1 *Networks, collaborations, and learning and knowledge creation*

The primary goal of this chapter is to introduce the overarching framework of the book. It will start with the concepts of collaboration and learning. Then, we introduce the issue of levels of analysis, which is crucial for understanding the knowledge creation and learning processes within and between organizations. Specifically, the chapter will show how different levels of analyses – industry level, multiple interorganizational level, dyadic level, organizational level, and scientists' network levels – are crucial for understanding knowledge creation and learning in biotechnology. The aim here is to establish the analytic elements that will be used further in the book, and to illuminate the complexity involved in a framework based on multi-level and multi-unit analyses.

Networks of collaborations and learning

Science organizations are experiencing constant changes – in part due to environmental opportunities and constraints, which lead to adaptive changes, and owing to the changing nature of the scientific process in various scientific areas. For example, if science must advance through the joint research of large groups of scientists, as in the case of physicists working around a supercollider, the structure of the organization of the scientific work is expected to change. The structure of groups may change to incorporate large groups of scientists and multiple projects may emerge to accommodate the needs of experts who will seek other experts for learning collaborations. The flow of knowledge will be shaped and reshaped as the groups of scientists will continue to explore collaborations. Consequently, changes in the organization of science are expected as both the internal procedures and allocation of resources of the hosting organization will change along with the norms of conducting scientific work in this organization.

Thus, changes in the opportunity structure, central actors, technology, resources, and flow of information in a scientific field are expected to lead to further changes in the structure of science, networks, and learning. These processes are nicely reflected in the area of biotechnology research.

The theoretical lenses of the present study are based on the underlying assumption that biotechnology-related scientific work is organized within a complex, ambiguous, and highly competitive environment. For most organizations in this organizational field new knowledge creation is essential for survival, yet knowledge is distributed between various organizations, including biotechnology firms, university, research centers, national agencies, and large firms. Since knowledge is distributed between various organizations and institutions, various forms of interorganizational collaborations and learning are needed.

Learning processes vary in terms of structure and process. Pisano (1996) differentiates between the concept of "learning-by-doing," which has featured prominently in the literature of technological innovation, and the concept of "learning-before-doing," which is associated with problem-solving that occurs long before a new product or process design is introduced. Pisano (1996) explores the impact of different learning strategies on development performance, with detailed data on 23 process development projects from pharmaceuticals and biotechnology, and his findings indicate that "learning-by-doing" is essential for efficient development in an environment such as biotechnology, where underlying theoretical and practical knowledge is relatively thin. In contrast, the need for "learning-by-doing" is far lower in environments such as chemical synthesis, where underlying theoretical and practical knowledge is deep enough to enable the design of laboratory experiments which effectively model future production experience. We learn from Pisano (1996) that in emerging technologies like biotechnology, which are typically characterized by less mature theoretical underpinnings and less accumulated practical knowledge, it is simply impossible for developers to anticipate and respond to manufacturing concerns without actually doing their work in the actual production environment. Thus, the locus of development competencies within organizations may be technology life-cycle-dependent. The high level of uncertainty about theory and accumulated knowledge may also be one of the forces which enhance the need for interorganizational and interinstitutional learning exchanges.

Knowledge-intensive organizations are targeted at enhancing knowledge creation, and appropriating this knowledge by transferring it into resources or forms which may be commercialized (such as patents and licencing, products, consulting specialties, and so on). Maximizing commercializing ability demands that the organization's most valuable resource (knowledge) should be well bounded within the organization.

On the other hand, it is well known that in the biotechnology industry the knowledge needed for the commercialization of related products does not exist under one organizational roof, but, rather, within the boundaries of various organizations (Powell & Brantley 1992; Liebeskind *et al.* 1996; Powell, Koput & Smith-Doerr 1996; Oliver & Liebeskind, 1998; Oliver 2001). Thus, it is argued that in order to commercialize science-based products in the biotechnology industry, interorganizational collaborations of various kinds are of vast importance.

Collaboration is a complex concept and has been interpreted in many ways (Huxham 1996, pp. 7–8). Definitions include, for example, "working in association with others for … mutual benefit," "a distinct mode of organizing … an intense form of mutual attachment," or "a new type of organization … type of transformational organization." Whilst collaborations are valuable, argues Huxham (1996), they are also difficult because of inherent hazards associated with them.

