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R&D Integration: How to Build a Diverse and Integrated Knowledge Community[1]

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Abstract

Stokes advocated the benefits of uniting basic and applied research as a way to facilitate research breakthroughs. Recently, the U.S. Department of Energy launched an initiative designed to foster better integration in research and technology development (R&D), such as the concurrent application of scientific and engineering knowledge. This paper suggests that in basic and applied research-- two arenas in the production of knowledge-- there are difficulties in integrating them because of two somewhat disparate barriers: (1) cognitive distance among the researchers and (2) structural differentiation in the idea innovation network. This paper discusses these two barriers in greater depth and explains why these barriers are increasing. The larger issue is to build a diverse and integrated knowledge community via the following kinds of mechanisms: complex charters, visionary team leadership, recruitment from diverse sources, multiple team and network integration mechanisms, and diverse sources of funding. These ideas emerge from not only the recent literature but more critically from a case study of a transformational research organization that built an international knowledge community in biomedicine, the Institut Pasteur.

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R&D Integration: How to Build a Diverse and Integrated Knowledge Community

1.0 Introduction

The growth in *research and technology development (*R&D) expenditures around the world has increasingly elevated the importance of technology management. However, despite the increases of R&D investment, the U.S. has also experienced a falling balance of trade in high technology sectors, causing concern among U.S. policymakers about maintaining America's global leadership in R&D and innovation [9]. One response to this problem has been increasing calls for better integration and coordination of basic and applied research.[2] These calls are now being pursued as part of the American Competitiveness Initiative and spearheaded within the U.S. Department of Energy (DoE) by Dr. Raymond Orbach in the DoE's Office of Science ([25]. But one might raise two questions about the pursuit of this policy: is this the right remedy and, if so, how best is it accomplished?

The answer to the first question depends upon how one defines the boundaries of the knowledge community. As we will discuss in greater detail, the boundaries of the knowledge community are best delineated by the technological regime or sector ([1]; Guerrieri and Tylecote, 1998; Malerba and Orsenigo, 1993 and 1997; Pavitt, 1984). Each sector includes six primary arenas of research--basic, applied, product development, manufacturing, quality, and commercialization--as defined in the idea innovation network [19], which builds upon the influential work of Klein and Rosenberg [26]. As R&D investment has grown and knowledge has become more complex, these arenas have become more differentiated, making the problem of their integration critical. [3]

Turning to the second question, the increasing differentiation of knowledge communities presents two significant obstacles that must be taken into account for any effort to increase R&D integration: (1) increasing cognitive distance between various disciplines created by occupational specialization [34], [46]; and (2) increasing structural differentiation among separate research organizations with distinctive cultures and desires for organizational autonomy. Both of these barriers present formidable obstacles to the creation of complex research teams and multiple networks, arguably the two key components for any knowledge community. Within this context, the challenge of integrating basic, applied and manufacturing research is exacerbated as the

[2] This notion of use-inspired research was most recently suggested in Stokes' well-known work on the so-call Pasteur's quadrant [40].
[3] Not unexpectedly, this is part of the explanation for the rapidly expanding literature on inter-organizational relationships [18] and the growing interest in the concept of the knowledge community [4],

number and diversity of research teams increases either because the scientific problem involves systemic science (such as weather prediction or the exploration of space) or the product is quite complex with a variety of technologies involved (such as airplanes, cars, and more generally technology systems)[4].

As we argue in this paper, the choice of solution then requires that research managers and policy makers must address these two obstacles, namely cognitive distance and structural differentiation. Based on an in-depth case study of a research organization that built a knowledge community in biomedicine, as well as a review of the existing literature, this paper argues that the following five mechanisms are best geared to overcoming these obstacles:

1. broad scope charter that focuses on the entire knowledge community
2. visionary team leadership;
3. recruitment from diverse sources, both nationally and internationally
4. intellectual and emotional integration mechanisms;
5. diverse sources of funding.[5]

In this paper, we discuss these mechanisms in detail and highlight how they might be used in creating a knowledge community. In doing so, the paper has two primary objectives. The first objective of this paper is explaining how knowledge growth has changed the way in which knowledge is produced and documenting this with a major European study [43]. The key conclusion is American firms have not responded well as evidenced by the decline in American trade balances in the high technology sectors. The solution to this problem, as well as the second objective of the paper, is the building of a diverse and integrated knowledge community within and across different sectors and sometimes across them. In this manner, it is possible to overcome the obstacles to R&D integration and more effectively realize the benefits of increase R&D investment. It is these issues to which we now turn.

2.0 The Paradox of Increased R&D Expenditures and the Decline in American Competitiveness

Despite America's leadership position in R&D investment and innovation, there has been increasing concern about the ability to maintain competitiveness in an increasingly competitive global R&D context. Over the past twenty years, R&D investment has significantly increased in

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[11], [28], [29], [32], [33], [35], [38].

4 In general, these illustrate what might be called broad scope research projects [21].

5 Several of these ideas have also been documented in the work of Judge, Fryxell, and Dooley, 1997; Kanter, 1988; Leifer et al., 2000. Likewise, the literature on the importance of cross-functional teams and cross-fertilization of communication for innovation is relevant, but usually the mechanisms for creating these teams and communication are not made apparent [22], [23], [30], [31], [41], [44].

a number of key countries. As Table one indicates, R&D investment in Japan has doubled since 1984 and now accounts for approximately 3 percent of the country's GDP, which has become a de facto national benchmark for many developed countries. In 2002, the European Commission agreed to devote at least 3 percent of GDP to R&D by 2010 [36]. While this may be unrealistic, it highlights the notion that R&D spending is recognized as a key factor for a vibrant, competitive research sector.

Table One: R&D Expenditures for Selected Countries in Constant Dollars (in billions)[a]

Year	United States	Japan	Germany	France	OECD
1984	$152	$53	$32	$23	$328
1989	$181	$74	$41	$28	$413
1994	$188	$78	$41	$31	$452
1999	$251	$96	$49	$31	$573
2004	$286	$105*	$54	$36	$643*

a. www.nsf.gov/statistics latest figures available in 2006

* 2003 is the latest figure available

Increases in R&D investment in the United States have kept pace with those of standard-bearer Japan, but a number of indicators suggest that simply increasing investment is not sufficient for maintaining American competitiveness. One indicator of the decline of American competitiveness is the number of non-American firms among the top 20 R&D spenders in 2003. Previously, the U.S. dominated this list but now only nine of the twenty are American firms. Four are Japanese, three are German, and two are Swiss while only one is British and one is Finnish. The twentieth firm, H-P had to spend 3.6 billion dollars in 2003 to qualify. This provides a strong indication of how globally competitive R&D has become.

