11

Product, Process, and Knowledge Architectures in Organizational Competence

RON SANCHEZ

INTRODUCTION

The ability of an organization to succeed in a competitive environment ultimately depends on its ability to provide product offers that are perceived as valuable and attractive by potential customers. Firms differ greatly in their approaches to meeting this basic "market test" of organizational competence, but all firms have in common the need to sustain effective processes for creating and realizing product offers. This discussion considers the fundamental impacts on a firm's competence of the *architectures* of the products a firm creates and of the processes a firm uses to create and realize its products. We consider in particular how a firm's product and process architectures shape the structure and content of the knowledge that a firm accumulates as it creates and realizes products—in effect, how its product and process architectures determine the *knowledge architecture* a firm acquires and uses to create new products in the future.

In this discussion, we especially investigate how adopting *modular* product and process architectures can significantly enhance a firm's ability to identify and manage its organizational knowledge in creating and realizing products. We consider both "supply side" and "demand side" impacts of modularity on knowledge management. On the supply side, adopting a disciplined modular approach to creating products and processes can greatly improve an organization's ability to identify the nature and extent of its technological knowledge. This leads to greater clarity about what an organization does or does not know technically and thus what it may or may not be capable of achieving in its strategies for product creation and realization. Greater clarity in understanding what technological capabilities an organization has enables managers to use an organization's current knowledge more effectively and to focus organizational learning on developing or accessing new knowledge that will improve the organization's options for creating and realizing new products. We also consider how modular architectures can help a firm access knowledge and coordinate learning processes beyond its own boundaries. In these ways, the adoption of a modular approach to creating and realizing products can greatly improve the *systemic flexibility* of a firm to respond to change and diversity in the markets it serves and the technologies it uses.

On the demand side, we consider how the flexibility of modular architectures to configure many product and process variations can be used to support new forms of market exploration, learning, and development. We consider the essential role of modular architectures in processes of real-time market research, in developing more fine-grained understanding of market preferences at the component level of products, and in supporting e-business strategies for mass customization and product personalization.

This discussion of the fundamental role of product, process, and knowledge architectures in organizational competence is organized in the following way. We first define the concept of an architecture and apply that concept in explaining the terms *product architecture, process architecture,* and *knowledge architecture.* We then introduce the concept of modularity and explain why adoption of modular product and process architectures can improve—often very significantly—an organization's ability to identify and use its own knowledge assets, to access and leverage specific forms of knowledge in other organizations, and thereby to improve its supply-side processes for creating and realizing products. Next we consider how modular architectures can be used as drivers of demand-side processes for organizational learning about market preferences and for defining an organization's options for serving those preferences. We explain how these supply-side and demand-side processes can be integrated in a modular architectural framework for planned organizational learning and for effective leveraging of current knowledge assets. We then consider how the use of a modular architectural framework for knowledge management helps to improve the *dynamic, systemic, cognitive,* and *holistic* dimensions of organizational competence. Concluding comments suggest two important but counterintuitive ways that the definition and discipline inherent in modular architectures can improve organizational flexibility and creativity.

THE ARCHITECTURES OF PRODUCTS, PROCESSES, AND ORGANIZATIONAL KNOWLEDGE

An *architecture*—whether it be for a physical product, a service product, a process, an artistic image, or whatever—is created when (i) a design is decomposed into component parts and (ii) the ways that the component parts will interact in the design are determined.

The *decomposition* of a design into specific kinds of component parts may be motivated by any number of objectives for the design, but leads to a segmenting of the design into *functional parts* that must work together in providing the overall function desired from the design. The functional decomposition of a design is most evident in an assembled product like a personal computer (typically decomposed into a microprocessor, memory card, hard disk, monitor, keyboard, and so on), but designs of services and other processes are also decomposable into specific activities that collectively provide a desired function. The vertical stack of blocks in Figure 11.1 represents the decomposition of a product design into functional components, while the L-shaped array of blocks represents the decomposition of a process design—in this case, the

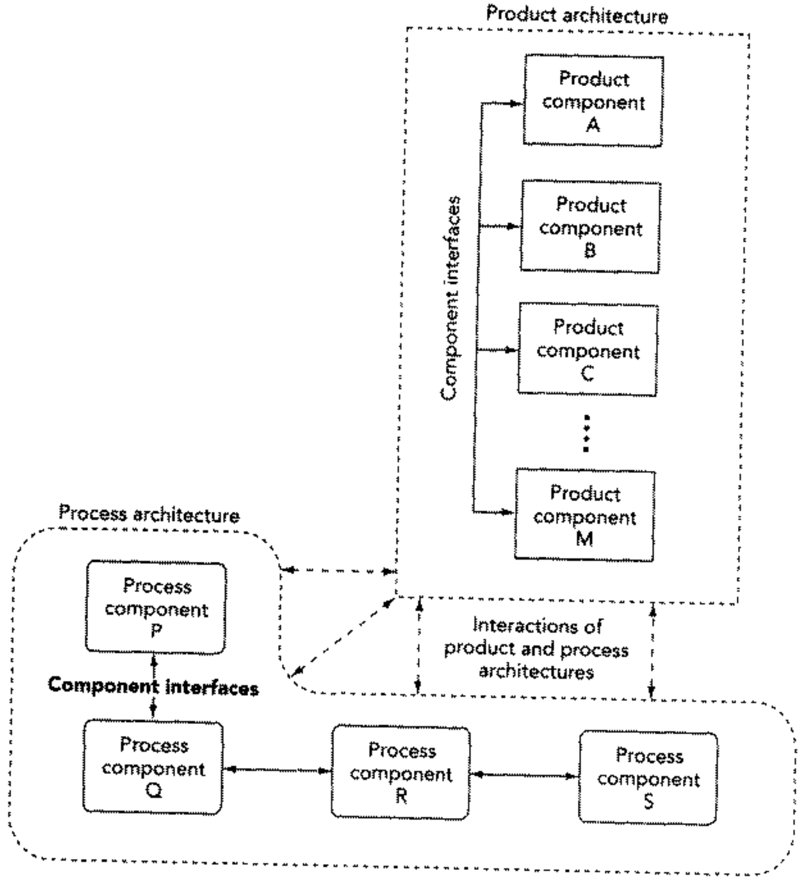

FIG. 11.1 *Functional components and component interfaces in product and process architectures.*

overall process for creating and realizing products—into its functional components (i.e. specific activities).

Determining the ways that the functional components of a design must interact to work together requires specifying what is most commonly referred to as the *interfaces* between components. Interface specifications determine the way one component attaches to another, the spatial position one component will occupy relative to others, the way in which the output of one component is transferred to another component, the way in which one component communicates with and controls or is controlled by another component, and other ways in which the functioning of one component may affect the functioning of another component within a design (Sanchez 1999). In effect, component interfaces define and control the way the component parts of a design fit and work together *as a system.* Component interfaces are indicated in Figure 11.1 by the solid arrows linking the blocks that represent the functional components of the product architecture and the process architecture.

