SERENDIPITOUS AND STRATEGIC INNOVATION

A Systems Approach to Managing Science-Based Innovation

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engaged in the business of invention—no matter how much effort is needed to turn the idea or prototype into a useful or marketable product. The terms "invention" and "innovation" are ingrained in the minds of corporate managers, scientists, business pundits, and many others. But not all have the same understanding or interpretation of the terms. The idea of "innovation" culminated for many centuries with the development of the wheel, and later the printing press, or much later, the steam engine, which were linked with new products, new processes, and new services. The word "genius" was coined with the thought of someone doing something that fascinated others. Innovation is a combination of need and surprise. The need for innovation in health and medicine goes back many centuries. The desire to cure diseases or prevent death gave rise to new methods of providing health. Yet in recent times, innovation in the medical field has been the tendency to focus on health creation, rather than on simply the curing of disease. Today, there is a plethora of medical implant devices, many of which would be considered as fashionable, rather than lifesaving, treatments. Innovation in the health and medical industries has proliferated across the entire value chain, strengthening what can be extracted as profits. The human choice for a higher standard of living has generated innovation in directions that would have been considered an impossibility only a few years ago. Some advances are the consequence of scientific endeavor, such as that in genomic research. Academia has provided the strong base for the development of science that has led to useful innovation. From the times of great surgeons and physicians such as Hippocrates of Cos (460-c.–370 BC), Galen of Pergamum (130-c.–200-c.), Andreas Vesalius (1514–64), Fabrizio (1533–1619), and William Harvey (1578–1657), scientists such as Robert Hooke (1635–1703) (experimented with blood transfusion), Sanctorius Sanctorius (1561–1636) (invented the clinical thermometer), and Luigi Galvani (1737–98) (discovered electrophysiology) have made invaluable contributions through disciplined research and procedures punctuated by serendipitous discoveries. Advances in the natural and physical sciences in turn have contributed to advances in medical innovation. Today, the natural and physical sciences are inseparable from the biological and medical sciences. Bioinformatics, for example, is a convergence of biotechnology, mathematics, and the information sciences.

The role of the individual is essential in synergizing thought and action in the processes of invention and innovation. Invention is the act of producing or thinking about something for the first time. Innovation, on the other hand, refers to making changes by introducing something new, and relates to change in or the alteration of what currently exists. There is always a beginning and an end to the innovation process. The inventive activities start the innovation process and end when the commercialization phase completes. Most inventions will not complete the entire journey of innovation. Further, some inventions yield positive social and economic outcomes, while others create social unrest, chaos, and destruction. The way we manage the process of innovation or coming up with solutions that can combat social stability is equally as important as creating marketable gadgets that create wealth and satisfy the curious inventor. The question is how inventive and innovative activities can be sustained? Surely, the answer lies in synergizing serendipitous and strategic innovations for the advancement of civilization and the world around us.

The journey of innovation, in our view, consists of four pillars: knowledge creation, organizations, strategy, and people. These four pillars are the foundation for all innovation. These pillars are interconnected processes that integrate various components of scientific and technological, business and socioeconomic systems. Human knowledge, both divergent and convergent, is the binding force of all inventive and innovative activities. Without people, their inventive spirit and commitment, inventions travel nowhere. Even with the best of efforts, the potential for success in turning an invention into a useful and innovative outcome depends on supportive structures and effective strategies.

In this book, we forward the concept of the "four pillars" for the construction of a useful system of innovation. Systematic thinking is required to make innovation work for nations, institutions, and individuals. In our view, the pillars are neither independent nor free-standing; they are interconnected and extended to endless frontiers. The innovation process will not be fulfilled in the absence of any one of the "pillars." All pillars do not have to be equal in strength for a given organization. Even within the same organization, the integration of "pillars" is necessary to reinforce the weak relationships and missing links. The climate for integration, which is also referred to as the "innovative culture," needs to be nurtured. Innovation culture evolves and shapes according to the configuration of pillars and it forms in response to strategic needs of an organization. Often, the winds of change for innovation culture flow from selected individuals who act as leaders and change agents. Leadership is an important ingredient in achieving sustainable innovation.

Our observations and investigations span many institutions, both private and public sector, to understand this apparently simple, but in reality a complex process of innovation. The laboratory is still the sacred sanctuary where knowledge continuously evolves. The dynamics in a research laboratory are very different from that of a boardroom in a firm. Yet, the resounding impulse of generating knowledge and turning it strategically into useful devices is common to both places. We have examined how inventions have come about in response to an individual action and the way such action ultimately led to serendipitous and strategic innovations that transform social and economic structures. We have also observed human failures in making innovation, spoken to many inventors, and seen the commitment and determination of those inventors who had the courage to carry on. This book is an attempt to capture some of the insights and experiences of a number of individuals who were responsible for inducing serendipitous and strategic innovations in organizations.

Our experience also draws on a variety of scientific and technological fields and practices, and this has naturally led to divergent views and syntheses of observations. With multidisciplinary medical, chemical, biological, engineering, and social-science backgrounds, we have attempted to find a middle ground to reflect on the four pillars of innovations. The insights outlined in this book have been enriched with years of experience in engaging in and analyzing the process of innovation. The pillars are as strong as they can be. Yet we cannot claim that we have seen all of the trees in the woods that we have traversed. To capture all about invention and innovation is simply a formidable task that none can expect to accomplish in a lifetime. This underscores the difficulty of the lenses that we are looking through to view the innovation process and their uniqueness to each episode in bringing an idea through to a new product, process, or service. Every invention is different and unique. All of the inventors to whom we have spoken have offered an interesting twist to their individual stories. This warranted looking at the innovation process from a systems perspective. We hoped it would provide us with a better framework, or at least another excuse for examining the process closely.

We have deliberately selected the field of medical sciences because it offers more complex issues in introducing innovation processes; further, two of the authors have had the good fortune to work as leading inventors and innovation champions in medical sciences. The fundamental objective in medical invention is the application of such inventions to the well-being of patients. The creation of knowledge and invention is exhilarating in all accounts of the medical innovation process.