The "networks-for-learning" approach focusses on interorganizational networks as resource-generating entities that have the ability to enhance learning in collaborating firms. Powell, Koput and Smith-Doerr (1996) contend that the locus of innovation will be found in interorganizational networks of learning rather than within individual firms. This work contrasts the strategic approach (Teece 1986; Williamson 1991) that deals with the calculation of risks versus returns in pooling resources with another organization. This latter view contends that effective collaborations are hampered by lack of trust, difficulties in gaining control, and differential ability to learn new skills. As we will see, the literature introduces two main lines of argument: one deals with the risks in interorganizational collaborations and the other highlights the advantages of such collaborations for the benefits of the firm.

The sociological insight offered by Powell, Koput and Smith-Doerr (1996) deals with learning as a social construction process wherein knowledge is created in a social community context. This approach is based on the view of von Hippel (1998) that the trading of know-how requires the establishment of long-term relationships, and on Cohen and Levinthal's (1990) concept of "absorptive capacity." The argument that was raised by Cohen and Levinthal (1990) states that a firm with high absorptive capacity has a greater capacity to learn, and hence is adept at both internal R&D and at conducting R&D collaborations with other organizations. Thus, outside sources of knowledge are often critical to organizational innovation. March and Simon (1958, p. 188) were pioneers in offering the argument that innovations usually result from borrowing rather than invention. They also maintain that the ability to exploit external knowledge is a critical component of the innovative process. Further, the evaluation and utilization of this knowledge is a function of prior related knowledge which includes basic skills such as shared language and knowledge of the technological and scientific developments.

The biotechnology industry is a relatively new phenomenon: it is an industry that has emerged from basic university science, with revolutionary implications for "doing science" and for science-based industries such as pharmaceuticals, food, and energy. One of the most salient characteristics of the industry to date has been the use of collaborative relationships to conduct exchanges between new biotechnology firms (NBFs), established pharmaceutical firms, universities, and other non-profit research organizations. These collaborative relationships exist at both the interorganizational level (Barley, Freeman & Hybels 1992; Kogut, Shan & Walker 1992; Powell & Brantley 1992; Oliver 1993; Powell, Koput & Smith-Doerr 1996) and the individual level (Liebeskind *et al*. 1996; Zucker, Darby & Brewer 1998 to name only a few of the early studies), forming a dense network structure among the actors in the industry. These collaborative relationships, it is argued, have allowed biotechnology firms to access commercially valuable scientific knowledge and complementary commercial assets as the industry has evolved, thereby allowing both NBFs and established pharmaceutical firms to reduce their risks and costs in this arena.

Levels of analyses: issues of micro-, mezzo-, and macro- in the study of networks

It is important to clarify when the subject of research is learning networks that there are at least three generic types of network relations. These three types were specified by Oliver and Liebeskind (1998):

- Intra-organizational network relationships that operate at the individual or interpersonal level.
- Interorganizational network relationships that operate at the individual or interpersonal level.
- Interorganizational network relationships that operate at the organizational level.

In differentiating between these three types of networks, the primary argument suggested was that each of them has different features and serves a different purpose within the overall process of biotechnology research and commercialization.

The three types of networks represent two distinct levels of analyses: individual- and firm-level. To date, we still know very little about the interrelations between these two levels, cases of compatibility of patterns, or lack of them. We also lack understanding about what happens when these networks do not match, or how the use of one network structure or process may enhance and increase the productivity and efficiency of the other network levels. Related questions would open the area of research of learning networks to new theoretical and empirical directions. Examples of such questions are:

- To what degree do past interorganizational collaborations on the organizational level affect new interorganizational collaborations on the individual level?
- How can biotechnology firms best enrich their intra-organizational learning networks by the individual-level interorganizational networks of their scientists?
- What happens to the personal individual networks of scientists when they become employed by biotechnology firms that have their established interorganizational organizational-level learning networks? Do the scientists abandon their individual networks in lieu of the new organizational networks in which they participate, or do firms encourage them to transform their individual-level networks into formal organizational networks?

