even if projects are lead by a project manager or process owner. Moreover, champion impact on firm performance appears to be indirect.

McDermott, 1999; conceptual. Studies show that information technology (IT) usually reinforces an organization's norms about documenting, sharing, and using knowledge and ideas. Thus, IT has inspired the knowledge management vision, but it cannot bring it into being.

McDonough III, 2000; 112 technical staff; empirical. The study suggests that establishing clear unchanging goals, team leadership, and cooperation were the three most frequently cited reasons for cross-functional team success. Champions, however, were rarely cited.

McKinnon, 1987; 367 technical staff; empirical. Of those 265 with a clear career preference, 2/3 saw their career as a progression from one interesting project to another. The rest saw their career as movement up a managerial ladder, or as movement up a technical ladder.

Merton, 1957; Book. Of interest to us, book discusses how locals largely confine their interest to the community and are concerned with its problems. In contrast, cosmopolitans significantly extend their interest to the world outside and are concerned with world problems.

Meyer, 1993, Book. This book describes the fast cycle time product development organization and compares it with the traditional, functionally based product development organization.

Nochur & Allen, 1992; 285 technical staff; empirical. Formally designating technical staff as gatekeepers was only partially successful. Formal gatekeepers adopted more new technologies, but were not effective in transferring technologies to others.

Nonaka & Konno, 1998; Conceptual. There are two types of knowledge: explicit and tacit. Explicit knowledge can be expressed using normal channels of communication. Tacit knowledge is personal and difficult to express using normal channels.

O'Dell, 1989. Conceptual. Companies are using teams. Reward systems need to support teamwork. For example, companies can create pay for knowledge and skills plans, reward team performance, and create gain-sharing plans that reward company performance.

Ohba, 1996; conceptual. It is important to set up conditions that Tmaintain the physical and mental health of technical staff in international assignments, such as making the technical environment like the home country and showing respect for the home culture.

Page, 1993; 189 companies; empirical. Over 76% of companies now use cross-functional teams to develop new products. Moreover, technical staff spend about 55.8% of their time supporting product development. In decreasing order, the functional areas participating daily in product development are marketing, R&D, engineering, and manufacturing.

Pelled & Adler, 1994; conceptual. A review of the literature suggests that a cross-functional team functional diversity will increase its effectiveness but also, although less frequently, will increase turnover and lower effectiveness.

Perry, 2002; conceptual. Some companies do most of the hiring of experienced technical staff through the Internet. Some companies link their websites to job boards. The Internet, however, cannot do the whole job. For example, referrals are still used frequently.

Petroni, 2000; 376 technical staff; empirical. An inadequate reward system, an inadequate understanding of engineers' expectations, and the failure to differentiate between professionals and other workers are strongly associated with career dissatisfaction.

Phillips et al., 1999; six companies; empirical. This article compares the stage-gate approach in six companies. The use of cross-functional teams reduces the numbers of gates found.

Quinn, 2000; conceptual. 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.

Ransley & Rogers, 1994; empirical. Four respected consulting companies examined best R&D practices. The authors believe that common practices have broad applicability. Some of these common practices relate to managing technical staff.

Reimers, 2001; anecdotal. Turnover is very costly. Concern about quality-of-life issues, competitive salaries, occasional perks, and job security help organizations retain valuable information technology workers.

Reynes, 1999; anecdotal. Some companies have developed in-house training programs for technical managers. In general, communication skills are emphasized. Still unresolved, however, is how to assess the effectiveness and benefits of individual programs.

Risher, 2000; conceptual. A new model for compensating employees uses pay more assertively to foster desired behavior and to improve organizational and individual performance. This new model is well suited to an R&D environment.

Robertson & Allen, 1993; 75 technical staff; empirical. The use of CAD communication features (i.e., file transfer) is associated with engineering performance. The relationship between the use of CAD analysis features and engineering performance approaches significance.

Rosenbaum, 1990; conceptual. The authority of the non-supervisory technical staff derives from two sources: technical expertise and interpersonal competence. While they can survive on their technical competence early, their future depends on interpersonal competency.