Another indicator is the decline in the U.S. balance of trade, not just in the low-tech industries, but, more critically, in the high tech industries as well. If one just takes the 11 advanced technology sectors that the NSF tracks, in 2000 the United States still had a positive balance of trade of about 30 billion in current dollars. By 2004, the U.S. had a negative balance of trade of over 37 billion dollars in these same 11 sectors. In a number of key high-tech areas, American leadership has waned or is facing significant competition. For example, South Korea is now a major producer of RISC semiconductors, while Taiwan specializes in what are called boutique or designer chips. Further, India has made major advances in pharmaceuticals and Singapore hopes to build a successful biotech complex.

A further indicator is the erosion of the American leadership in the production of scientific knowledge, as measured by publications. The U.S. share of scientific and engineering papers published worldwide declined from 38 percent in 1988 to 31 percent in 2001. Europe and Asia are responsible for the bulk of growth in scientific papers in recent years. In fact, the U.S. output was passed by Western Europe in the mid-nineties and Asia's share of the total is rapidly growing.

These troubling indicators have not gone unnoticed. The Taskforce on the Future of American Innovation created by the Council on Competitiveness [9] issued the following recommendation:

> *Increase significantly the research budgets of agencies that support basic research in the physical sciences and engineering, and complete the commitment to double the NSF budget. These increases should strive to ensure that the federal commitment of research to all federal agencies totals one percent of U.S. GDP* (*Innovate America*, Council on Competitiveness, December 2004, p. 32).

In other words, given the competition over innovation, increases in R&D expenditures are not stopping as countries use each other as a standard of how much should be spent.

But we would argue that simply increasing the amount of money spent on R&D, and in particular industrial R&D, does not necessarily improve competitiveness. A recent Booz, Allen, Hamilton study of the top 1000 R&D spending companies finds that the amount of expenditure does not translate into increased profits and sales growth [16]. While various questions can be raised about the design of the research study[6], *the implication is the management of technology is the more critical problem, not the amount of investment.* Given the concern over American competitiveness despite increasing R&D investment over the past twenty years, we would argue that greater emphasis must be place on the management of technology. But how does one manage technology in the high tech sectors? To answer this question requires that we first understand the changing nature of the production of knowledge, as discussed in the introduction.

2.1 The Changing Nature of the Production of Knowledge

Over time, the annual increases in R&D investment have lead to paradigmatic

[6] Two primary criticisms are that the study: 1) included companies from all economic sectors, including those that spend little on R&D; and 2) did not allow for a long time delay characteristic of radical innovations.

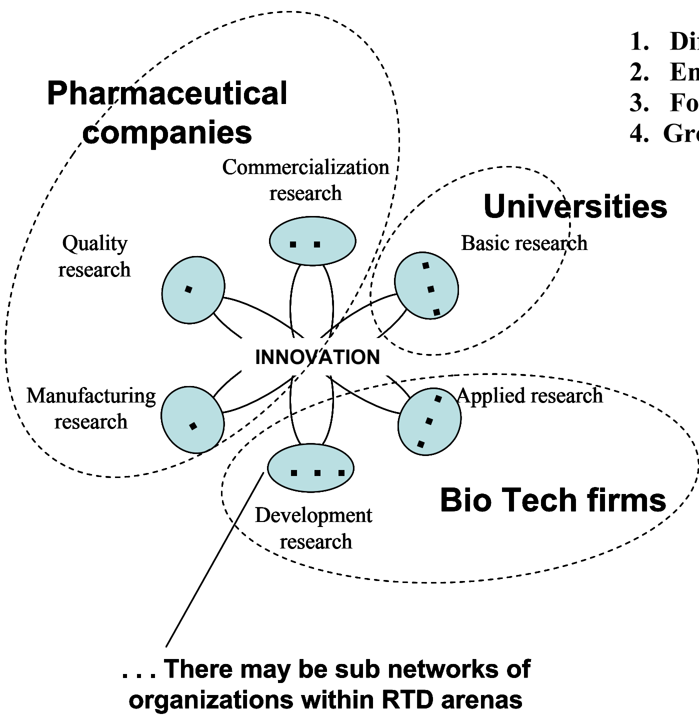
breakthroughs, which in turn have changed the production of knowledge in technological sectors, such as the biotech sector highlighted in Fig.1. [19] (2000) reported a considerable amount of evidence to support the general outlines of these evolutionary patterns. Further, support for these patterns have been advanced in the work of [14].

Figure 1

An Example of the Evolutionary Predictions in the Idea Innovation Network Theory [19]: Bio-tech/Pharmaceutical Sector

Evolutionary Predictions

1. **Differentiation of arenas**
2. **Emergence of small firms**
3. **Formation of networks**
4. **Growing strength of connections**



The growth in knowledge associated with an increase of R&D expenditures produces both occupational specialization and structural differentiation of research organizations into separate functional arenas. Occupational specialization becomes necessary because of the limits to how much individuals can learn. Similarly, structural differentiation is necessary because of the limits that organizations find in coordinating a diverse array of specialties [3], [18], especially if one desires intense and frequent interaction. The latter is necessary for the exchange of tacit knowledge, which becomes most critical when radical advances are made in any one of the six research arenas. When this occurs, there is much that is not understood and only frequent interaction will provide a strong enough connection so that the new knowledge can be transmitted successfully to the other arenas.

An exact and direct test of the idea innovation network was provided as part of a comprehensive European Union study [42], [43]. The authors examined the two technological regimes of telecommunications and pharmaceuticals in four Western European countries: Austria, Finland, Germany and the Netherlands. With a research team for each country that knew the language, the culture, and the history, the teams studied the changes that occurred in the idea innovation networks within each of these two sectors in each of the four countries given either a major set of scientific advances or a number of technological breakthroughs particularly over the period of 1985-2000.

What is especially interesting about van Waarden and Oosterwijk study [43] is that growth in knowledge in the pharmaceutical case occurred because of paradigmatic breakthroughs in basic science (molecular biology, genetics) and applied research and especially in the development of a number of new tools grouped around the idea of bio-technology, making applied research and product development important arenas. In contrast, the growth in knowledge in the telecommunications case represented the development of a number of technological breakthroughs including digital rather than analog transmission, the movement to network architecture, and the use of optical fiber cables that could handle large volumes of data transmission, making both quality and commercialization research the more critical of the six arenas [42].