The structure of this book has therefore been shaped alongside the journey of making scientific enterprise more relevant to organizations. Chapter 1 outlines the key issues confronting the management of innovation. It focuses on the mindset necessary to view the innovation process in totality. Some would find it easier to modularize innovation functions. It is somewhat easier to examine knowledge exploration through research activity. It forms the foundation for idea generation. Many of the ideas that are generated require testing and evaluation for validity and rigor. The concept of the four pillars of innovation allows us to examine knowledge exploration, especially in research institutes. The first chapter provides a general overview of innovation and its place in the economy and in society. Innovation in the modern context has to be examined alongside social dynamics—not separately; it would be a fatal mistake for a firm to not be concerned with greater social considerations. Take, for example, the cases of Nike ICI and Shell. These companies have had major public-relations problems owing to the lack of corporate social responsiveness at some stage or other in their corporate history. Innovation introduces change, which also inevitably has social and economic consequences. A corporate reputation can easily be tarnished, in some cases beyond repair, if a good corporate image is not upheld. Pressure groups, including labor unions, human-rights activists, and environmental lobbyists, can exert great influence over a good corporate image. In addition, increasing legal threats are being leveled at some innovation outcomes, as well as corporate wrongdoing or investment in failed innovations. Managing innovation requires an understanding of the whole, and not only the parts and components, of the innovation system. Systems theory is drawn on to examine such integrative and interlinked processes.

Chapter 2 examines inventive and innovation activities as an evolutionary process, which extends dynamic relationships with academic, industry, and government institutions. Knowledge in action is the main constituent for initiation of the innovation process. The importance of the knowledge pillar is outlined using specific examples. Perhaps an important lesson for managing the knowledge pillar for firms is to never underestimate the importance and usefulness of prior knowledge. Innovation is the synthesis of existing knowledge as much as the production of new knowledge. Even in science-based innovations, new knowledge is built on past proven knowledge, and a good understanding of its presence and its value to an organization must never be underrated. To understand these intricate dynamic relationships, it is necessary to identify the concept of linkages and boundaries of innovation. Research linkages, for example, foster collaborative and trusting relationships that are useful to promote specific types of invention or innovation. A firm's success can be achieved only through understanding how innovation activities and functions are interlinked with business and technology. This chapter outlines how business, science and technology integrate to produce useful innovation. Various models and theories of innovation have been considered with several case studies that depict the way innovation comes about and progresses through vast reservoirs of existing knowledge and the combination of such knowledge with new knowledge.

The third chapter examines the way clusters can contribute to innovation, and innovation contributes to clusters. Strategic integration and direction are the most recurrent themes in innovation. Without a well-articulated innovation strategy, integration of innovation with business development is difficult. Another concept of innovation is the proximity. Physical and intellectual proximity is, interestingly, an important consideration. However, does distance matter, where information technology can coexist with old and outdated technology, as is evident in call centers located in Indian cities like Bangalore? The coevolution and coexistence of technological capability have induced different types of organizational innovation in the service sector. Most manufacturers today aimed at outsourcing certain information-processing functions to companies elsewhere in the world. The connectivity through information and communication technology has enabled firms to identify the weakest links in their value-creating process and to outsource them to those who are strongest in performing those tasks, in order to create profitability. Various integrative mechanisms that determine the formation of industry clusters that contribute to innovation quotation are examined in this chapter.

Chapter 4 examines national innovation systems theory whereby knowledge, people, strategy, and organization intersect. This chapter examines salient features of the national efforts and shows that the formation of national regional innovation capacity evolves along strategic and directed pathways. The role of the public sector in innovation is especially examined to identify the key underlying forces.

Chapters 5 and 6 deal with organizations and human capabilities. Both issues are of great importance to innovation in the areas of health and medicine. Chapter 5 outlines medical innovation in the fields of cardiac technology and hypertension. The key to medical innovation is the interface between practicing physicians and researchers. It is important to understand the options available in medical research. There can be thousands of clinical possibilities; however, in the end, what works is what physicians would regard as robust, reliable, and good for the patients. Fortunately, there are no shortcuts in medical innovation. The chapter outlines the intrinsic features in introducing innovative medical developments and their links with organizational capability development and assessment. Developing innovation capability is discussed in this chapter with reference to cardiac technology development. The process of innovation is intriguing, and the device and drug development innovation requires scientific and clinical precision and are often subjected to legal and public scrutiny.

The pillar of people is outlined in Chapter 6. People are the essential link in all inventive activities and are the prime determinants of success and failure of innovation. People's decisions and traits are important in both instigating and accepting new ways of doing things. This chapter examines people's traits and the relationships, trust, and collaborations among individuals as drivers of innovation. From the systems viewpoint, innovation comes as a mental construction and through systemic thinking. No matter how many incentives are provided, people have to leverage their intellectual capital in the most efficient and effective way. This can be done by careful identification of people-related issues. Cultivating serendipity as a way of looking at innovation provides enormous opportunities for research institutions. There are some business routines that need to be adhered to; however, managing effective innovation also involves some serendipity—to realize that invention happens. This requires people to think outside the box, to take risks, and to accept failures or shortcomings. After all, you never know until you try.

Chapter 7 examines the business of the commercialization of innovation. When scientific knowledge is constructed, such knowledge becomes useful to a firm only through strategic positioning of this knowledge into a firm's value-creating process. Business models that shift a firm's focus from the low end to the high end of the value chain are several types. The most effective models are developed on collaborative and knowledge sharing strategies. However, there are no simple and single solution and a model to attain the most efficient and effective innovative approach in a given time. A combination of factors including strategic maneuvering, surreptitious sanctioning, and systems thinking are required to respond to most commonly occurring business problems that need appropriate and timely solutions. In the commercial world, people have to respond quickly and responsibly. There is no room for second thoughts, as someone will move faster than you. Authors' insights of the innovation system in Europe provide valuable lessons in managing science-based innovations.