Creating an architecture of a product or process requires some essential forms of knowledge about how an overall function desired from a product can be decomposed into functional components and how those components would have to interact to work well together in providing the desired function. Since many ways of decomposing a design may be technically feasible, firms often differ in the ways they decompose their product and process designs into functional components. The way a firm decomposes its product architectures will profoundly shape the way it builds and uses its knowledge in creating products. In essence, technical knowledge in an organization will tend to become clustered around the design, development, and improvement of the specific types of components that the organization commonly uses in its product designs (Henderson and Clark 1990).

The dotted arrows in Figure 11.1 represent the interactions between the functional components in a product architecture and specific activities in the process architecture for realizing each component and bringing all components together in the final product. In effect, for each component it uses in its products, a firm will have to have a corresponding process component for creating, producing, shipping, and servicing the component. The way a firm decomposes its product designs into functional components will therefore largely determine the kinds of processes a firm will follow in developing, producing, distributing, and supporting its products. Sanchez and Mahoney (1996) have expressed this impact of an organization's product designs on its process designs by arguing that although organizations ostensibly design products, at a more fundamental level "products design organizations."

Just as a firm's product-related knowledge becomes clustered around the components it uses in its product architectures, the process knowledge an organization develops will also become clustered around the component activities in its process architecture. Since the specific processes a firm must use to create and realize a product will be largely determined by the component structure of the product's architecture, both the content and the structure of an organization's *process* knowledge will also be greatly influenced by the *product* architectures the organization uses. Thus, a firm's choice of product architectures is not simply a technical matter, but rather is a strategically critical issue that will largely determine the content and structure of much of the knowledge that an organization develops.[1]

[1] The *content* and the *structure* of knowledge are inextricably interrelated concepts. The content of knowledge simply refers to what some bit of knowledge is about—i.e. its subject matter. The structure of knowledge refers to how the contents of the various bits of knowledge an organization has *are perceived within the organization* to be related or not related to each other. For example, suppose an organization that designs personal computers has knowledge of how to design both the microprocessor that executes applications programs and the power supply that powers the microprocessor. In one organization, the relationship between the two kinds of knowledge may be perceived as limited to determining the kind of electrical current the power supply must provide to enable the microprocessor to perform its function. Another organization, however, may understand that basic relationship, but also be aware that heat generated by the power supply (a new knowledge content) may interfere with the functioning of the microprocessor (a new relationship in the firm's knowledge structure). In this way, both the content and the structure of knowledge in the second organization are different from—and more elaborated than—the content and structure of knowledge in the first organization.

We can now define the concepts of *product architecture, process architecture,* and *knowledge architecture* (Sanchez 1999). These definitions will then serve as the springboards for our discussion of modularity and the role of modular architectures in knowledge management and organizational competence.

Product architecture

The decomposition of a *product design* into functional components and the specification of the component interfaces that govern how the functional components interact in the product to work together as a system.

Process architecture

The decomposition of a *process design* into functional components (activities) and the specification of the component interfaces that govern how the functional components interact in the process to work together as a system.

Knowledge architecture

The structure and content of an organization's knowledge about (i) decomposing product and process designs into functional components, (ii) how those components function, (iii) defining the interface specifications that govern the interactions between functional components, and (iv) assuring the ability of each of its process components to create and realize each of its product components (i.e. assuring the compatibility of its product and process architectures). An organization's knowledge architecture therefore fundamentally determines the product and process architectures the organization can create and realize.

MODULAR ARCHITECTURES

As system designs, the architectures of products and processes may be composed of either *tightly coupled* or *loosely coupled* functional components (Orton and Weick 1990; Sanchez and Mahoney 1996). The functional components in an architecture are tightly coupled when the ability of one component *design* to function properly depends on the use of a specific *design* for each component with which it interacts. Components are loosely coupled in an architecture when the proper functioning of one component design does not depend on its being used only with a single specific design for another component. In effect, loosely coupled components can function properly when used with a range of design variations in other components (Sanchez 1995).

Modularity is the property of an architecture in which a specified range of variations in loosely coupled functional components can be "substituted" into or "mixed and matched" within an architecture (Garud and Kumaraswamy 1993; Sanderson and

Uzumeri 1997). In essence, modular architectures enable the configuration of a range of variations in products and processes by assembling different combinations of "plug-and-play" compatible component variations.

The substitutability of a range of component variations within modular product and process architectures is suggested in Figure 11.2. In a modular product architecture, any component variation of a given component type can be mixed and matched with any of the component variations in other component types that the modular component interfaces have been specified to accommodate. Perhaps the most familiar example of a modular product architecture is again the personal computer, which makes possible the ready configuration of many different personal computer varia-

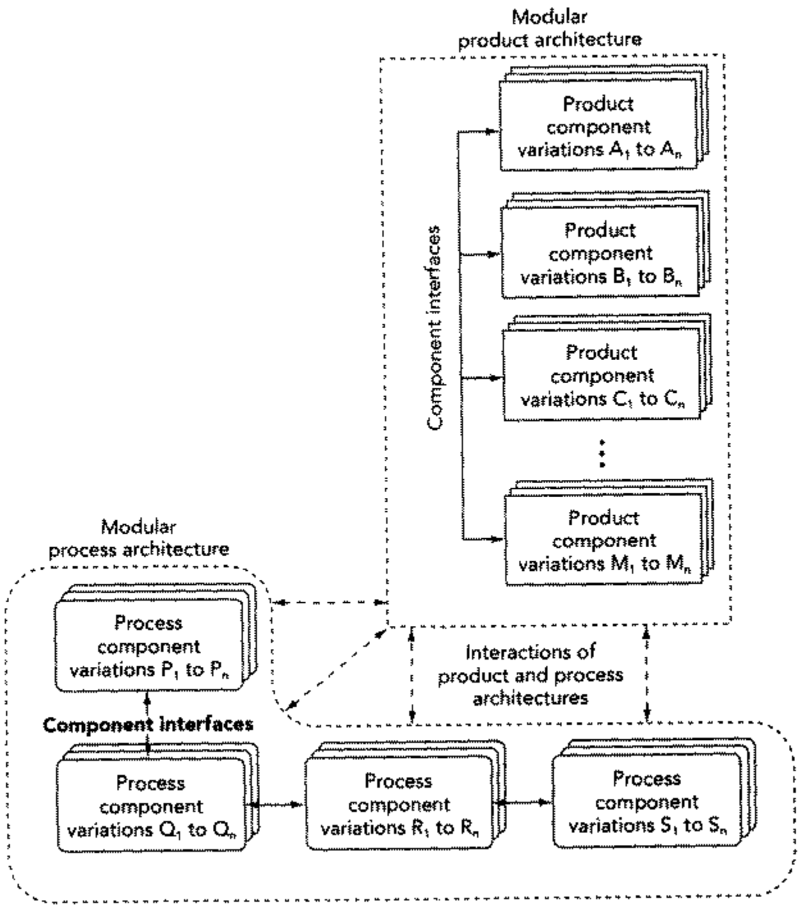

FIG. 11.2 *"Plug-and-play" component variations in modular product and process architectures.*

tions from various combinations of microprocessors, memory cards, hard disks, and other components within the same personal computer architecture.