Most of the predictions in the Hage and Hollingsworth theory [19] were supported in van Waarden and Oosterwijk study [43]. For example, a number of new firms for services and equipment emerged in telecommunication and were internationalized. While concentration in those sectors that required large capital investments did occur, the major players largely outsourced various activities. Further, the telecommunications industry largely withdrew from basic and applied research altogether. These research arenas moved into the universities and specialized research institutes, depending upon the particular country and its historical patterns. As the idea innovation network predicts, functional differentiation of research did occur. Finally, van Waarden and Oosterwijk [43] document that there is also now much more cooperation among researchers from different companies who now must join forces on particular projects.

The increases in the complexity of the idea innovation network were particularly striking in the telecommunications sector [42]. The improvement from the combination of digital, network structure, and optic fibers led to a proliferation of end products, linkages between different systems, and the blurring of the sector boundaries, especially between the computer science, telecommunications, and multi-media industries. Interestingly, some industrial products have become sectors in themselves, such as the mobile phone. This blurring is less apparent in biotech, but it is occurring as well.

Another prediction of the theory is the development of networks connecting smaller organizations with the larger ones. Sub-networks developed in the following arenas of the telecommunications regime: specialized research, marketing, physical infra-structure of the networks, manufacturing of end-line equipment, and managing of call centers. A particularly interesting development is the telecommunications manufacturers organizing mobile operating and business equipment, and customers in international user-groups where networks of product managers, marketers, users and researchers discuss problems. In other words, commercialization research has become an extremely important part of the strategy for product innovation. Much the same story exists in the biotechnology and pharmaceutical sector.

One of the more interesting findings in the van Waarden and Oosterwijk study [43] was that the increased scientific presence in these industries led to the production of basic knowledge or research itself becoming more differentiated. This substantiates perhaps one of the most important insights of the theory of the idea innovation network, that is, the differentiation of arenas, including not just product development but also the scientific basis of product innovation.

Another finding was the internationalization of the idea innovation networks, with differentiation by country. Most of this specialization is occurring either at the beginning of the idea innovation network or at the end. Another important finding is that the main innovation networks have been differentiated into sub-networks within specific arenas, which have become interdependent as well, creating a complex web of networks within each technological sector. A parallel process has occurred with the supply chains of the major equipment suppliers who have surrounded themselves with many suppliers and have conducted joint research with them. In telecommunications, the major players are outsourcing manufacturing, starting with accessories and parts, then whole products and finally even the assembly work. The extreme case is Nokia which now specializes in research, software production, product design and brand management. Actual production is outsourced, and 30 percent of the Nokia workforce world wide is in research in various arenas.

The research findings from the four European countries provide considerable evidence for the predictions about the changes in the production of knowledge. These changes make it more and more imperative that managers of technology be concerned about the integration of basic, applied and manufacturing research. In the following two sections, we turn to the two primary obstacles facing technology managers that have been heightened by the changes in the production of knowledge.

2.2 The Problem: Differentiation in the Idea Innovation Network

Correctly recognizing the causes of the problem of a decline in American competitiveness requires that we carefully delineate the boundaries of the knowledge production system and thus the boundary of the relevant knowledge community. If drawn too narrowly, then either the wrong remedy or an incomplete one might be chosen. We propose that the only satisfactory definition of the boundaries are delineated by the technological regime or sector [1], [17], such as:

Knowledge community $_{df}$ ≡ all the research teams, organizations and research networks within the same technological sector.

Fig. 1 provided a good example of how the boundaries around the knowledge community in the bio-tech/pharmaceutical technological regime would be drawn. The definitions for research teams and research networks are provided in our discussion of potential solutions. However, our task in this section is to justify this particular definition for a knowledge community.

As can be seen in Fig. 1, we argue that the knowledge production system involves six arenas, some of which may be differentiated from others [19], The familiar areas are basic research, applied research, prototype development, manufacturing research, and commercialization research, as described by [26]. They argued that these research areas should not be approached in a linear fashion since a good idea might originate in any one of these five and then move backwards and forwards with multiple feedbacks among the different research areas, hence the adoption of the network structure. In their work, ideas bounce back and forth in some approximation to a research network rather than the older model of a linear chain, i.e. from basic research through to commercialization. Because it is a network, the boundaries of the definition of the knowledge community have to be drawn so that basic science is connected to the research on the commercialization of industrial products. Hage and Hollingsworth [19] added a sixth arena, quality research, and generalized these to the level of arenas involving one or more research organizations at the technological sector level. The six arenas are defined further in Appendix A.

With this definition of a knowledge community, one can understand the community-based model of knowledge creation, such as the one documented in the development of the Linux kernel. This perspective broadens both the concept of community of practice [6] and of knowledge communities [32] to include more kinds of research teams, organizations and networks. Indeed, the original insight of Kline and Rosenberg [26] is that a good idea for innovation could occur in any one of these areas and therefore measuring the added value of investments in R&D requires tracing how these ideas move back and forth.

A number of advantages are derived from defining the boundaries of the knowledge community in this way. Three primary advantages are: (1) recognition of gaps in funding and in the supply of researchers; (2) identification of failures in the evolution of the knowledge community either in the emergence of new research organizations or their integration; and (3) inclusion of both market dynamics and competition between research organizations. One of the most important differences between the various sectors is that they vary in the amounts of R&D that are spent, as Pavitt (1984) has demonstrated. However, as soon as one recognizes that R&D is allocated across these six arenas, then the differences between sectors becomes magnified. Specifically, the relative importance (as measured by the amount of research dollars or scientists) of investment across the arenas may vary significantly among technological sectors. For example, the relative cost of quality control research is exceptionally high in pharmaceuticals because of the cost of clinical trials, which in the U.S. are about one billion dollars per drug, whereas the major expenditure in the automobile industry is the research for design and product development, again easily a billion dollars per design. Conversely, the design and product development in bio-tech is relatively small and the costs of improving quality control in the building of automobiles are small. In some sectors, the costs of basic and applied research is quite high, as for example the semiconductors industry; whereas the costs of such research in the software industry are relatively low in comparison.

An important implication for policy makers is that the focus should not be solely on how much is spent on research, but more critically how it is allocated across the six arenas that form the basis of the knowledge production system. The problem of declining competitiveness may not reflect a lack of R&D expenditures, but more rather a mis-allocation of existing investments across the different arenas. However, such an insight relies on understanding what arenas of the knowledge community are most critical for success in specific technological sectors at this point in time.

In a similar vein, the definition of the knowledge community as equivalent to the idea innovation network in the technological regime allows one to identify where either the processes of evolution might be occurring too slowly or have failed to occur. It is important to point out that the theory about the production of knowledge which underlies these ideas, which is described in the next sub-section, recognizes that the knowledge community changes across time. If new research organizations within a differentiated arena fail to develop, then this has an impact on the performance of the entire sector. For example, in Germany, small bio-tech companies did not emerge and, in response, the German government has made a concerted and successful effort to stimulate their formation.