Chapter 8 is the synthesis of all chapters. What are the new insights into managing innovation that we have to offer? We can summarize this in one statement. Innovation has to be deeply entrenched in human minds and organizations in a way that resembles a vital organ, such as the heart, that is critical to running the body. It needs nourishment, proper care, and the right inputs. The concept of systems thinking provides a framework for analyzing serendipitous and strategic innovations. These innovations are continuously transforming the social and economic landscape by introducing cutting-edge discoveries, inventions, and resulting technological and organizational innovations that are fundamental to sustainable life around us, yet they diminish support to science as the focus shifts to economic rationality, rate of returns, and commercial gains.

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Four Pillars of Innovation: Complexity and Systems Thinking

SHANTHA LIYANAGE

Change in all things is sweet.
—Aristotle

Creativity differentiates us from other living creatures. The ability to think, learn, and act propels the human race ahead of other species. Since time immemorial, people have thrived on innovation, using available resources for the creative synthesis of human knowledge to generate useful invention and innovation. Discovery and invention are the acts of producing or thinking about something for the first time. The term "innovation" refers to both exploration and exploitation of new ideas through the creation and development of these ideas into commercially or socially useful products, processes, and services. Invention, together with commercialization, completes the process of innovation and has a beginning and an end. However, the products of some inventions, such as the QWERTY keyboard, can last forever. Some would argue that the journey of innovation extends beyond a firm's boundaries and continues to have an impact on society and the economy. For example, once the product is established, it could trigger another cycle of innovation on waste treatment, disposal, and sustainable management of resources.

PROPELLERS OF INNOVATION

For an innovating firm, the journey of innovation is never-ending. Human efforts to introduce new products, processes, and services have continued throughout history, with some eras highlighted by extremely creative outcomes. Such outcomes are determined by the prevailing scientific, technological, organizational, and socioeconomic conditions of the time. Scientific knowledge is certainly a significant force that acts on the process of innovation. We also regard innovation as a dynamic process that contributes to the financial and intellectual wealth of the firm. This is nothing new and indeed, many have regarded innovation as a dynamic process. The difference, however, is the consideration of the innovation process as a multilayered capability that extends beyond a firm's immediate boundaries. To understand the process of innovation, it is important to isolate these capabilities. In doing so, one needs to delineate the capabilities that are ultimately responsible in the delivery of the outcomes.

We identify four fundamental components that constitute the process of innovation:

- Knowledge
- Organization
- People
- Strategy

Innovation, especially science-based innovation, is a result of the transformation of these capabilities into diverse new uses. These interconnected components give rise to continuous innovation in organizations (Fig. 1-1).

Knowledge is the fundamental force that fuels the process of innovation within human minds and organizations. We separate knowledge from people. The concept of knowledge in our view extends beyond what an individual or a collection of people knows. This is because knowledge resides in people, products, processes, systems, artifacts, and technology in general. Knowledge is embedded

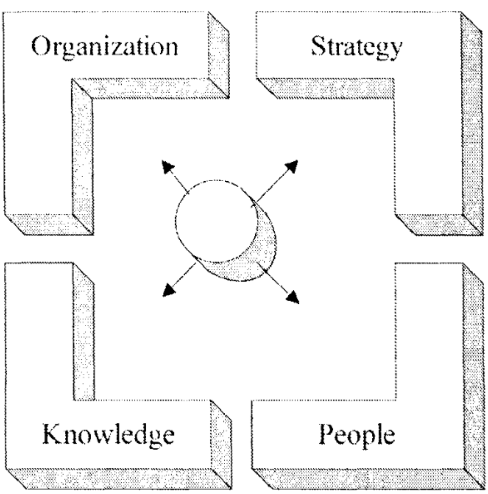

FIGURE 1-1. Four Pillars of Innovation

in animate and inanimate objects, and business processes. Usually, embedded knowledge can be acquired through technology acquisition and transfer. The organization pillar provides a structure and a framework for people and knowledge to operate. The organizational pillar also represents a culture of learning and a nexus of contracts for the transaction, construction, and reconstruction of knowledge and human action. The organizational rules and procedures facilitate the process of innovation. People are fundamental to all innovation processes. Without capable people, innovation processes will not continue. People have the capability to use language, symbols, and artifacts to synthesize individual and organizational knowledge over time. People also perform unique innovation functions that are difficult to imitate. For example, Albrecht Dürer's monumental woodcuts in fifteenth-century Germany illustrate the power of the people pillar in innovation and creative synthesis. The strategy pillar, on the other hand, leverages knowledge, organization, and people. Without adequate strategy and business support, most innovation will not complete the journey to commercialization. Emperor Maximilian I was responsible for supporting and commissioning Dürer's intricate, innovative woodwork. These pillars are intertwined and are combined to provide different capabilities, which enables the process of innovation. Without people and their commitment, inventions do not progress into everyday use. Even with the best of efforts, turning inventions into useful innovations relies on supportive structures and effective strategies. Our analysis and treatment of discovery, invention, and innovation in this book are primarily based on reference to these four pillars that underpin innovations.

Needs and Innovation

Innovation arises largely in response to specific requirements or needs. Human beings invented fire by striking two stone flints, or by rubbing together two pieces of wood, to satisfy a need for controlled fire, warmth, food preparation, and as a means of transforming other materials into useable forms. Individual, group, and organizational needs perpetuate in accordance with symbiotic and synergistic relationships, and innovations are the outcomes of satisfying those relationships. Such relationships include knowledge of experimentation, sharing information, shared learning, collaborative partnerships, and flow of information. They need to be combined with human aspirations in order to produce fundamental innovations. For example, the invention of the flying machine revolutionized the world beyond our imagination by meeting needs for air-based transportation. Many innovations have transformed world economies, created civilizations, and built social and physical infrastructure for other innovation. Some needs are transitory. The history of humankind is filled with useful—and not so useful—inventions. Innovation is the process whereby human thought is manifested, developed, and implemented in the form of commercial or social goods, processes, and services. Transitory needs give rise to an array of innovations that exist only for a brief period. The continuity of any given innovation is linked with both market-need factors, which are determinants of economics of innovation, and technological-need factors, which, on the other hand, are determinants of the superiority of innovation.