Similarly, a modular process architecture is one that allows the flexible configuration of a number of process component variations within a stable process architecture. For example, in a modular process architecture, various kinds of development, production, distribution, and support activities may be performed by a firm's own functional groups or outsourced from external suppliers, but all providers of all activities can "plug-and-play" within the same process architecture. IKEA, the Swedish furniture manufacturer and retailer, has created a modular process architecture that provides plug-and-play compatibility among more than 2000 suppliers of furniture components around the world (Normann and Ramirez 1993; Sanchez 1999). All of IKEA's suppliers have been qualified to provide product component variations for IKEA's modular furniture architectures—for example, various table leg sets that can be combined with a number of table top variations. In addition, IKEA's suppliers have also been qualified to be plug-and-play compatible in IKEA's process architecture by following standardized process interfaces that define how orders will be transmitted from IKEA and confirmed by a supplier, how each type of component is to be packed in cartons and loaded into shipping containers, how transportation is to be provided to IKEA's facilities in Sweden, and so on. Qualifying its suppliers to function within its modular process architecture allows IKEA to place orders for product components with any of its suppliers while following a single way of working in coordinating its global network of suppliers.

Modular product and process architectures can bring a firm significant *strategic flexibilities*. Modular architectures enable firms to mix and match component variations to configure product variations to serve diverse market preferences. Modular architectures enable firms to improve product performance by "designing in" upgradability by directly incorporating technologically improved components in products as soon as they become available. Creating modular process architectures helps a firm to reconfigure its supply chains for developing, producing, and supporting products to meet a changing and diverse array of market demands (Sanchez 1995, 1996, 1999).

MODULAR ARCHITECTURES AND TECHNOLOGICAL KNOWLEDGE

Creating modular architectures imposes special demands on an organization's knowledge architecture. The nature of those special demands can perhaps best be understood by contrasting the conventional approach to creating a new product with the process that must be followed to create a modular product architecture (Sanchez and Mahoney 1996; Sanchez 2000).

In the conventional approach, development processes are typically focused on creating new component designs that often use new technical solutions intended to meet new performance or cost targets. The interface specifications that define how the new components will interact in a product design are generally allowed to evolve as component development groups explore and evaluate alternative designs for their individual components. In effect, the designs developed for individual components are allowed to "drive" the specifications of the interfaces between components. The architecture of a new product will therefore be determined by the set of component designs and their resulting interface specifications in the new product design that eventually *emerges* from the development process. This conventional approach to developing products also typically results in components that are tightly coupled in the product architecture—i.e. each component design can typically only be used with the other component designs in the specific product design that emerges from the development process.

By contrast, the creation of a modular architecture reverses the relative priority given to components and interfaces in the development process. A modular development process begins with the full specification of the interfaces between components and then standardizes or "freezes" the interface specifications for the duration of the development process (and often for the commercial lifetime of the product). Standardizing component interfaces has the important effect of constraining individual component development groups to develop component designs that will be compatible with the standardized interface specifications. Constraining development of each component to conform to standardized component interface specifications is the key to creating loosely-coupled component variations that are "plug-and-play" compatible with other component variations in a product architecture (Sanchez 1995, 1999).

The special demands that creating a modular architecture imposes on an organization's knowledge architecture derives from the high level of understanding of the *system behaviors* of the components in its products that an organization must have in order to fully specify modular "plug-and-play" component interfaces in an architecture *before* beginning actual development of components. The distinction between *know-how* and *know-why* forms of knowledge helps to explain this required higher level of understanding (Sanchez 1997).

Know-how knowledge is practical, "hands-on" knowledge of how a given system design currently works and can be maintained in its current state. Know-why knowledge is more fundamental, theoretical knowledge of why a given system works and is the form of knowledge required to create new designs of such systems. Establishing interfaces for a set of existing component designs in a conventional development process is largely a matter of practical, hands-on, know-how driven problem solving. Given a specific set of components emerging from individual component development processes, component developers need only be able to determine a set of interface specifications that will enable that specific set of component designs to work together acceptably. To specify modular component interfaces that will enable a range of different component variations (that are yet to be developed) to work together reliably, however, requires more in-depth, theoretical, know-why understanding of the essential forms of interactions among components in a system design that must be controlled through interface specifications.

When a firm attempts for the first time to fully specify modular interfaces for a range of loosely-coupled component variations in a product architecture, the limitations in

the firm's technical knowledge about the system behaviors of the various types of components in its products will become much more apparent than when the knowledge in the firm is only being applied to defining workable interfaces for a single set of components in a single product design. In effect, trying to create modular architectures is a process that helps a firm understand more clearly what it knows—or does not know—not just about how its current products and processes work, but about how to create system designs for products and processes that have high levels of configurability. When a firm begins to realize that it has limited ability to specify modular interfaces for some of the components in its products or processes, organizational learning can be focused on improving its knowledge of those components and their system behaviors. In this way, efforts to create flexible system designs in the form of modular product and process architectures can become the driver of strategically important technological learning at the know-why level.

Furthermore, when a firm goes through processes intended to create modular product and process architectures, the interface specifications that the firm is able to create provide important insights into the current state of technological knowledge in the firm. Far from being merely a technical detail to be kept on file in the engineering department, the interface specifications a firm creates for its product and process architectures become a strategically important indicator of the level of knowledge the firm currently can apply to creating reliable, flexible system designs for its products and processes. In this regard, interface specifications may serve as both negative and positive indicators of the current state of a firm's strategically important knowledge and capabilities.

As a negative indicator, when a firm's current interface specifications constrain the firm to use only specific component designs in its product or process architectures, the inflexibilities in its component interfaces are likely to impose critical strategic inflexibilities on the firm. For example, a product component interface that requires use of a specific component design will limit the firm's ability to provide a product that meets various customer needs for the function provided by that component. Dependence on a single component design may also create a strategic dependence on a single supplier of that component. Similarly, an inflexible process component interface that locks a firm into using only its own internal processes in performing some activity can prevent the firm from considering outsourcing that activity to external suppliers. In effect, inflexibilities in a firm's current product and process component interfaces constitute "capability bottlenecks" that limit a firm's ability to respond to its competitive environment (Sanchez 2000).

As a positive indicator of firm capabilities, to the extent that the interfaces a firm creates bring it flexibilities to configure product and process variations, the range of product and process variations that the firm's interfaces can accommodate indicate the range of responses the firm is capable of making to changing markets, technologies, and industry conditions. In this sense, the flexibilities designed into the interface specifications of a firm's modular product and process architectures present a "balance sheet" of the organization's current ability to respond to a range of strategic demands and opportunities. Understanding both the constraints and the flexibilities inherent in the interfaces of a firm's product and process architectures is therefore essential to understanding the firm's *systemic flexibility* to respond to diversity and change in its competitive environment. When a firm's architectures include component types and interfaces that are standard within an industry, the firm may then benefit from the capabilities of suppliers and standard components. Thus, a firm's product and process architectures will also determine its ability to address technological knowledge and capabilities beyond its own boundaries.