More critically, the networks that provide the integration between arenas may develop slowly. Therefore, policy makers might want to encourage a more rapid development of them through the use of incentives or other measures. For example, American industry has been moving out of investing in basic research and concentrating on applied research and product development. As this evolution occurs, the issue is whether sufficient network connections exist between the basic research arenas in universities and national laboratories, to name two key types of research organizations, and industrial firms. As indicated below, the decline in American competitiveness in the high tech sectors suggests that the lack of network connections between arenas might be a key problem in the United States. As is evident, this view of the knowledge community avoids focusing on the corporate laboratory as the only way of combining the six arenas. The knowledge paradigm of organizations tends to only focus on the creation of knowledge within the firm and not the larger community in which the firm is embedded.

Another set of advantages with the idea innovation network definition of the knowledge community or knowledge production system is that it also encompasses market dynamics. As knowledge grows, different firms can select different market niches as others have observed. These same processes of seeking some comparative advantage also propel research organizations to differentiate themselves into more narrow aspects of some scientific problem. These processes of differentiation lead naturally into our next topic, namely the two primary obstacles to managing technology within a changing knowledge production system: cognitive distance and organizational culture.

2.3 The Problems: Cognitive Distance

Attempting to integrate basic, applied and manufacturing research confronts another problem at the level of the research project, that of cognitive distance. Nooteboom [34] argues that cognitive distance is the tendency for people who think differently to avoid communicating with each other, often to the detriment of innovation. Given the emphasis on the importance of cross-functional teams for innovation in the literature [5], [23], [27], [30], [31],[41], [44], the problem of how to overcome cognitive distance is an issue. This problem is made even more difficult when the research team must span two organizations because the organizational culture, as well as perhaps desires for autonomy, creates even more barriers to effective communication involving tacit knowledge.

None of these changes in the organization of the production of knowledge would necessarily creative difficulties, if in fact it was easy to integrate individuals who think differently about a problem via the internet, virtual teams and other communication channels that are popular these days. As long as the task is simply the transmittal of information rather than developing creative breakthroughs, then the internet is often efficacious. But when researchers who are thinking differently about a problem are brought together in the same research team, and especially if the team spans organizational boundaries with different cultures as increasingly it must if basic, applied and manufacturing research are to be combined, then the virtual team tends to break down. The research of Dougherty [5] demonstrates that various functional departments have different funds of knowledge or expertise and systems of meaning that create barriers. Beyond this, is the problem of honest communication. Peck [quoted in 22] defines a knowledge community as containing:

> "A group of individuals who have learned how to communicate honestly with each other, whose relationships go deeper than their masks of composure, and who developed some significant commitment to make others conditions their own."

As Nooteboom [34] argues the greater the cognitive distance the less the communication (regardless of method) between people and thus concern over the sheer volume of communication. However, if communication, especially effective communication occurs, then more radical innovation becomes possible. In subsequent research, Wuyts, Colmbo, Dutta, and Nooteboom [46] suggests that there is an optimum distance, but did not explore the specific problem of the integration of basic and applied research, nor, in particular, mechanisms of integration that would allow for radical innovation. Instead the search for the optimal balance between cognitive distance and radical innovation, deflects attention from the more interesting issue of mechanisms that can increase the extent and amount of radical innovation. Nor in the empirical research of Mohrman [32] on knowledge communities has there been much search for the mechanisms that generate knowledge communities. Yet, the heart of the matter for technology managers interested in making America competitive is to find mechanisms that create greater diversity and overcome the cognitive distances for effective knowledge communities that can produce radical innovation. The issue is not optimal balances but what can one do to have better integration of diverse knowledge communities that span organizational boundaries and unite basic, applied, and manufacturing research that are increasingly in separate research organizations.

3.0 The Solution: Mechanisms for Creating Diverse and Integrated Knowledge Communities

The previous section introduced a definition of the boundaries of the knowledge community. In that definition, the words research teams and research networks are indicated as the building blocks of the knowledge community. And if there is one key idea that flows through the various literatures on innovation--management, organizational, and scientific--, it is the importance of cross-fertilization of ideas, complex research teams and networks [5], [22], [23], [27], [30], [31], [41], [44]. But none of these literatures carefully defines their terms or, most critically, indicates what are the various mechanisms that encourage the development of cross-functional teams that have high rates of communication and are connected to extensive internal and external networks. Before we explore the various mechanisms that can stimulate the construction of the idea innovation network knowledge community from the ground up, let us first define our terms and then indicate how these concepts can be measured. The simplest component of a knowledge community is a team, which is defined as follows:

Research Team $_{df}$ ≡ all the individuals who work and interact together on a common research problem.

A number of individuals are attached to research groups but this does not mean that they necessary work together as a team. The issue is a common focus and the extent of the interaction. Teams come in variety of types and sizes. First, they vary in the degree of complexity defined either in terms of number of different occupational specialties, the measure that is used in the organizational literature on innovation or in the number of different functions (see for example [24]), the measure that is used in the management literature on innovation. Cross-functional teams usually have at least three functions: research, operations, and marketing but could involve all six of the arenas as outlined in Fig. 1. Complex cross-functional teams thus would involve both a count of the number of occupational specialties within each function and the number of functions. Teams can also vary in their size, depending upon the nature of the research problem. Some problems in science or industry are quite large and necessitate a program of research, which typically may consist of a number of research teams. For example, complex cross-functional teams are most appropriate for systemic science or complex products [21].

Research networks are quite similar to the concept of research team in the sense that they can come in a variety of shapes and sizes. Our definition for this idea is as follows:

Research Network $_{df}$ ≡ all the individuals, teams or organizations who are connected by some content such as a resource, in particular information or knowledge, and/or common focus.

Our main concern here is with internal and external networks that involve exchanges of information or knowledge within the same technological sector. The idea of research teams and research networks can be combined. but it would appear better to keep them separate especially as many of the measures of networks are based on exchanges of information, or patterns of consulting or inferences about this (e.g. co-authorship of papers or patents, see [45].

Jordan [21] has developed a research environment survey that offers a potentially important tool for measuring the foundations of the knowledge community in three distinctive approaches: (1) internal and external collaborations; (2) the strength of the collaboration via exchanges of technical ideas within and across disciplines; and (3) the number of research teams with varying degrees of complexity both internal and external to the research organization. The specific measures of the first approach are the amount of time spent in:

- internal communication;
- collaborations with others inside the research organization;
- collaborations with others outside the research organization.