Doing Things Differently

Human beings have always attempted to do things in a different way that is more efficient and purposeful. Innovations are wellsprings of different discoveries and inventions that are conceived by people; these have contributed to the agricultural, industrial, and information technology revolutions and are now producing the knowledge-based revolution. Indeed, the study of innovation is intriguing, not because innovation creates wealth and tantalizes curious minds but because it provides hope, a reason for existence, and continuity of the world around us. Technological innovations are the drivers of industrial and nonindustrial innovation systems. The making of new products involves reconfiguring existing knowledge as much as it involves incorporating new knowledge. The way we harness inventions is as important as the way we produce products arising from them. Human history attests to our ability to harness inventions and to become innovative for the betterment of all.

Complexity in Innovation

An understanding of the exact process of innovation and all of its components is difficult owing to its complexity (Kanter, 1990). In a study of innovation, there are many questions to be answered: What triggers innovation? How is knowledge generated? Why do only some ideas give rise to successful innovation? How can innovation be made to work? To generate a useful innovation from an invention, it needs to perform a particular function or meet a specific need. The rate of innovation has increased rapidly over the past 50 years (Nelson, 1977). This is largely a result of the increase in investment in human resources, education, growth of science, and some platform technologies such as information and communications. Science-based innovation, which is the primary focus of this book, is the main root cause for the exponential growth of new products, processes, and services. Managing science-based innovation is not an easy task. It requires resources, organization, commitment, and good planning. In addition, most innovations are socially embedded and determined.

Most inventions fail to complete the entire journey of innovation. Coming out with an invention is one thing, but commercializing it is another. Commercialization requires more effort, resources, timing, and good luck. The commercialization phase is seen as the "Valley of Death" for many inventions. To be commercialized, all inventions should have some utility value. Innovation often brings forth a trail of destruction in producing new forms of goods and services. An invention such as the steam engine, for example, had a profound impact on modern civilization. Arguably, every conceived innovation has the potential to display a dual character of creative construction and destruction. New inventions lead to the ultimate replacement of existing products and processes with superior ones. As a result, existing products, processes, and services may be left behind and rendered useless.

Innovating firms have to compete to stay ahead of their competitors by allocating resources and outsmarting their nearest rivals. Intense rivalry is seen, for example, in the video-game industry, where the key players such as Sony PlayStation 2, Sega Saturn, and Nintendo are significant competitors to gain and maintain their markets. These firms continuously review their strategies for the introduction of new innovations and to capture a significant market share to maintain a dominant role in the industry sector. The failure of one important product innovation, for example, Sega Saturn, could make a fundamental difference to the competition. Firms are naturally resistant to having their product overtaken by others.

Besides economic gains, social and behavioral patterns of human societies lead to innovations. As automation took over repetitive tasks, workers were replaced with machines to perform routine tasks. Such mechanizations had some positive impacts in terms of productivity gains but also had social implications through changes in employment and demography. Advances in sciences have also proved a shift of change in the patterns of innovation. Nuclear power, biological warfare, chemical warfare, information and bio "terrorism" are the manifestations of the power of science-based innovation, which hold potentially enormous consequences for human progress. The recent debates on cloning human beings and stem-cell research are expressions of the social context of scientific knowledge production and consequential innovation. The continuous search for new ideas is inevitable. The creative use of those ideas is a significant challenge faced by the human race.

ABOUT THIS BOOK

Many books have been written on the subject of innovation. These books have covered the utilization of resources, strategy, and capability as a process of innovation from the perspectives of organizations, firms, or national systems. Descriptions explaining the process of innovation as a synthesis of human knowledge from the perspectives of generations of scientific thought and its translation into technological development and the diffusion of technologies are sadly lacking. We have focused here on the knowledge-based view of the firm and the systems thinking that allow us to expose and explain some of the complex processes in managing innovation, especially in science-based innovation. In most innovating firms, scientific knowledge acts as an enabler that helps a firm maintain and leverage its competitiveness alongside other components of knowledge.

In this context, we regard the process of science-based innovation to be time bound, selective, and purposeful according to social and economic conditions. The innovation process is both dynamic and complex. Because of its complexity and its interaction with internal and external conditions, systems theory is useful in understanding both atomistic determinants of innovation activities and integrating forces that holistically bind the connectedness of those determinants. The systems theory provides a new philosophy of managing the innovation process. For example, it allows the acceptance of failure as a process that is inherent to all innovations. In addition, it provides a philosophy to examine the impact of the change in one component to related components. New inventions often lead to change, and sometimes the total replacement of an existing product with a new one, thereby rendering an array of existing products, processes, and services useless. Systems theory helps us understand the links between knowledge, people, strategy, and organizations, as well as their interaction with the external environment. Indeed, on some occasions, innovations spring from activities other than logical and systematic thinking. Although speculation could lead to inventions, its development requires strategic maneuvering. A systems framework allows us to think laterally, or outside the box, and to deal with uncertainty, serendipity, and discovery associated with the process of innovation.

This book explores the fundamental processes of exploration, exploitation, and application of science-based innovations—in particular, biomedical innovations that allow us to examine the fundamental forces of the process of innovation. It examines diverse ways of creating and establishing innovative capacity in individuals and organizations. The innovation process derives from individual efforts supported by organizational contributions and national commitments to citizens, groups, and organizations. In other words, innovation is like a flowing stream that is fed from wellsprings of knowledge and experience. Its forces and directions are socially and politically determined. Nowadays, many scientists are compelled to adopt entrepreneurial traits, and they will have diminished time for exploration of knowledge with more encouragement for exploitation of such knowledge. Consequently, researchers are directed to generate knowledge with greater private returns rather than pure public return to research investments. The evolution of innovation requires a balance between exploration and exploitation efforts, and the success of such innovation still relies on social and political acceptance of its outcomes.