MODULAR ARCHITECTURES AND MARKET KNOWLEDGE

Modular product and process architectures can improve the *breadth*, *depth*, and *speed* of a firm's processes for developing knowledge about its markets.

Developing broad knowledge of various customer preferences for a given kind of product requires observation and analysis of customer reactions to many different product variations. The more opportunities a firm has to interact with customers in its markets by offering more product variations for customers to react to, the greater the potential for the firm to understand the different sensitivities of various kinds of customers to the functions, features, and performance levels available in its products.

Figures 11.3(a) and 11.3(b) suggest how modular architectures can improve the breadth of knowledge a firm develops about the customer preferences that compose its markets. As suggested by the learning cycle in Figure 11.3(a), a firm that creates single products (or a limited number of related products) will have a limited number of opportunities for customers to interact with its products, to analyze various customer reactions to its products, and to create new products that serve customer preferences more effectively. By contrast, as suggested in Figure 11.3(b), a firm that can create modular product and process architectures that let it readily configure and bring to market a wide range of product variations can significantly broaden the scope of its interactions with its customers—and thereby improve the breadth of its knowledge of customer preferences for the kind of products it offers.

When modular product and process architectures are decomposed so that each function, feature, and performance level provided by a firm's product offers is "contained" within an individual modular component,[2] the ability to mix and match components in configuring modular product variations can help a firm learn about customer reactions to specific component-based functions, features, and performance levels in its products. The potential for this form of market learning is greatest when a firm can offer its customers menus of mix-and-matchable components that let individual customers configure the combination of components each would most like to have—as Dell Computer does in offering its customizable personal computers. In this regard, modular architectures not only make possible product e-business strategies of

[2] "Containing" product variety and change in specific components that deliver specific functions, features, or performance levels in a product is one of several *modular design principles* that enable modular architectures to be used as drivers of market exploration, technology development, and organizational learning (Sanchez forthcoming).

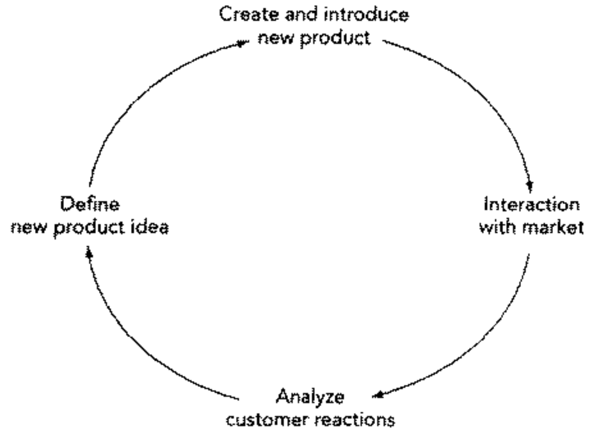

Fig. 11.3(a) *Limited market learning through product-focused development processes.*

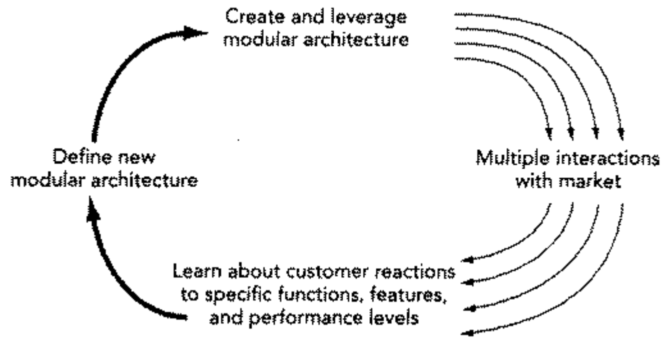

Fig. 11.3(b) *Expanded market learning through architectural development processes.*

mass customization and product personalization (Pine 1992; Sanchez 1995, 1999), but enable a firm to develop much more fine-grained understanding of the characteristics of its products—at the component level—that customers most appreciate. As a firm develops deeper insights into which components in its architectures provide functions, features, and performance levels of greatest concern to customers, it can focus its organizational learning activities on improving those components.

The speed with which a firm learns about market preferences may also be accelerated when a firm can use fast, low-cost configuration of product variations to learn about market preferences in "real time." In real-time market research (Sanchez and Sudharshan 1993), rather than conducting time-consuming forms of traditional market research to determine which future product variations customers might prefer, a firm simply configures and brings to market small batches of product variations (ranging from a few to a few thousand units, depending on the product type) to test customer reactions in real time. Sony used modular architectures, for example, to configure more than 160 variations of its Walkman product for the USA market in the 1980s. By analyzing customer responses to a stream of product variations, Sony was able to discover which combinations of functions (e.g. single direction or auto reverse cassette drives), features (styling variations in plastic cases), and performance levels (Dolby noise reduction, bass enhancement) customers preferred in its new product concept. Today Nike explores evolving market preferences in real time through its Nike Town stores by introducing a changing array of new shoe variations based on "mix-and-match" combinations of soles, primary and accent materials, colors, and ties. By observing in real time which new products based on combinations of modular components elicit the strongest customer response, both Sony and Nike become fast, "real-time" explorers of evolving market preferences.

USING MODULAR ARCHITECTURES TO INTEGRATE TECHNOLOGICAL AND MARKET KNOWLEDGE

Many organizations have adopted long-term planning processes that include forward-looking assessments like market trend forecasting and technology roadmapping. What many firms continue to lack, however, is a clear framework for exercising the "corporate imagination" (Hamel and Prahalad 1991)—i.e. a framework that would help managers to integrate expected developments in markets and technologies into a vision of feasible future products and processes, and to identify new capabilities that would enable a firm to create future products and processes.

When market forecasting and technology roadmapping suggest that there are several possibilities for new technologies and future market preferences, selecting specific future products to develop often becomes quite problematic. On the one hand, very strong—and usually risky—assumptions about which future technologies and market preferences will become dominant would have to be made in order to identify the "most valuable" or "most promising" possibilities for future products. On the other hand, managers who are uncomfortable with making explicit assumptions about future outcomes may prefer to follow their "gut feel"—with the result that selection of future products for development often becomes *ad hoc*, arbitrary, and subject to undefined decision criteria that vary from manager to manager.