This measures the nature of the research networks. Then the strength of the connectedness in these networks is measured by determining the frequency of the following:

- provides critical thinking;
- exchanges technical ideas with others in the same problem, functional or disciplinary area;
- exchanges technical ideas with others in different problem, functional or disciplinary areas.

The latter measure indicates how much cross-fertilization has occurred, an important idea in the management literature. They also provide a method for indicating how well integrated a research organization is. Finally, the number of research teams is measured in four ways:

- internal with three or less research specialties or disciplines;
- internal with four or more research specialties or disciplines;
- external with three or less research specialties or disciplines;
- external with four or more research specialties or disciplines.

These measures allow one to measure the complexity of the research team and at the same time examine the inter-organizational teams that exist.

With these definitions and measures in place, we turn to a closer look at specific mechanisms for facilitating the creation and growth of a knowledge community. The following mechanisms were identified from insights gained in using the research environment survey in a series of case studies, an in-depth case study of a transformation research organization that created a knowledge community in biomedicine (the Institut Pasteur), and from the literatures on organizational innovation and the management of innovation [23], [22]. Based on these various sources, we have identified the following mechanisms:

1. broad scope charter that focuses on the entire knowledge community;
2. visionary team leadership;
3. recruitment from diverse sources, national and international;
4. integration mechanisms of various kinds;
5. diverse sources of funding.

In subsequent sections, we discuss each mechanism in turn with the use of anecdotal illustrations from the Institut Pasteur case study. While many of the lessons of the Institut Pasteur are drawn from actions taken over a century ago, we argue that these lessons are well-suited for contemporary issues. Most importantly for our purposes, the actions taken by the leaders of the Institut Pasteur reflected thinking beyond the organizational boundaries with the objectives of creating a diverse and integrated knowledge community that was international in scope.

3.1 Broad Scope Charter that Focuses on the Entire Knowledge Community

The first important mechanism we will discuss in the development of complex and cross-functional research teams connected to internal and external networks is the establishment of a complex, visionary charter that considers the entire knowledge community as we have defined it. Since much of the literature on the knowledge community has been completed within an organization, this larger perspective has been lost to view [4], [22], [29], [33], and the growing interest in this larger perspective has not received the attention it deserves. The original charter of the Institut Pasteur focused on at least four important arenas of research in the production of knowledge:

1. Basic microbiological research;
2. Applied medical research, especially the development of technologies;
3. Changing public health through education;
4. Produce products for financial independence from the state.

This is a complex charter that mandates the combination of basic, applied and manufacturing research and later quality research. This combination of kinds of research moves considerably beyond the proposal of Stokes [40] to combine basic and applied research by adding in manufacturing and quality research.

The first objective avoided the narrow scope perspective of basic research on bacteriology by focusing on the much broader issue of microbiology. This broad scope then legitimized the addition of a number of different kinds of specialties and allows the visionary team that is discussed in the next sub-section to construct the knowledge community in the nation and beyond.

Equally visionary was the third objective, the strategy for changing the practice of public health by teaching physicians how to conduct medical research and expose them to the latest ideas and technologies in biomedicine. Equally revolutionary was the production of products, goal number four, to achieve financial independence which was unheard of at the time when the Institut Pasteur was founded, although today the spin-off of biotech firms by universities or scientists within them reflects a similar idea.

What are the specific advantages of integrating the quite diverse views of basic science and applied science and in addition manufacturing research? In Kanter's [23] review, she argues that it is critical to be close to the customer. The applied researcher, in our case medical researcher, has a much better understanding of the client's needs, in this instance, the patient, than the basic researcher. The same can be said for the production side of the Institut. Here the customer is the purchaser of vaccines and serums in large quantities, especially for the state. Hence, the issues of quality and cost become important, leading to an emphasis on manufacturing research being combined with quality research.

A broad charter with four goals encourages the leaders or managers of a research organization to recruit quite a diverse set of skills and talents and establish a complex set of interpersonal and as well as inter-organizational networks of advice and of team research. In particular, the goal of microbiology as opposed to bacteriology meant being open to a considerable variety of scientific perspectives. The goal of production also meant that one had to become concerned about a different set of skills, namely those of veterinarians, than one would typically find in a research institute. In addition to increasing the diversity of the knowledge community around the Institut Pasteur, the charter provided a template for how research teams should be constructed. Teams should include basic, applied and manufacturing research specialists. But the template had other implications for the definition of work in the research as well. It also meant that senior researchers taught the medical education course, and many of them worked on quality problems in producing vaccines and serums in addition to their other research problems. In other words, we have the equivalent of what Kanter [23] called a broad scope job, which she felt encouraged creativity and innovation. This reasoning is supported by the research on complexity and cross-functional teams [5].

A visionary charter can have a tremendous influence in the development of a new research unit. In our case study of a co-location initiative [20], the visionary leader of the new co-located research unit observed that the researchers that were focusing on the applied problems in manufacturing and quality research had little time to do basic research. As a consequence, he decided to create a special research unit that would combine basic and applied research for the manufacturing of this particular product, which had a number of special problems due to the deterioration of the product over time. With the creation of the unit, he recruited both kinds of researchers and then asked them to create research teams with specialists in other departments in this large public research organization. In turn, this lead to the development of a larger research community that even went beyond the boundaries of this organization as they began to hold conferences with researchers elsewhere that were concerned with the same issues.

How does this kind of a complex charter at the Institut Pasteur apply to a private firm? At first glance, it would appear to be quite foreign. Nonetheless, it highlights that each business in a high tech sector should want to be concerned with how its own applied research or product development should relate to basic research and vice versa. In other words, businesses should be concerned about making contributions to science in their own best self-interest, including maintaining absorptive capacity for research done elsewhere. Having this goal reorients how the firm thinks about its scientific environment, and also increases the likelihood of making explicit the tacit knowledge involved in basic research, which is frequently the key to effective exploitation for applied research. The problem of absorptive capacity is more than just a question of R&D investments but also the diversity of arenas of research that are represented.

3.2 Visionary Team Leadership

The word vision means many things but one common denominator in the many meanings is the idea of change, and in particular, change in the future. Closely akin to this term is the concept of "transformational leadership", now common in the business literature [2]. While here too, there are a variety of definitions, the primary theme that runs through the literature is the need for leadership that inspires and motivates individuals, particularly through organizational change periods. We prefer to emphasize the vision and more specifically the content of the vision. In the instance of a research organization, visionary leadership can have one or more of the following three contents: (1) creating new scientific disciplines, research specialties or technologies; (2) building the teams and networks of the knowledge community; and (3) reconstructing the larger institutional environment. All three of these are illustrated in the visionary team that led the Institut Pasteur during the period of 1890 through 1916 and each is discussed below. The most dramatic of these is, of course, the reconstruction of the institutional environment. When this occurs, then we have an example of institutional entrepreneurs or what Hage [18] has called institutional innovators.