MANAGING THE INNOVATION PROCESS

Innovation deals with everything from simple items, such as matchsticks, to complex products, such as fighter jets. Drawing on biomedical and health research, the focus of this analysis is on the fundamentals of knowledge-based firms and the principles involved in the generation of scientific and technological ideas that ultimately lead to successful complex innovation outcomes.

Managing innovation, or rather, the process of innovation, is essential for all organizations. What are the best ways of creating, sustaining, and managing innovation in organizations? There is no particular way to generate ideas, develop them into products, and take them to markets. Some innovations are generated in response to organizational and social needs, whereas others are generated through systematic pursuits of knowledge creation and exploitation. As outlined in case studies here, knowledge and its management ultimately hold the key to introducing useful innovation that draws on both new and existing knowledge resources. These cases and research show that the roots of innovation are solidly anchored in the human thought process. Without human interactions and involvement, innovation will not thrive. Innovation starts with a novel idea, which in turn needs to be converted into useable products, processes, or services.

Why Didn't I Think of That?

The journey of innovation begins with the emergence of an idea, recollection of an experience, or thought about a solution to a problem. For effective innovation, thinking alone is insufficient. What exactly is the process of generating a new idea? Not all ideas give rise to successful innovation, and only some ideas lead to useful products and processes. The ideas have to be filtered and further developed. The novelty or originality of an idea challenges the element of obviousness and is a useful concept in determining the potential candidates suitable for exploration within the innovation process.

Dealing with the Obvious

Often, things seem obvious once someone demonstrates or explains how a certain item functions. Simple concepts and ideas like tie tags for freezer bags and cat's-eye reflectors on roads do not require "rocket science"—just intuitive thinking. Once we see them, the first question that comes to mind is: *Why didn't I think of that?* Indeed, in many cases, you might have *thought* about it. Seeing the relationship that others have not necessarily seen is the salient feature in turning an idea into an innovation. The accidental discovery of a phenomenon is another way of bringing an innovation to work. Some innovations, such as 3M's *Post-it* notes, come about as the result of stumbling into a realization of the nonobvious. Art Fry, inventor of the 3M *Post-it* note, saw an opportunity for his failed glue to provide a business application that is now used by everyone from schoolchildren to scientists. He was fortunate that there was someone at 3M who realized the potential of his idea, which needed further development before it eventually reached the market.

Success in introducing an invention rests on the considerable efforts of a variety of people; you can invent unaided but often you cannot do all the necessary things to make a successful business by yourself. The process of innovation is not necessarily about coming up with a brilliant idea but rather is about making it work, protecting it, and developing strategies to take it all the way to generating successful business within a viable business proposition. Furthermore, once established, it needs to be developed to a sufficient state that it can be diffused widely for general use and consumption. Edison's efforts to develop electrical current required sustained effort, determination, and commitment to come up with a series of inventions such as the electric bulb, filament, vacuum globe, contacts, switches, etc. It also required further development of the way electricity was made available to household consumers, by changing from a DC (direct current) to an AC (alternating current) distribution of electricity, which in turn required a considerable amount of lobbying and political wrangling in order to make such a change acceptable.

Parts, Components, and Connections

To make an invention work once it has been generated, developers may need to invent additional components. However, all components have to work in unison to contribute to a particular design and function. The difficulty in the innovation process is finding a way to integrate the parts and components with external factors such as social, organizational, and market components. The jet engine, for example, has numerous parts and components that are connected as a system and in turn link to the standards and requirements of the aviation industry. By considering the connection of fully integrated components of a system, we will be able to study the complexity of this process. Both invention and innovation comprise of several parts and components and those are interconnected in order to provide a composite sum. Some of the parts and components, such as an understanding of the industry context and social structures that support innovation and the ultimate acceptability of the products and processes of innovation, are fundamental to the study of innovation. As innovations become more complex and costly, it is necessary to understand the interrelationships and interdependencies between parts, components, and connections. The interrelationships and interdependencies constitute the properties of a system and its subsystems. In other words, the entire process and outcome of innovation need to be viewed as a whole.

I Did Not Do Anything About It

Making a mental note of a potentially valuable idea takes more than mere good fortune. We often observe that others are implementing relatively simple applications—and, of course, wealth is created from those ideas. We might have even thought about that very idea. The difference is that we did not do anything about it, while someone else acted on it. Innovation requires focused action as much as focused thinking. This includes thinking about various configurations and components and their interrelationships. It not only involves thinking and combining knowledge but also requires thinking differently in order to replace something that may already exist. Once something has been accomplished, the human mind contemplates how to do the same thing better. Innovation is about more than coming up with brilliant ideas, developing processes, and building products to achieve certain functions. It is also about successfully introducing and promoting them in the market. Consider, for example, the gene-sharing technology developed by Australian research organizations. Although the technology was proved, no one in Australia was prepared to take the risk of commercializing this technology, and it was eventually licensed to the French company Limagrain. The completion of the process of innovation can go beyond the original inventor.

Innovation also relates to inspirational concepts and designs that give rise to a new outlook for economic and social synthesis of knowledge. A parallel can be drawn between the development of creative industries and scientific discoveries. Peter Jackson ignited the creative industry in New Zealand with his *The Lord of the Rings* movie trilogy. Like the drug discovery and development process, such movies require hundred of millions of dollars to make but provide lucrative returns to investors if they become "blockbusters," as in the case of *The Lord of the Rings* trilogy. Both design and creativity are integral parts of the innovation process.

INNOVATION NETWORKS

Physical artifacts continue to be the most visible forms of innovation, whereas social transformation and organizational development follow as more elusive outcomes of innovation. In the process of innovation, there is a tendency to focus too strongly on individual intellectual space without having connection to others (Hargadon, 2003). The synthesis of ideas followed by directed action through a series of performance and decision-making processes leads to outcomes that are more efficient and effective than earlier practices. The concept of innovation is embedded in a social milieu of inspiration, creativity, and cultural progress. Leonardo da Vinci's paintings of a flying machine and Charles Babbage's mechanical calculator, which transferred the science of numbers to machine-readable outputs, are among the cornerstones in inspirational beginnings of innovations. However, it was not these men who built the aircraft or the computer. The connected social network is often the trigger for innovation.