An alternative approach to strategic decision making under conditions of irreducible uncertainty about future markets and technologies is to refocus the attention of the firm on identifying and creating *strategic flexibilities* that will enable a firm to respond to a range of market and technology possibilities in the future (Sanchez 1993, 1995). The inherent flexibility of modular architectures to support configuration of many product variations offers a way out of decision-making dilemmas in product planning processes. Compared to asking managers to agree on specific products to develop when future market preferences and technology possibilities are uncertain, it is much more feasible for managers to discuss and agree on a *range* of future product variations to serve possible developments in market preferences and alternative technologies that managers consider most likely. When an organization's knowledge architecture enables it to create modular architectures for configuring a range of future product variations, a firm's long-term planning process can be redirected to defining and developing future-generation modular architectures that can respond to a range of future market and technology possibilities.

Moreover, much organizational learning and development of new capabilities takes place in product development projects. When a firm's long-term planning process is focused on individual products, project-driven organizational learning often builds unconnected islands of technical and market knowledge relevant only to specific future products. If the products a firm must create in the future change because of future developments in technologies or markets, the narrowly focused knowledge a firm has created in pursuing its original set of future products may not be readily applicable in creating a new set of future products. Organizational learning in projects to create future modular architectures that can support many product variations, however, will be inherently more deployable across a range of future product possibilities.

Some firms have recognized that processes for planning, creating, and leveraging modular architectures provide a powerful new framework for integrating a firm's evolving technical and market knowledge into effective product strategies (Sanchez 1995; Sanchez and Collins 1999). Figure 11.4 suggests some of the ways that modular architectures lead to a more integrative framework for leveraging an organization's current technological and market knowledge and for focusing organizational learning on creating new knowledge and capabilities with significant strategic benefits.

The objective in creating a next-generation modular architecture is to give a firm the broadest possible market coverage and the fastest possible upgrading of its products as technologically improved components become available. In essence, the objective for a next-generation modular architecture is to create a "platform" for responding effectively to a defined range of near-term market demands for product diversity and near-term opportunities for technological improvement. In effect, the next-generation architectures the firm creates will determine the *strategic options* the firm will have to bring product offers to its markets in the near term (Sanchez 1993, 1995). Creating next-generation modular architectures therefore provides a process for integrating identified near-term market opportunities with any new technological knowledge and capabilities the firm has created.

The leveraging of current-generation modular architectures consists of configuring product and process variations to explore markets and discover which configurations of products offer the best options for serving current market preferences. Leveraging current-generation architectures thus becomes the primary way a firm responds to both technology and market development opportunities in the near term. Technology development is focused on developing new component variations for the current-generation modular architecture. Market exploration then tries to determine which combinations of component variations are most effective in serving the current preferences of various customer groups. When marketing processes develop insights into

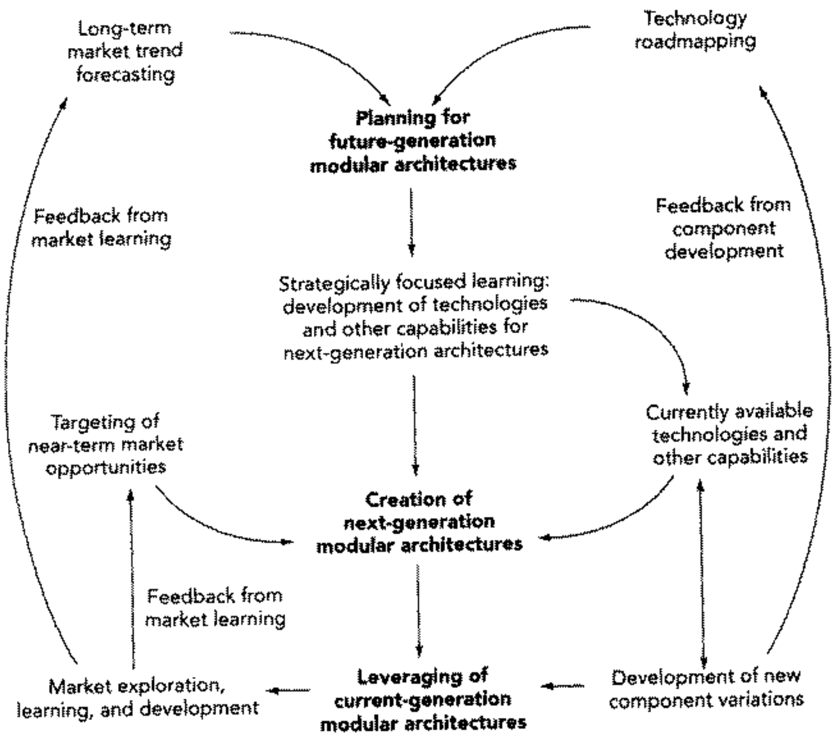

FIG. 11.4 *Planning, creating, and leveraging modular architectures as a framework for integrating technology and market knowledge.*

which component-based functions, features, and performance levels customers are most sensitive to, technology development efforts can be directed to creating a wider range of choices in those types of components and to developing higher performing versions of critical components.

Through its processes for exploring current market preferences, a firm may develop insights into possible evolutions of market preferences that become important inputs into a firm's long-term market forecasting. Similarly, the technical knowledge a firm creates in developing component variations to be used in next-generation and current-generation modular architectures can provide insights that improve a firm's technology roadmapping activities. For example, a firm's own experience in improving key components may help to form more accurate expectations as to future rates of technological improvement in those components, and such technological insights can improve a firm's planning processes for future-generation architectures.

IMPACTS OF MODULAR ARCHITECTURES ON ORGANIZATIONAL COMPETENCE

Sanchez, Heene, and Thomas (1996) proposed a working definition of organizational competence as "the ability to sustain the coordinated deployment of assets in ways that help a firm achieve its goals." As noted in the opening chapter of this volume, this simple definition incorporates the "four cornerstones" of the competence perspective:

1. The environment of a firm is *dynamic*. The normal state of affairs for most organizations is that both the markets they serve and the technologies that can be used to serve those markets are changing. An essential characteristic of the competent organization therefore is that it can sustain its ability to create value in its markets by responding advantageously to the market and technology dynamics in its environment.
2. Organizations are open systems that are embedded in larger "macrosystems" of industries and societies. Change in organizations is therefore *systemic* in nature and calls for approaches to managing change that can coordinate all the interacting elements of an organization in creating the new capabilities needed to respond to a changing environment. In effect, a key challenge in improving organizational competence is to increase the flexibility of the firm as an open system to respond effectively and quickly to the dynamics and diversity of its environment.
3. Managing systemic organizational change in a dynamic environment poses substantial *cognitive* challenges for managers. Much change in an organization's environment is uncertain, and the systemic adjustments needed in an organization to respond to various forms of change can be quite complex. The capacity of the human mind is constantly challenged by the complexity of the management task, and organizations must try to imagine and implement better approaches to managing complexity under conditions of dynamic uncertainty.
4. Managing organizations as systems in a changing and uncertain environment requires an understanding of the *holistic* nature of organizations. As open systems, organizations depend on ongoing flows of resources from many resource providers. As a result, the individual interests of many providers of essential resources intermingle in an organization. To continue to attract and access the best available resources in carrying out its processes, managers must recognize and provide adequate incentives and rewards to all providers of essential resources needed by the organization.