3.2.1 Building the scientific discipline of biomedicine

Each of the three individuals in the visionary team--Duclaux, Roux, and Metchnikoff--that led the Institut Pasteur from the time of Pasteur's illness in 1890 to the death of Metchnikoff in 1916 had a different vision of how to build the new scientific discipline of biomedicine. Together they added the following new specialties or technologies in the course of about 25 years:

1. cellular approach to immunology*
2 physiology
3 bio-chemistry*
4 virology*
5 fermentation
6 protozoology*
7 biology of radium treatments for cancer
8 chemical therapy*
9 phage research*
10 bio-physics

The asterisk indicates that when it was added, it was the first in the world.

Duclaux created the world's first institute of biochemical research, and also added research on fermentation. He also started bio-physics. He founded the journal *Annales de l'Instiut Pasteur*, which by-passed the control of the Academy of Science, and thus gave an international outlet to the various ideas within this new knowledge community. The expansion of diversity by Roux meant not only the development of serum technology but the creation of the first hospital for the study of infectious diseases in Europe. Roux also added the study of the biology of radiation treatments for cancer, tropical medicine, and chemical therapy for the treatment of diseases to the diversity of the Institut's knowledge community. Roux created the first biomedical course in medical technologies of research, which became celebrated throughout the world. Likewise, Metchnikoff created the cellular approach to immunology and pushed for the addition of physiology and chemistry to the study of problems in this area. He also pioneered the technique of pathology for medical research. All three of them, decided to add physiology as a specialty so that there would be better integration between biochemistry and the medical studies of the causes of disease.

3.2.2 Creating creative research teams

Together the three men, and in particular Metchnikoff and Roux created a number of research teams of various kinds. These two men worked together to handle the German criticisms of the cellular approach to immunology. For this work, Metchnikoff won the Nobel Prize in medicine and physiology.

Roux worked in several teams of basic, applied and manufacturing research as he developed his most important scientific breakthrough. With his research assistant, Yersin, a surgeon, they began research on the causes of diphtheria. They were able to push the research on this deadly children's disease with the discovery of the actual toxins that caused paralysis and the recognition that there were soluble. This represented the first time that a toxin from a microbe had been isolated. Roux returned to the problem of developing an effective treatment for diphtheria in 1893 after a period of illness. Working with Louis Martin, a clinical physician and Edmond Nocard, a veterinarian**,** they found that they could prevent diphtheria and treat it in small laboratory animals. Then, they developed a strong antitoxin in horses, whose blood could then be employed as a serum for patients. For this work, Roux won the Copley Prize.

On Roux's research department, both virology and phage research was encouraged, the later resulting in a prize for d'Herelle. While in the research department of Metchnikoff, one of the researchers won a prize for his work on immunology and another for his work on syphilis. Many of the scientists at the Institut Pasteur remarked on how much their own creativity was encouraged by these two men.

One of the more interesting examples of complex research teams were those sent out by the Institut Pasteur to other countries to determine the causes of major epidemics and then develop a vaccine or serum to cure the illness. Now days we tale rapid deployment forces for granted but at the time it was quite visionary and in some cases, researchers died.

3.2.3 Creating national and international research networks

One of the more important themes in the discussion of knowledge communities is that of networks, both internal and external. These reflect one of the easiest mechanisms for encouraging the development of a knowledge community, once one moves beyond cross-functional teams that are integrated. In this area, the contemporary literature has much to offer. Research by Ancona and Caldwell cited in [5] demonstrates that when there are more functions represented in the cross-functional team there is more external communication. Many of the mechanisms identified in Kanter's [23] famous article in one way or another deal with cross-fertilization that emerges from a rich network of information and contacts. This line of research is important because it is connecting the construction of the team with its external communication.

It has been found that inter-organizational networks do not necessarily increase the rate of innovation. Clearly one reason is the increase in the diversity of ideas. What is missing from this research are the various kinds of mechanisms that help the integration of external teams with internal ones. The role of external cross-functional teams is illustrated in a series of studies of Japanese firms. The extensive use of supplier networks and research networks was very important to the product development process because these networks allowed for continued learning of new technical skills in the supplier firms. Not only were products developed more quickly but they also had higher quality. One of the important new areas of research that complements that on external inter-organizational relationships and consortia is on internal networks [32]. In previous research, we have demonstrated the structure of internal networks play an important role in the research process [20].

These same insights about the role of internal and external networks in creating a knowledge community around microbiology, medical research and manufacturing research apply to the Institut Pasteur. The external networks of the Institut Pasteur were quite extensive. The Institute was responsible for the creation of 13 sister institutes in the period of 1891 through 1913, not only in the French colonies but also in Turkey, Belgium, China, and Thailand. In addition, eight annex laboratories were created within France. Beyond this within France, there were close linkages of research collaboration between Roux and Vaillard at *Val de Grâce* and the former with Nocard at *Alfort*. Similarly, Duclaux retained research positions at the Science Faculty of the University of Paris and at the *Institut Agronomique*. This external network also meant that there was a considerable enrichment of intellectual problems as various researchers rotated from the Institut Pasteur out to the sister institutes or annex laboratories, and then rotated back.

3.2.4 Reconstructing the institutional environment

Roux's course in microbiology at the Institut Pasteur was a major change in the scientific and medical context of France, and quickly became celebrated. Furthermore, it was created without the permission of the Ministry of Education. At the time, the only biological courses available were botany and zoology. At first the *grand cours* created by Roux lasted only five weeks and involved only 11 students. It emphasized becoming skilled with a microscope. Then Roux added first Metchnikoff (immunology) and Borrel (virology) as instructors. By 1894 there were 45 lessons over an eight-week period with 12 teachers. By 1911, the number of lessons had grown to 104 with 23 teachers, while the annual number of students had surged to over 100, almost evenly divided between French natives and foreigners. Again, this impact on European medical research is an important part of the Institut Pasteur's contribution to the development of an international knowledge community around the issue of biomedical research. In the twenty-five years between 1889 and 1914, some 2,000 students attended the *grand cours*, most of them physicians and, secondarily, public health officers and pharmacists.