The 2003 award of the Nobel Prize in Physiology or Medicine to Professor Paul C. Lauterbur (United States) and Sir Peter Mansfield (United Kingdom) illustrates how two individuals with completely different ideas about producing two-dimensional and three-dimensional images using magnetic resonance technologies in the early 1970s gave rise to a widely used medical technology that today is used to image internal organs of human beings—Magnetic Resonance Imaging (MRI). The first commercial MRI devices were introduced to medicine quite rapidly, and these developments were quickly adopted by commercial companies a mere decade after the ideas were first conceived.

In a global search of knowledge for similar invention and possible innovation, the opportunities are never captured, owing to varying commercial and market conditions. In science, parallel development is plausible because several groups work simultaneously on similar problems and it is difficult to establish the

Case Example: Development of Magnetic Resonance Imaging Technology

Paul C. Lauterbur discovered that the introduction of magnetic field gradients in a magnetic field made it possible to create two-dimensional images of water molecules contained in structures.

Peter Mansfield used gradients in the magnetic field to more precisely show differences in the resonance and showed how the detected signals could be rapidly and effectively analyzed mathematically and transformed into an image.

Peter Mansfield embarked on scaling up the apparatus to create the world's first whole body image. British Technology Group (BTG) brought together technologies from U.K. teams and assisted in funding, coordinating development, taking on complementary innovations, and licensing the manufacturing of equipment to secure high returns.

The medical use of MRI developed rapidly. The first medical magnetic resonance image was produced in the 1980s. Since then, MRI has been used extensively around the world. In 2002, approximately 22,000 MRI devices were in use worldwide and about 60 million MRI examinations were performed. The technique is particularly valuable for examination of the brain and spinal cord and in cancer diagnosis.

origins and evolution of ideas. For example, contributions and controversies of complex innovations such as MRI continue, as more than one stake a claim as the inventor of MRI. The evolution of knowledge and techniques is a composite synthesis from many sources, and the commercialization and development of such inventions remain in the hands of a few individuals who have the capacity to pursue the idea into a meaningful product and application. With the gradual evolution of knowledge, the human race has acquired an array of products and processes to deal with natural and physical environments. As the innovation process unfolds, so does the journey of innovation that combines the existing knowledge with new knowledge. The complexity of generating new knowledge and synthesizing future knowledge, as in the case of MRI, is often the character of this journey. Networks of institutions, knowledge, people, and strategy have combined to add to and transform both scientific and social value for sustaining a particular innovation.

The Pace of Innovation

Often, the pace of innovation is enhanced substantially by the latest advancement in scientific and technological knowledge. Essential knowledge in developing innovation is embedded in individuals and in organizations. The pace of innovation rests on the ability to unlock such knowledge to proceed to the stage beyond current levels of inventiveness. The sophistication of analytical methods, observation, and experimentation is a result of unprecedented advancement in both science and technology that assists individuals and organizations in generating new ideas at a faster rate. Innovations in biotechnology are one such example—what nature took billions of years to create may now be rapidly recreated in a laboratory. With rapid advances in scientific and technological knowledge, the rate of introducing innovation, hence the consequent social and organizational change, has hastened. The rapid pace of innovation warrants the examination of how we assemble components and parts of an innovation system that requires an understanding of both the exchange of interconnections and the transactions of various matter with immediate environment. For example, the pace of innovation in pharmaceutical drugs is governed by several subsystems that are responsible for development, testing, quality control, distribution, manufacturing, regulations, consumer satisfaction, and marketing. Some of these systems are open systems. In an open system, the exchange of inputs and outputs with its environment takes place and is subject to change and renewal of its established position. Therefore, the pace of innovation is governed by external dependencies and is subject to circular, longitudinal, and integrative approaches.

SYSTEMS VIEW OF THE INNOVATION PROCESS

An alignment of culture of operations and organizations' specific routines and procedures contributes to internal and external acquisition of resources in building capability. None of these processes can be viewed in isolation, and they are interconnected and interrelated. Thus, innovation is a result of system dynamics and operations and links to the system's philosophy. The basic premise for systems thinking was the consideration of a system consisting of sets of components that work together for the overall objective of the whole (Churchman, 1968). Aristotle's "The whole is more than the sum of its parts" was the underlying philosophy of systems thinking. The concept of systems theory is useful in the explanation of innovation for several reasons. The knowledge, organization, people, and strategic pillars are an ensemble of components, and the relationships among them are simply a way of thinking about these components and the relationship as a whole. The system will function if a sufficient proportion of the components, actors, and relationships perform with an adequate degree of effectiveness and consistency. The general systems theory (GST) originated when von Bertalanffy (1968) decided that simple forms of life, such as a cell, needed to be considered as an integrated whole nourished by the existence of not only single units but also the connection between them. He promoted interdisciplinarity by improving the communication between specialist and nonspecialist functions (von Bertalanffy, 1968). The basic concern was that while looking at the micro-level atomistic activity, there was a tendency to overlook the whole. This approach is critical in an examination of innovation because of interrelation and extended value chains of innovation beyond the firm's boundaries. Innovation is a synthesis of components and their interactions across several individuals and organizations.

The connectedness and synthesis of various ideas are essential for the progress of innovation functions such as the generation of knowledge, production and manufacturing, and marketing and sales.

Innovation Systems and General Systems Theory

Innovation functions proceed through different stages of development and often receive inputs from a variety of internal and external sources. These stages involve the continuous renewal of knowledge and understanding of inventive steps and the acquisition of dynamic capabilities and resources. Bringing fresh ideas into existence can be compared to the development of an embryo, with a few cells that proliferate and take on a useful form given the right environment. An innovation often thrives as a result of both internal and external conditions that sustain knowledge, understanding, and effective action. In this sense, the entire innovative process exhibits complex system characteristics. The key elements that determine innovation in a system include the following considerations:

1. Innovation environment
2. Existence of defined boundaries of the system and its components
3. Existence of inputs and outputs into the system
4. State of a system and availability of functions and processes
5. Ability to connect with different functions and system components
6. Hierarchy of activity in the system
7. Presence of a goal-directed and strategic purpose

In the process of innovation, there is a need for people to share mental visions in different intellectual spaces. Time and space are essential factors that determine the strength of the innovation system. Indeed, the innovation system cannot always be regarded as an open system where inputs and outputs are exchanged freely with the outside environment.