Roth, 1988; 20 organizations; empirical. Dual ladders are currently popular to attract, retain, and motivate technical staff. Dual ladders, however, share some problems. These problems are the result of poor design, mismanagement, and the specific professional environment.

Rothstein, 1998; anecdotal & survey. Although short term contract work for engineers and several other professionals has been a staple for decades, the expanded nature of the trend tends to be oriented further up the tree toward more senior professionals. ASME survey supports statement.

Rozgus, 2000; R&D survey; empirical. Many scientists and engineers are finding that e-commerce helps them do a better job. They use the Internet to buy equipment and supplies, sell unused equipment, and hire new staff.

Sakkab, 2002; Anecdotal. This article describes how knowledge management is done at P&G. P&G has twenty chartered communities of practice.

Schilling & Hill, 1998; conceptual. Two important factors reducing cycle time and achieving customer satisfaction with new products is the involvement of executive champions and the use of CAD.

Schonberger, 1994; conceptual. Extensive changes in human resources management are required to sustain total quality management (TQM) and business process reengineering (BPR). These changes should neither precede not follow TQM and BPR, but should occur in concert.

Studt, 2001; anecdotal. Outsourcing of R&D is especially valuable to a company where no internal expertise exists and in situations where internal resources are strained and rapid to-market issues are critical for the enterprise survival. As in all things, the rule is moderation.

Studt, 2000; 1500+ readers respond to R&D survey; empirical. Technical staff spend an average of 66 minutes per day in the Internet. The three highest reasons for using the Internet were: to communicate using e-mail, and to search for product and technical information.

Sweeney, 1999; anecdotal. Companies such as Ford and Bechtel leverage the Internet to streamline product development, manage geographically dispersed teams, and reduce development time.

Thompson & Dalton, 1976. 200+ technical staff; empirical. Professional careers develop in four stages: apprenticeship stage, independent contributor stage, mentor stage, and sponsor stage. Each stage differs form others in the activities required, the relationships that must be developed, and the psychological demands it brings.

Triendl, 1998; anecdotal. At Sony, special bonuses for highly profitable patents are calculated on the basis of the revenues the patent generates for the company. There are no limits on the amounts of these bonuses.

Trygg, 1993; 109 business units; empirical. The most widely used approach to increase the efficiency and effectiveness of new product development is concurrent engineering. The key ingredient in concurrent engineering is cross-functional teams limited to 10 – 12 members.

Tsui et al., 1992; 1705 miscellaneous workers; empirical. Being different in gender has a more negative effect on attachment for men than for women. Being different in race has a more negative effect for whites than for nonwhites.

Valenti, 1996; survey; empirical. Distinguished academics and engineers have identified several key areas for engineering educators to focus on. These include the newer technologies as well as expertise in team leadership, financial planning, and other management skills.

Wageman, 1997; 43 teams; empirical. The quality of a team's design had a larger effect on its level of effectiveness than coaching. Also, good coaching had a more powerful effect on well-designed teams than on poorly designed ones.

Waterman et al., 1994; conceptual. The traditional covenant between employers and employees is null. Instead of the traditional focus on employment, the focus should now be on employability—having competitive skills required to find work when need it.

Wentling & Palma-Rivas, 1998; 12 diversity experts; empirical. The four strategies most frequently used for managing diversity were training and education programs, organizational policies, mentoring programs, and career development programs.

Werner & Souder, 1997; conceptual. Different metrics for measuring R&D performance are discussed.

Womack & Jones, 1996; conceptual. 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.

Younger & Sandholtz, 1997; study of technical staff; empirical. A study of Thompson & Dalton's four career stages suggests that the stages remain an effective way to describe careers in technical and other professions, and viewing the organization through the lens of these stages identifies a number of areas of concern for R&D groups.

Zirger & Hartley, 1996; 29 general manages of electronics firms; empirical. The degree of cross-functional representation on teams was significantly correlated to team performance. Similarly, projects that had more dedicated team members were higher performers.