The most important institutional change that the Institut Pasteur made was the creation of a new career. To achieve this, it had to accomplish three major institutional changes. *First*, there had to be growth in the number of positions available, i.e. *opportunities*. With the diverse sources of funding, the Institut Pasteur grew rapidly in size during the period of 1890-1915. In 1890, there were only five chiefs of services and several assistants but, by 1915, the Institut had 75 full-time researchers. This, however, was not the only source of job opportunities as related institutes were created elsewhere, the appointment of personnel in the network of research organizations discussed above was controlled by the Institut Pasteur.

Second, one had to have access to these positions relatively early in one's career and be ensured of *promotion*. Individuals were promoted quite early in comparison to the rest of France and on the basis of their ideas, not their diplomas. In fact, researchers were discouraged from studying for diplomas by Roux. Third, *new publication outlets* had to be created that would allow for research in this new discipline. By 1910, there were 37 chiefs of laboratories in the Institut Pasteur alone and about one-half that number in the other institutes and annexes. Most of the individuals were promoted in their mid-thirties or early 40s. In contrast, individuals who received a chair in the Faculty of Medicine and the Faculty of Science were in their mid-fifties. Furthermore, none of the chairs in science were open to biomedical researchers and only a few in the medicine where instead the emphasis was on clinical practice.

Third, to achieve these promotions, the researcher had to have an outlet to publish their findings. The Academy of Science (which included the Academy of Medicine) was in the biology section controlled by zoologists and botanists who were uninterested in biomedicine. Therefore, the creation of the *Annales de l'Instiut Pasteur* allowed this new scientific specialty to be represented and for the researchers to receive *recognition* that would facilitate their promotion. This was one of the major contributions of Duclaux.

The case study reported above also illustrates how networks were created between the new unit and other units as well as external to the research organization via joint conferences. There are other ways in which the example of the Institut Pasteur can be applied even to industrial firms. The visionary team leadership might be called the Hewlett-Packard model of transformational organizations. The team model recognizes that even the most brilliant individual leader does have particular blind spots, and that these are corrected by a team approach to leadership. But visionary teams of leaders for research reflect another critical point, namely that the production of knowledge is changing constantly, and that it takes dynamic leadership working within the framework of a complex charter to track and absorb these changes.

3.3 Recruitment from diverse sources, both nationally and internationally.

Building a diverse knowledge community requires the recruitment of people who think differently about the same set of problems. And although the idea of the diversity of occupational specialties has been related to organizational innovation, the importance of recruitment from different prestige hierarchies and different countries has not been emphasized. The visionary team at the Institut Pasteur recruited quite different occupational specialties, from different countries and from different parts of the prestige hierarchy in France. Duclaux drafted Roux who came from a less prestigious educational background and even paid for his medical studies [9]. When G. Bertrand made his discovery, Duclaux immediately hired him and quickly promoted him to be a chief of service or department head (a quite unusual title at the time) at the Institut [12]. Duclaux was also very active in recruiting Fernbach, Mazé, Etard, Trillat, Mouton, and Staub, as well as his own son [12]

It is, of course, a critical part of leadership to recruit good people, but it is unusual to have *three* separate individuals engaged in this enterprise, especially in the beginning.The importance of their recruitment strategies becomes obvious once one recognizes that each of the leaders had a particular bias reflecting their own training, drafting individuals from that same school system. Duclaux, a "normalian", that is a graduate of *Ecole Normale Supérieur* himself, tended to recruit individuals from the *grandes écoles*, especially his own and *Institut Agronomique*, where he had a joint appointment during his years at the Institut, , as well as from his students at the University of Paris, Faculty of Science. These were the schools at the top of the prestige hierarchy in French science. In contrast, Roux recruited medical doctors, especially with the aid of Vaillard and veterinarians with the aid of Nocard, as we have seen. These schools were much lower in the prestige hierarch. And Metchnikoff recruited foreign nationals who were outside of the system. *Perhaps the most interesting aspect of their recruitment bias was intellectual; Duclaux preferred physical chemists, Metchnikoff zoologists and later pathologists, and Roux research technicians.* The diversity of leaders led to a much more complex pattern of recruitment and ensured that a large diversity of ideas was obtained and all the goals of the complex charter were implemented.

The implication of this diversity in recruitment means that the teams constructed with these individuals became complex or diverse in a variety of ways: occupational specialty, basic vs. applied vs. manufacturing research focus, national background, etc. Although one of the most consistent findings in the management literature is that cross-functional teams tend to be more innovative, there has been little research on the recruitment patterns of the leaders of the organizations, especially those engaged in research. However, it is implied in the work of Kanter [23] who observes one should be open to a variety of new ideas and, of course, diverse recruitment is the simplest way of achieving this.

3.4 Both intellectual and emotional integration mechanisms

As has already been suggested one of the major obstacles to creating effective knowledge communities is overcoming cognitive distance in research teams and organizational cultures in external networks. In the knowledge paradigm of the firm [6] the importance of integration has been recognized [15] but as yet, there is much to learn about how best to achieve this. The assumption is that integration lies at the heart of organizational learning, which it does [7]. One of the easiest ways of creating this integration is via the construction of cross-functional teams, as we have already observed because of their different communication patterns [5].

One of the more instructive aspects of studying the Institut Pasteur is the variety of integrative mechanisms for the entire knowledge community. *Intellectual integration* was created via the provision of a common language through the new course in microbiology techniques that was quite broad in scope and that everyone had to take. The breath of the scope was ensured by the team teaching of all the major researchers at the Institut Pasteur. This created a common language that reduced the cognitive distance within biomedical research in general since so many physicians were trained in this course. The creation of the *Annales de l'Institut Pasteur* allowed for the continued up-dating of the various biomedical researchers knowledge and therefore further reduced cognitive distance. This extended the boundaries of the knowledge community beyond the Institut Pasteur and its sister institutes and annexes to include biomedical researchers world-wide.

As any student of organizations knows, even organizations involved in the same network develop their own distinctive cultures. Within the network of research institutes associated with the Institut Pasteur, this problem was overcome via the rotation of researchers between these various institutes. Thus, the external network increased diversity while the patterns of rotation ensured more integration.

An extremely important mechanism for creating integration was the presence of team leadership. Metchnikoff and Roux worked together and published together. A number of the researchers not only were involved in their teams but moved between their two departments, again facilitating intellectual integration and diminishing cognitive distance. Finally, the team research between departments, especially those involving medical technology and the production of vaccines and serums, resulted in a large number of joint publications that also overcame cognitive distance.

Emotional integration was created via the presence of socio-emotional leaders and the sense of belonging to a family, the Pasteurian family. The importance of emotional integration for creating a knowledge community and especially overcoming cognitive distance cannot be overstressed. When a researcher feels accepted, then it becomes much easier to both accept and give criticism and the problem of prestige hierarchies is overcome.