Innovation activity is regarded as a technoeconomic organization (Dosi, 1982; Dosi et al., 1988). In such situations, the innovation system includes the principles that are applicable to decision-making processes and behaviors. These decision-making systems need to identify, manipulate, optimize, and control the various components that give rise to specific outcomes. Therefore, it is necessary to account for multiple objectives, aspirations, causes of action, constraints, and resources, as well as identify risks, costs, and benefits.

Systems Thinking

What makes systems thinking more appropriate for explaining the process of coming up with a new product or process? Innovation is essentially multidisciplinary, involving interactions and a convergence of various skills, competencies, and disciplinary inputs. There are several subsystems within the innovation process and its organization. The subsystems that support the innovation processes are resources, knowledge, capability, and relationships. GST, through the convergence of different disciplines, can explain the complex interactions and relations. The basic principle is analogous to combining the individual sciences and bringing all knowledge closer to a unity of science forming holistic, teleological, synthetic, and cross-conceptual thinking (Johannessen and Solem, 2002). Innovation also proceeds through the complementary activities of several stakeholders and actors. It is also about building value across internal and external actors involved in a firm's growth. The complementarity of systems components paves the way for understanding complex phenomena using more than one perspective. This is an essential characteristic of innovation that forms the foundation for critical systems thinking (Jackson and Keys, 1984). The operational functions and methods in the innovation process follow the systems methodology along a specific development path. The key structural and process characteristics between systems theory and innovation systems concepts are outlined in Table 1-1. Systems thinking, however, needs to be considered in relation to nonformal knowledge that resides in social structures. In the innovation process, people can exercise conscious choices and make rational decisions in selecting innovation imperatives. Not all innovation functions will be accepted as socially desirable. Innovation systems have the characteristics of refutability (a fundamental reason for change), disorder, instability, and difficulty of sustaining or maintaining it over long periods of time. Therefore, the application of systems thinking in innovation process must be regarded as having characteristics of both open (exchanging matter with their environments) and closed (able to be manipulated by logically closed theoretical models) systems. In other words, part of knowledge is socially constructed and is embedded in organizations. Our concept of pillars is a conceptual framework based on systems thinking; it is a body of knowledge and tools to analyze various innovation processes.

Discovery, invention, and innovation all have distinct inputs and outputs. They have specific boundaries of operation and influence from various external conditions such as resources, legislation, and scientific norms. Innovation processes often adapt to those circumstances, reaching a steady state that allows the transfer of information and knowledge across various agents involved in the innovation system. Inventive activities are goal directed and operate within rules of hierarchy and leadership.

Several authors have argued that innovation, like other complex systems, needs "total systems intervention" (Flood and Jackson, 1991; Midgley, 1992). Innovation is a complex system because of internal and external relations, which are connected by several discrete activity subsystems such as exploration, exploitation, and commercialization of knowledge and its products. There is a continuity and extension of the system to encompass innovation as an adaptive system that integrates with socioeconomic structures. As a result, innovation activities require some level of cooperation among several agents who are acting on the system (Senge, 1990). Senge characterizes this cooperation as the five disciplines of

TABLE 1-1. Systems Characteristics of the Innovation System

Systems Characteristics	Innovation Systems
Systems environment and existence of boundary	The process and network characters of innovation—boundaries are defined in terms of fields of sciences and socio-economic objectives
Systems inputs and outputs	Inputs at various stages; financial and labor inputs and outcomes and impact indicators—often refers to subsystems such as knowledge; patenting activity; product-process development
State of the system—reaching equilibrium and the presence of system functions and processes	Existence of ideal conditions for innovation, process characteristics by technological trajectories and guideposts
Goal-directed behavior and systems hierarchy	Existence of market pull, technology—push conditions of innovation; outcome drives, the existence of uncertainty and chance processes. There is an order of hierarchy—some activities must be conducted before proceeding to the next stage.
Flow of information—open systems	Flow of knowledge; reciprocity and reflective action through learning and change management; deal with multiple objectives
Adaptive and complexity	Adaptive and connects with systems components; link between knowledge, people, strategy, and organization—existence of network characteristics; involves risk and decision management points
Stable and dynamic systems	Complexity grows as knowledge intensity of innovation

learning, namely personal mastery, mental models, shared vision, team learning, and systems thinking for learning. Innovative firms require very similar practices.

Decision Processes

The innovation process also consists of a series of decision-making points. The advantage of examining innovation as a system is the ability to identify these decision points. Once such decision points are understood, it is possible to leverage them to optimize, control, and fine-tune the process. These decisions are made at various points of the value system. Systems thinking is about extending the value chain all the way from producers to consumers. This invariably has implications on efforts of individuals and organizations. The value-generating activity, which was earlier confined to a firm's internal system, has now extended to external agents. In this context, the traditional input-output model is not suited to modern innovation systems. What is more appropriate is to regard the innovation process as overlapping layers, each with specific capability. For example, firms conducting exploratory research on drug development have layers of high scientific and technological competencies, moderate manufacturing, and low marketing and business development capability layers. Depending on the stage of the development of a particular innovation, organizations may focus on building different layers of innovation capability. The organizational layers are similar to a bulb of an onion, where one may peel out specific capability or develop targeted capability under a particular business structure. In this way, organizations are able to take advantage of a particular innovation and create an appropriate structure to reap the benefits from such innovations (Nelson and Nelson, 2002).