We now consider how learning to create and leverage modular product and process architectures can improve an organization's ability to manage its knowledge in ways that contribute significantly to each of these four dimensions of organizational competence.

Responding to environmental dynamics

Organizational competence requires the ability to respond advantageously to changes in both markets and technologies. Using modular architectures can significantly improve the responsiveness of a firm to both forms of change.

During the life cycle of a product, changes in market preferences typically evolve through several distinct stages (Sanchez 1995). When a new product concept is first introduced, potential customers who are unfamiliar with the new product concept are likely to be uncertain which "bundle" of functions, features, and performance levels they would prefer if they were to start using the new product. By creating a modular product architecture that can provide a range of product models based on different combinations of mixed-and-matched functional components, a firm may be able to stimulate initial trial of a new product by offering low-cost introductory product models that provide only the "core" set of functions, features, and performance levels essential to the new product concept. As adopters of a new product concept gain experience in using the product in their patterns of living, they may develop the ability to imagine the benefits to be derived from more fully featured, higher performing models, which the modular architecture may then be used to bring to market. As customers become more sophisticated in their understanding of the uses of the product, and as groups of customers begin to develop preferences for specific bundles of functions, features, and performance levels that best suit their individual lifestyles, modular architectures may be used to leverage a broad range of product variations to serve emerging market segments. In the most advanced stage of evolution of a market, some customers may come to understand how each component in a product contributes to the overall functionality and performance of the product. Modular architectures may then be used to present menus of component choices to customers that enable them to configure their own preferred, mass-customized product variation.

In this pattern of market evolution, it may be both necessary and desirable to create a succession of progressively more elaborate modular architectures to serve the increasingly sophisticated and diverse preferences of customers. Compared to trying to develop a growing range of individual product variations one at a time, however, creating modular architectures offers a much faster and more cost efficient way for a firm to investigate customer preferences as a market evolves (Sanchez 1999).

Used in this way, modular architectures can also help a firm use and develop new technological knowledge more effectively in serving evolving customer preferences. Changes in technology are normally embodied in either higher performing versions of current components or in wholly new kinds of functional product or process components. Anticipated technological changes—whether generated internally by the firm or adopted from external sources—may often be accommodated in modular architectures by "designing in" the flexibility to upgrade key product and process components as technologically improved components become available. Personal computer architectures, for example, typically use standardized component interface specifications that allow direct introduction of progressively higher performing components, such as the progressive upgrading of CD-ROM drives from 1X to 24X read speeds. Current generation personal computer architectures also have flexible interfaces for connecting computers to future-generation peripheral devices and complementary products. The FireWire port now designed into personal computers, for example, provides an interface for connecting computers to a growing number of new technology products like digital photograph and video cameras, audio systems, and televisions.

Beyond enabling a firm to leverage its current technical knowledge into product markets more effectively, modular architectures can also help a firm develop new technological knowledge that will be effective in serving evolving market preferences. By using modular architectures to explore market reactions to different combinations of component-based functions, features, or performance levels, a firm can more precisely direct its technological learning to improving components and creating new components that will provide the product characteristics most appreciated by customers.

Managing the firm as an open system

The "market test" of the competent organization is its ability to bring successful products to markets. Creating and realizing successful new products requires the ability to access and coordinate the best available resources for developing, producing, distributing, and supporting the products a firm brings to market. When a firm's knowledge architecture enables it to create modular product and process architectures, the firm can access a wider pool of resources for creating and realizing products, can coordinate those resources with reduced levels of financial and management inputs, and can accelerate the speed of its product creation and realization processes. The effect of these benefits is to give a firm more—and more valuable—*strategic options* to develop and realize products. Having more strategic options increases the *strategic flexibility* of the firm as an open system to respond advantageously to diversity and change in markets and technologies. Each of these elements in the new "strategic logic" of modular architectures deserves further explanation (Sanchez 1995).

First, let us consider how modular architectures make it possible for a firm to access a wider pool of resources for creating and realizing products. Recall from the discussion above the critical difference between conventional and modular development processes. In conventional development processes, the interfaces between functional components are determined by the designs of the individual components being developed and thus "evolve" during the component development process. Since individual component designs must work together in a product or process design, however, component designs must always be coordinated technically to assure that they will work together as a system. The investigation of alternative component designs by various component development groups therefore creates a constant stream of "interface issues" (Sanchez 2000). For example, when development groups for two interacting components create component designs that must subsequently be modified in order to work together, which group's component design should be modified, and in what ways? If design changes have to be made in one development group's component design because of a design change made by a second component group, which development group's budget should the cost of the design change be charged to? And how will such changes affect each development group's performance evaluations? Since resolving such issues may take a great deal of time and could become quite contentious if the component development groups are in different firms, conventional development processes are most commonly carried out within a single "authority hierarchy"—i.e. within the boundaries of a single firm—to enable managerial resolution of such issues (Sanchez and Mahoney 1996).

In contrast, by initially standardizing interface specifications for all components, the modular approach to creating product and process architectures essentially prevents such interface issues from arising and makes it much more practical for a firm to collaborate with component development resources beyond its own boundaries. When a firm's knowledge architectures enable it to define and standardize the interfaces between the components in its new product and process architectures before beginning development of new components, the firm effectively creates a well defined and stable technical environment for developing new components. The ability to define stable component development tasks that will not generate interface issues makes it much more possible for a firm to work with other firms in its own development processes. Thus, creating modular product and process architectures can make it possible for a firm to access a greatly enlarged pool of component development resources beyond its own boundaries, and thereby may greatly expand the number and range of products the firm can create and realize (Sanchez 1999).

Furthermore, establishing standardized component interfaces for a modular architecture creates an *information structure* that provides *embedded coordination* of component development tasks. Because standardized interface specifications effectively prevent interface issues from arising, modular development processes require much reduced levels of management inputs.[3] Alternatively, for a given level of management resources, modular architectures may let a firm greatly expand the range of products and processes it develops. When modular architectures improve a firm's ability to access development resources outside the firm, the financial resources a firm must directly invest to develop new products may also be reduced.

Modular architectures can also substantially reduce the time required to create and realize new products and processes. The key to accelerating product development is fully specifying—and then freezing—component interfaces to enable truly concurrent component development processes. When firms attempt to implement concurrent engineering practices, but do not fully define and standardize interface specifications governing interactions between components, the result is typically a form of "concurrent chaos" in which uncontrolled development of component designs quickly generates a complex and potentially paralyzing tangle of incompatible component designs. Firms that can fully define and standardize modular component interface specifications before beginning concurrent development, however, have reported 50 to 80 percent reductions in development time (and resources) required to design components for new products (Sanchez forthcoming).

[3] Although fewer management inputs will be required during development of components, increased management inputs will normally be required in processes for defining the interfaces in modular architectures. Moreover, those management inputs may be qualitatively different from the inputs normally provided by managers to development processes. Since the modular architectures the firm creates will effectively determine the strategic flexibility of a firm to respond to market and technology opportunities, a primary input required from managers is a clear strategic vision of the range of market and technology opportunities the firm will seek to respond to through its product and process architectures. (See Sanchez forthcoming.)