Another level of analyses, not always acknowledged in interorganizational network research, is the level of the industry as a whole, or the subsectors within the industry (Powell *et al.* 2005). Evolutionary theory of networks argues that we cannot fully capture lower levels of networking activities without understanding the general and specific structure of networks on the industry or subindustry sector. Thus, firms operating in industrial settings, in which R&D interorganizational networks are dominant, will not only have a higher propensity to search for R&D alliance partners, but may also find it easier to find them. When collaborative R&D is dominant within an industry, all the actors in the industry are expected to have a higher inclination and propensity to form such alliances.

By the same token, in an industry in which the rate of entry of new firms is high we may find another pattern of networks associated with the industry level. Since new entrants are less known and established in the industry they may experience network entry barriers, and thus be able to form alliances only with other new entrants. In this context, Powell *et al.* (2005), in a most impressive study of network dynamics and the evolution of the biotechnology field, found a clear picture of a continuing flow of new entrants into the field, yet these new entrants have "high-quality" links to other well-connected organizations. This pulling-in of newcomers reflects the process of "sponsored mobility" as new firms are assisted by existing firms at their initial entry to the industrial network.

Integration of levels of analysis

Once again, the primary argument here is that each of the three suggested networks serves a different purpose within the overall process of biotechnology research and commercialization. Oliver and Liebeskind (1998) argued that exchanges of new scientific knowledge take place primarily through interpersonal network relations, both intraorganizational and interorganizational. Thus, "networks of learning" in biotechnology are embedded within the context of personal relationships, whereas interorganizational ties serve primarily to support the commercialization of knowledge, and encompass transfers of "commoditized knowledge" in the form of intellectual property rights and of assets essential for commercial development.

In addition, Oliver and Liebeskind (1998) observed that individual-level network relationships in biotechnology were becoming increasingly encumbered and influenced by organization-level policies and practices. This change in the level of organizational influence on individuals' actions fosters and promotes the formation of certain types of individual ties, and inhibits the formation of – or even severs – other types of ties. Thus, there is a reciprocal interplay between individual-level network relations and organizational policies.

The dense pattern of interorganizational ties observed between NBFs and other organizations arguably reflects the fact that NBFs, as new firms, lack many of the resources and capabilities required to commercialize their discoveries (Teece 1986; Kogut, Shan & Walker 1992; Oliver 2001). Alliances with incumbent pharmaceutical firms allow an NBF to conduct research while the incumbent firm provides "complementary assets" (Teece 1986), such as marketing and distribution, product-testing capabilities, and development capital. Whilst a number of NBFs have managed to develop these capabilities internally over time, many remain specialized in R&D. Many NBFs therefore occupy an intermediate position in the biotechnology industry: between universities, where basic scientific research is conducted, and large established firms, where biotechnology products are brought to market (Arora & Gambardella 1990; Liebeskind *et al*. 1996). Consequently, the survival and success of NBFs depends on their network ties, since structural positions are an important determinant of competitive success in the biotechnology industry.

Research on networks of collaborations

Much of the research on network relations in biotechnology has focussed on organization-level ties between organizations. Shan (1990), Barley, Freeman and Hybels (1992), Kogut, Sham and Walker (1992), and Powell *et al*. (1996) have all examined the organization-level ties among NBFs, whereas Pisano (1990) as well as Arora and Gambardella (1990, 1994) have examined organization-level ties between NBFs and large pharmaceutical firms. Most recently, scholars of strategic alliances in biotechnology could show a large and detailed picture of the networks within the industry. This was achieved by the use of advanced network graphic methods, large-scale datasets, and advanced statistics by Powell *et al*. (2005).Their study focussed on collaborative ties between all actors over time, offering us an evolutionary approach to the industry based on the alliances that were formed longitudinally.