This idea of the importance of emotional integration in implied in the recent literature on radical innovation. For example, a comparison of the four highly innovative bio-tech firms with four that were less so [22], stressed the importance of learning in the following quote:

> "We talk as much about how we do work around here as what we work on. The key is to constantly learn from previous experiences and continuously improve our workplace relationships."

And another scientist from the same firm reported:

> "This organization is different from any other that I have been a member. Discussion is maximized and hierarchy is minimized."

These patterns allow this firm to be a learning organization explaining how the more successful firms were able to reinvent themselves.

Equally important to various integrative mechanisms are those structures that negatively impact on intellectual and emotional integration by *increasing* cognitive distance. In the above quote is a reference to the absence of hierarchy or bureaucracy. This was also present in the Institut Pasteur. The absence of typical mechanisms of control and of coordination that one finds in many organizations facilitated integration.

A variety of factors influence the integration of a diverse set of scientific perspectives and cultures. On the positive side one wants both intellectual and socio-emotional integration. These are achieved in different ways and of the two, the latter is the more critical one. On the negative side, one needs to avoid bureaucratic coordination and control mechanisms that make integration of different perspectives impossible.

3.5 Resources from diverse sources

One important mechanism for maintaining a diverse perspective is to be sure that there are diverse sources of resources, thus eliminating dependency and control by any one organization. In the case of the Institut Pasteur, the sources of funds were the following:

- public subscriptions in the beginning;

- royalties from patents donated by Pasteur [9], Roux and others as well as prize money donated by Roux and Laveran;
- purchase of serums and vaccines by the French government on a large scale that provide supported for the production departments and quality research;
- small operating grants from various ministries;
- bequests and wills.

The latter in particular allowed the Institut to have a great deal of autonomy. Between 1887 and 1918, 52 bequests generated more than 50 million dollars. Two of the large ones were used to build the new Institute of Bio-Chemistry and the hospital for studying diseases. The largest, the Orisis bequest, was used to create a large endowment and to buy adjacent land. These bequests provided the extra funds to pay for the expansion in laboratories, the addition of new specialties and most critically rapid promotion of bright researchers as described in the next section.

Why are diverse sources of funds so important? Multiple sources of funds have been demonstrated to lead to more innovation and higher quality services [18]. Mohrman et al [33] found that multiple sources of funding appeared to facilitate the formation of the knowledge community and individuals working together. Clearly, different sources have different agendas. But while this may seem obvious, its corollary is that multiple sources mean multiple agendas are being maintained, which reinforces the complex charter and the visionary team's implementation of that charter as the research organization responds to changes in the knowledge context.

4.0 Concluding Discussion

If the U.S. is to remain competitive, particularly in the high tech sectors, and if publicly funded research is to optimize its contributions to solving national problems, the appropriate knowledge communities must be built. Concretely this means that the managers should construct cross-functional teams with as many arenas of research as is feasible and needed in the circumstances and build both internal and external networks so that all the arenas of research in the larger knowledge community are connected. Another consideration is increasing the complexity or diversity of disciplines represented in each of the arenas of research.

Since these building blocks of the knowledge community are so fundamental, we advocate that research managers use the research environment survey developed by Jordan [21] to measure the three dimensions discussed above: 1) internal and external collaborations; (2) the strength of the collaboration via exchanges of technical ideas within and across disciplines; and (3) the number of research teams with varying degrees of complexity both internal and external to the research organization. Beyond this, the critical issue is how many of the functional arenas are in each complex or cross-functional team and/or connected in either an internal or external network.

The main objective of this paper has been to delineate those factors that encourage the construction of diverse and integrated teams and networks and therefore knowledge communities. It is precisely these factors that have been largely ignored in the management of innovation literature as well as in the organizational literature on innovation. And while some of the ideas have emerged from a research organization in biomedicine, we have indicated how they are substantiated in various ways in different management literatures as well as our own research case studies. First, expand the strategies of the firm to be at least concerned about all the functional arenas even if not directly involved. This will help in the building of networks. Second, create visionary teams that try to build disciplines and even alter their research environment. High-tech products need both visionary leaders in science and in business as the founding years of Hewlett-Packard would attest. In other words, visionary teams are not just concerned about the success of their firm but realize that the health of the research environment is a critical factor in making that success possible.

Third, recruit individuals with diverse perspectives both nationally and internationally. In particular, do not focus too much attention on the most prestigious universities. However, recruiting a diverse pool of people carries the added cost of developing more effective communication mechanisms. One way of accomplishing this is to be sure that each new researcher can communicate technically with those in other specialties, the strategy of M.I.T. when it was building its very successful biology department. Another way of reducing the costs of this is to recruit individuals who work well with others or are, in effect, team players.

Fourth, given the importance of integration of teams and of networks, technology managers want to employ a variety of intellectual and emotional integration mechanisms to help overcome the problem of cognitive distance and the cultural differences between organizations. Duo-team leadership, especially when they represent different organizations, is one effective device. Another is rotation between teams and between organizations. This creates what are called boundary-spanners, individuals who can communicate with disparate perspectives.

Fifth, seek funding from diverse sources and not just one customer to help broaden the intellectual agenda and maintains independence of thought. Indeed, dual sources of funding are an excellent predictor of innovation.

While many of the lessons of the Institut Pasteur are drawn from actions taken over a century ago, recent research suggests that these lessons are well-suited for contemporary issues (see for example [20] and [39]). Most importantly for the purposes of this paper, the actions taken by the leaders of the Institut Pasteur reflected thinking beyond the organizational boundaries with the objectives of creating a diverse and integrated knowledge community that was international in scope. Given the increasing globalization of R&D, as well as the changes in knowledge production identified in the paper, the lessons of the Institut Pasteur offer a good strategy map for managers and policy makers alike.

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Appendix A

Functional Arenas in the Idea Innovation Network

Functional Arena	**Definition**
Basic Research	Experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundations of phenomena and observable facts, without any particular application or use in view.
Applied Research	Original investigation undertaken in order to acquire new knowledge. It is, however, directed primarily towards a specific practical aim or objective.
Product Development or Product Innovation	Systematic work, drawing on existing knowledge gained from research and practical experience, which is directed to producing new materials, products and devices, including prototypes.
Production Research or Process Innovation	Research to design new manufacturing products or processes.
Quality Control Research and Research on Qualities	Research aimed to improve the quality of products as well as research in order better to understand and control the effects of products.
Commercialization of Research	Research designed to understand needs of customers or to improve distribution channels.