The strategic flexibility of a firm to respond to opportunities and demands can be expressed in concrete terms by the set of definable *strategic options* the firm has to bring specific products to market. The more component variations the interfaces in its architectures enable a firm to use, the more strategic options the firm will have to configure product variations that can respond to change and diversity in markets and technologies. Because modular architectures may also enable a firm to draw on a wider base of development resources, to coordinate those resources with fewer management and financial resources of its own, and to use concurrent design of components to bring new products to market faster, a firm that learns how to create modular product and process architectures may create more strategic options—and thus greater strategic flexibility. Moreover, to the extent that a modular-capable firm creates its strategic options at lower costs and can exercise those options (i.e. bring new products to market) faster than other firms,[4] each of its strategic options will also be more valuable than it would otherwise be. Used in this way, modular architectures can increase the strategic flexibility of a firm as an open system to respond advantageously to change and diversity in its environment.

Managing cognitive processes

Sensemaking is a fundamental activity of organizations. Managers must "make sense" of the organization as a system, of the change and complexity in the organization's competitive environment, and of the best prospects available to an organization for survival and success. The primary way that a firm seeks to survive and succeed in its environment is through creating and realizing products. When managers think in terms of developing individual products as the way to respond to environmental change and diversity, the ability of managers to develop a clear, coherent strategy for a firm may be overwhelmed by the large number of product variations needed to serve diverse market demands and keep up with competition. The cognitive complexity of managing change and diversity in competitive markets can be significantly reduced, however, when managers begin to think in terms of creating modular architectures that can serve a range of market demands and can support significant extensions and renewals for a range of products.

The concept of logical incrementalism (Quinn 1978) helps to clarify the way in which modular architectures can simplify the cognitive processes involved in managing competitive dynamics and complexity. The basic notion of logical incrementalism is that organizational change can be managed more effectively when it is undertaken in incremental steps that progressively and logically lead to new organizational activities.

[4] The value of an option increases with the length of time during which an option can be exercised. However, when the value of the underlying asset (the asset that can be claimed by exercising the option) can be expected to decrease or "erode" over time, the optimal time to exercise an option may be sooner rather than later. When a firm has a strategic option to bring a new product to market, but the potential value of that opportunity is decreasing with the passage of time because other firms can be expected to bring competing products to market, a firm's ability to bring a new product to market faster (i.e. to exercise its option sooner rather than later) will increase the value of that option (Sanchez 1993).

In essence, the best approach to managing an organization in a changing environment is likely to be continual, progressive adjustments of its products and processes in ways that are readily understood by everyone in an organization.

The usual interpretation of logical incrementalism is that decomposing change into small increments is generally beneficial, because small adjustments are easier to accomplish in organizations than radical, "big bang" transformations. What an architectural perspective on managing change helps us to understand, however, is that trying to manage change by making "too many" incremental adjustments that are "too small" can generate its own form of organizational complexity. In particular, trying to make large numbers of incremental changes in individual products in an effort to keep up with high rates of market change can create organizational complexity that makes it difficult for managers to maintain clear direction and focus in an organization's market strategies. Given the dynamics and diversity in market demands that many firms face today, developing individual products is often simply too small an incremental adjustment to sustain coherent, manageable, strategically focused organizational processes. Even if a firm that develops individual products manages to sustain high levels of product development activity in many projects, its managers may lose a clear understanding of where all its development activities are headed, and why.

Modular architectures, however, offer a larger unit of incremental adjustment that is more appropriate for conceptualizing and managing a firm's response to dynamic competitive environments. By offering managers a feasible basis for thinking in terms of making incremental adjustments that can cover a range of current and future market possibilities, modular architectures offer a more comprehensible—and thus more cognitively feasible—unit of incremental adjustment in formulating an organization's strategies for responding to high levels of change and diversity in product markets.

Managing organizations holistically

Organizations are communities of convergent—but not identical—interests. The interests of key resource providers to an organization will necessarily have something in common—namely, a desire to see an organization succeed, at least in ways that can help individual resource providers achieve their goals. But the differences in goals that typically exist across individuals suggest that there will rarely be perfect alignment of interests among all individual resource providers to an organization. To attract and maintain the best possible flows of essential resources, the competent organization must understand what kinds and levels of rewards it must distribute to all individual providers of essential resources. The concept of managing organizations holistically is therefore not a simplistic communitarian notion, but rather a concept that recognizes the importance of defining, measuring, monitoring, and rewarding the contribution that each resource provider makes to the overall ability of an organization to create value through its product offers.

Developing new products in the conventional way—i.e. by letting component interfaces be driven by component designs—inherently creates a tight coupling between

component development activities. When component development groups are not constrained to honor standardized component interface specifications, design decisions made in one development group are very likely to affect the suitability of the component design decisions made in other development groups. This technical interdependence between component designs creates two conditions of tight coupling. Both the performance of a given component in the product and the performance of each component development group in designing their component will depend on decisions made by other development groups. Since both modes of performance depend on factors beyond the control of any development group, the tight coupling of component development processes in conventional development processes makes it virtually impossible to determine the relative performance of individual component development groups in the overall development of a product. When the relative performance of component development groups cannot be ascertained, determining an appropriate distribution of rewards to development groups becomes problematic.

When a firm follows a modular approach to creating and realizing products, however, the standardizing of component interface specifications before component development begins means that design decisions made in one component development group will not be affected by design decisions made in another development group, as long as all development groups honor the standardized component interface specifications applicable to their component. Component development activities therefore become loosely coupled, and this makes it more feasible for a firm's managers to assess the relative performance of each component development team in carrying out its design task, and to distribute rewards accordingly.

Adopting modular process architectures brings a similar improvement to the evaluation of groups in performing activities in a process architecture. When the interfaces that define the inputs and outputs of process activities are not fully specified and standardized, variations in the outputs of one process activity may have disruptive impacts on the downstream process(es) it provides inputs to. When a group responsible for a process activity is subjected to inadequately controlled variations in inputs that affect its ability to perform its task well, it is difficult if not impossible to fairly assess that group's performance and to allocate appropriate rewards. When an organization has a modular process architecture, however, the well defined and standardized input and output interfaces between activities creates a loose coupling between activities. The loose coupling of activities in a modular process architecture makes it more feasible to assess and reward the relative performance of each work group in carrying out its process activity. Having well defined processes and interfaces also improves the ability of a firm to benchmark the practices and performance levels of its work groups against those in other organizations.

CONCLUSION

Compared to current practices in most organizations, the use of modular architectures requires a higher degree of definition of an organization's current knowledge and capabilities and a more disciplined approach to learning through product creation and realization processes. Making the transition to a more defined and disciplined modular way of working, however, can help an organization understand and manage some fundamental—but at first counterintuitive—aspects of organizations. We conclude this discussion of modular architectures in organizational competence by summarizing two counterintuitive ways that the definition and discipline inherent in modular architectures can improve organizational flexibility and creativity.