However, other research suggested that interorganizational ties represent only part of the overall set of network ties in the

Table 1.1 *Number of scientific collaborations resulting in published research classified by exchange governance mechanisms*

No. of research publications			
	Firm *X*	Firm *Y*	Total
No. of publications	503	345	848
No. of publications based on research collaborations with external scientists	257	256	513
Percentage of total	51	74	60
Of which are governed by market (contractual) arrangements that are:			
Interorganizational	0	2	2
Individual-level	0	0	0
Number of publications produced only by scientists-employees	246	89	335
Percentage of total	49	26	40

Sources: Corporate records, North Carolina biotechnology database, Bio Scan. (Cited in Liebeskind *et al.* 1996.)

biotechnology industry. For instance, Liebeskind *et al.* (1996), who studied the organizational mechanisms through which NBFs source scientific knowledge, found that interorganizational agreements were unimportant in these exchanges. Rather, the NBFs these researchers studied sourced scientific knowledge through a dense network of individual-level ties among firm scientists and university scientists, almost none of which were governed by an overarching interorganizational agreement (during the period covered by the study). In that study the economic importance of individual-level collaborations for NBFs was also illustrated, finding that scientists at the two NBFs studied were involved in a very large network of collaborative research projects with scientists at universities and other research organizations (Table 1.1 and Table 1.2 summarize these data).

Another important element of the study of interorganizational ties is the content of the exchanges carried out through network ties. For example, a number of studies classified some organization-level agreements as R&D agreements (Pisano 1990; Powell, Koput & Smith-Doerr 1996), although there are important differences between the two types of ties. For instance, many R&D agreements consist of arrangements whereby the pharmaceutical firm funds a program of

Table 1.2 *Exclusive versus shared patent rights of firms X* **and** *Y*

	Firm *X*	Firm *Y*
Total number of patents	28	21
No. of exclusive patents	25	19
No. of shared patents	3	2
No. of patents shared by new biology firm (NBF) with institutions or scientists at institutions with which NBF has a formal contractual agreement	3	2
No. of patents shared by NBF with institutions or scientists at institutions with which NBF scientists have collaborated in published research	0	2

Source: Based on corporate records and US Patent Office records. (Cited in Liebeskind *et al.* 1996.)

research at the NBF,[1] and the NBF agrees to license any resulting intellectual property to the pharmaceutical firm, or when a university provides a license to a firm in order to use a patent assigned to the university. In both cases, no direct scientific collaboration is necessarily involved in such an agreement. Hence, it cannot be classified as a "learning" alliance in the pure sense. On the other hand, other R&D agreements may involve active collaboration in research between a university professor and a firm research team, or between two NBFs, which will result in interorganizational learning. These distinctions are not simple to specify and tracing them in large datasets that do not provide sufficient information on the alliances is almost impossible.

Finally, network studies of the biotechnology industry may suffer from problems associated with the study of networks in general – of boundary specification. These arise from the fact that multiple actors are involved in the industry (pharmaceutical companies, NBFs, universities, hospitals, research centers, and others); from the large number of units of each institutional form, and from the high rate of entry and exit over time (Barley, Freeman & Hybels 1992; Powell *et al.* 2005). These complexities reduce researchers' ability to specify stable and compatible boundaries and thus to provide a coherent picture of network relations.

[1] New biotechnology firms – for description and clarification of these firms as actors in the biotechnology industry, and as an organizational form, *see* Chapter 2 and Chapter 3.

Levels / Extent	Individual level	Organizational level
Intra-organizational	Intra-organizational individual-level ties	Empty cell
Interorganizational	Interorganizational individual-level ties	Interorganizational organizational-level ties

Figure 1.1 Types of network ties and levels of analyses.
Source: Oliver & Liebeskind 1998

The new dynamic methods for studying networks over time may offer some remedy to this problem, yet a theoretical approach that accounts for the effect of entries and exits is needed.

Based on these limitations, Oliver and Liebeskind (1998) offered a model for studying interorganizational networks in professional and knowledge-intensive industries characterized by multiple institutional arrangements. Our model of network relations in the biotechnology industry integrates partial findings and identifies some directions for future research.

The model

As discussed above, an integrative model must incorporate both organizational-level and individual-level network relations within the biotechnology industry. It must also explain how these two levels of networking interact. Given the two levels of networking that have been observed, three types of network relations may be identified, as illustrated in Figure 1.1. All three types of network relations are important to the commercialization of biotechnology research.

Individual-level

Individual collaborative relationships in biotechnology center on the research process – be it within a single organization or between organizations. Biotechnology research involves collaboration among scientists in many different disciplines, such as molecular and cell biologists, geneticists, and protein chemists, as well as technical