In our usual perceptions of the product creation process, we observe new products emanating from organizations and therefore are likely to surmise that "organizations design products." Viewing the product creation process from an architectural perspective, however, helps to reveal the profound impact that an organization's product architectures have on the way an organization is structured and functions—i.e. the fundamental ways in which "products design organizations." Without the benefit of this architectural perspective, efforts to improve an organization's competence in creating new products are likely to be focused on improving the way the organization currently works. Such efforts usually try to add new coordination procedures, more communication links between development groups, more reporting or oversight responsibilities, and so on. In a basic sense, however, trying to improve product creation competence by improving conventional development practices is tantamount to treating the symptoms of a dysfunction rather than correcting the underlying cause of the dysfunction. The architectural perspective helps us to understand that significant improvements in an organization's product creation competence must begin with improvements in the architectures of the products the organization creates. Improved organizational flexibility in product creation will not be attainable unless an organization's product architectures become more flexible, and modular architectures are the quintessential flexible architecture.

Another common perception is that generating "creative" new products requires a "creative" organizational environment, which is often assumed to be an essentially unstructured, unfettered environment in which "creative" people may freely try out all kinds of new product ideas and ways of doing things. As a consequence, many people would consider an environment that requires disciplined adherence to a well-defined process structure to be inimical to creativity. What the architectural perspective makes plain, however, is that disciplined adherence to a well-defined *modular* development process can enable many new configurations of products and processes to flourish.

Music offers an instructive analogy. The tonal scales of notes in music are a well-defined but flexible structure for inventing virtually unlimited new combinations of notes. Creativity in music can be expressed both by inventing new kinds of music architectures for arranging notes (sonatas, blues, bebop jazz) and by composing new combinations of notes within existing architectures. It would be difficult to argue that accepting the discipline of working within the tonal scale structure compromised the creativity of Amadeus Mozart or Miles Davis in creating and using music architectures. On the contrary, the discipline of following the tonal scale structure has enabled the creation of many music architectures that facilitate an endless stream of creative

improvisation. In an analogous way, learning to work in a well-defined and disciplined modular process can help organizations create architectures that enable creative, improvisational configuring of new products and processes that work effectively together. Creating and using modular architectures may well become an essential capability of those organizations that know how to be both creative and effective in meeting the market test for competence.

REFERENCES

GARUD, R. and A. KUMARASWAMY (1993). "Changing competitive dynamics in network industries: An exploration of Sun Microsystems' open systems strategy," *Strategic Management Journal*, 14 (5), 351–69.

HENDERSON, R. and K. B. CLARK (1990). "Architectural innovation: The reconfiguration of existing product technologies and the failure of established firms," *Administrative Science Quarterly*, 35, 9–30.

HAMEL, G. and C. K. PRAHALAD (1991). "The corporate imagination and expeditionary marketing," *Harvard Business Review*, 69 (4), 81–93.

NORMANN, R. and R. RAMIREZ (1993). "From value chain to value constellation: Designing interactive strategies," *Harvard Business Review*, 71 (July–Aug.), 65–77.

ORTON, J. D. and K. WEICK (1990). "Loosely coupled systems: A reconceptualization," *Academy of Management Review*, 15 (2), 203–23.

PINE, J. D. (1992). *Mass Customization: The New Frontier in Business Competition*. Boston: Harvard Business School Press.

QUINN, J. B. (1978). "Strategic change and logical incrementalism," *Sloan Management Review*, 20 (1), 7–16.

SANCHEZ, R. (1993). "Strategic flexibility, firm organization, and managerial work in dynamic markets: A strategic options perspective," *Advances in Strategic Management*, 9, 251–91.

—— (1995). "Strategic flexibility in product competition," *Strategic Management Journal*, 16, 135–59.

—— (1996). "Strategic product creation: Managing new interactions of Technologies, Markets, and Organizations," *European Management Journal*, 14 (2), 121–38.

—— (1997). "Managing articulated knowledge in competence-based competition," in R. Sanchez and A. Heene (eds.), *Strategic Learning and Knowledge Management*. Chichester: John Wiley, 163–87.

—— (1999). "Modular architectures in the marketing process," *Journal of Marketing*, 63 (Special Issue 1999), 92–111.

—— (2000). "Modular architectures, knowledge assets, and organizational learning: New management processes for product creation," *International Journal of Technology Management*, 19 (6), 610–29.

—— (forthcoming). *Modularity, Strategic Flexibility, and Knowledge Management*. Oxford: Oxford University Press.

—— and R. P. COLLINS (1999). "Competing in modular markets," working paper #IMD 99-7, IMD—International Institute for Management Development, Lausanne, Switzerland.

—— and J. T. MAHONEY (1996). "Modularity, flexibility, and knowledge management in product and organization design," *Strategic Management Journal*, 17 (Winter Special Issue), 63–76.

SANCHEZ, R. and D. SUDHARSHAN (1993). "Real-time market research," *Marketing Intelligence & Planning*, 11, 29–38.
—— A. HEENE, and H. THOMAS (1996). *Dynamics of Competence-Based Competition*. Oxford: Elsevier Pergamon.
SANDERSON, S. W. and M. UZUMERI (1997). *Managing Product Families*. Chicago: Irwin.

Knowledge Management and Organizational Competence

Edited by
RON SANCHEZ

OXFORD
UNIVERSITY PRESS

OXFORD
UNIVERSITY PRESS

Great Clarendon Street, Oxford OX2 6DP

Oxford University Press is a department of the University of Oxford.
It furthers the University's objective of excellence in research, scholarship,
and education by publishing worldwide in

Oxford New York

Athens Auckland Bangkok Bogotá Buenos Aires Cape Town
Chennai Dar es Salaam Delhi Florence Hong Kong Istanbul Karachi
Kolkata Kuala Lumpur Madrid Melbourne Mexico City Mumbai Nairobi
Paris São Paulo Shanghai Singapore Taipei Tokyo Toronto Warsaw

with associated companies in Berlin Ibadan

Oxford is a registered trade mark of Oxford University Press
in the UK and in certain other countries

Published in the United States
by Oxford University Press Inc., New York

First published 2001

British Library Cataloguing in Publication Data

Data available

Library of Congress Cataloging-in-Publication Data

Knowledge management and organizational competence / edited by Ron Sanchez
p. cm.
Includes bibliographical references and index.
1. Knowledge management. 2. Organizational learning. 3. Organizational
effectiveness. I. Sanchez, Ron.
HD30.2 .K63685 2001 658.4'038—dc21 2001034046

ISBN 0-19-924028-0

1 3 5 7 9 10 8 6 4 2

Typeset by
J&L Composition Ltd, Filey, North Yorkshire
Printed in Great Britain
on acid-free paper by
T.J. International Ltd., Padstow, Cornwall