Innovation—As a Chance Process

An intriguing feature of innovation is its spontaneity. Discovery and invention also have intrinsic characteristics of an erratic and unpredictable nature. Curiosity and reasoning are the fundamental forces that provide tools for dealing with change. Such tools inevitably help the survival of the human race, as well as the exploitation of resources for their advantage. Traditionally, input-output models were used to explain the advent of inventions and innovations. This approach, however, cannot explain why some innovation does not occur despite all of the inputs. This is because innovation is a probabilistic process with an uncertainty attached to its success. Inventions can evolve as a chance event rather than from systematic investigations. Most theorists have shown that, historically, the way capital was accumulated and distributed in society led to technical and organizational innovations that could be generated either endogenously or exogenously to the organization (Singh and Singh, 2002). Scientists depend on the work of other scientists, who, in turn, depend on the work of others still (Comroe, 1977). Comroe argued that crucial discoveries, essential to later medical miracles, were often made by those not directly concerned with diagnosing, curing, or preventing disease and that this work was judged to be impractical, impossible, irrelevant, or absurd at the time of discovery. The chance of discovery is often high when inventors stumble upon the unexpected while looking for something else.

Systematic Organizations

Innovation is thus closely linked with the systematic organization of activities in a society. Whether it is the Marxist theory of communism or Victorian imperialism, technological change and industry structure play a major role in the transformation and trading of resources that are distributed among nations. Innovation and business competitiveness are closely related, because innovation empowers a business to achieve its objectives in a most effective manner. The strategy of both nations and organizations increasingly reflects a focus on innovation as the core of organizational and national competitiveness.

Sony recently developed a strategy to reduce the number of components used in its manufacturing process from the current level of about 840,000 to 100,000 by 2005. Such a move will inevitably involve redefinition of their current innovation strategy, and this will have implications on the manufacturing processes, suppliers' networks, logistics management, procurement strategies, and management of end products, including quality control and warranty systems. It also involves the redefinition of the firm's internal and external relations and the connections between the many components and external and internal connections, as well as changes to people, processes, and structures of the firm.

THE INNOVATION VALUE CHAIN

The value creation activities in the innovation process range from internal innovation functions of a firm to externally connected functions. The relationship between manufacturing and a logistics management firm is an example. Such value chains are operated in many industry sectors, such as in chemical and petroleum products. Given the complexity of knowledge-based innovation process and its relationship with various external stimuli, the systems of innovation can be studied as interconnected value creators. This would allow for the valuation of the inventive steps and an understanding of what is required for successful accomplishment at each stage of the innovation process. Several models and approaches have been used in the past to explain the dynamics of the innovation process undertaken by different individuals and firms. The simplistic model is the linear model of innovation, which predicts a particular path or trajectory of idea generation and taking this idea to a viable product that can be commercialized in a particular market. However, most innovations do not follow a simple route. Usually, inventive steps interact and connect with feedback loops and follow a trajectory or a set pattern until a desirable outcome is reached. This is also known as the *innovation chain*, where one activity connects with the other.

Cumulative Knowledge and Experience

Cumulative building of knowledge is the result of the actions of inventors, scientists, and entrepreneurs. Knowledge and the experience of doing things better are two of the most important contributions to the innovation value chain. Cumulative experiences have been passed on from one generation to another and have contributed to the incremental improvement of the known, as well as enabling discoveries of what was previously unknown. Prior knowledge combines with new knowledge to form an element of real value for the organization and society.

Research institutions are the powerhouses of inventions and discoveries. For example, Edison's laboratory in Menlo Park produced over 400 patents from 1876 through 1881; some were useful, and others will never be put into practice (Hargadon, 2003). The conditions that lead to the successful application of products and processes are determined by the entrepreneurial capability of people, institutions, and nations. For example, in the cases of gunpowder, printing, and the wheel, it was not the nation that discovered these products that took the full advantage of the inventions but rather those who exploited the discoveries for business purposes.

Clusters of Innovation

Table 1-2 shows the key technological innovations in the twentieth century. Some of them came as waves of economic development and have revolutionized the economic and social landscape in human civilization. The impact of some innovations was initially felt only quite latently, such as mass spectroscopy in the 1920s, and became more effective when combined with other development applications such as nuclear magnetic resonance (NMR) in the 1970s and electro magnetic resonance (EMR) in the 1980s. Some of these inventions truly reflect the way innovation systems have evolved as complex systems. The study of biological systems, for example, has become more dominant and moved from individual molecular analysis to large interactive systems that combine knowledge of chemical, electrical, and protein chemistry to explain neural functions, including the brain.

Some innovations are interlinked and are closely associated with the given state of scientific knowledge, although such knowledge is not always available at the time of inventing some devices and products. Science-based innovations are, of course, the direct result of synthesis of knowledge-driven innovation. The coevolution of scientific and technological innovations gives rise to industry and technology clusters. For example, the developments of telecommunication, computers, and satellite communication are closely fed into each other with the advancement of science and technology. A succession of technological developments from analog, digital, to broadband technologies has greatly changed the way scientific research is organized. The emergence of biomedical research that combines biology, computing, and genomics is a good example.

THEORIES OF INNOVATION

Theories of innovation allow us to understand how firms can continuously innovate in a competitive environment. These theories are drawn from a wide range of disciplines, including science, engineering, technology, economics, finance, sociology, information and computer sciences, behavior, and psychology. Social capital theory, neoclassical economics growth theories, resource-based theories, and the studies of knowledge creation are among some of the leading

TABLE 1-2. Key Innovations in the Twentieth Century

1920–1940	1941–1960	1961–1980	1981–2000
1918 Mass spectrometer	1942 Electronic digital computer	1962 Point-of-sale database for inventory control	1982 Human growth hormone
1921 Tetraethyl lead	1945 Nuclear power	1964 Mainframe computers	1984 Liquid crystal displays
1925 Bell Telephone Laboratory	1945 Discovery of penicillin	1968 Computer mouse	1984 CD-Rom
1927 Television	1947 Cellular phone	1969 Automated teller machine	1984 Customized mass retails
1928 Fleming discovers penicillin	1947 Microwave oven	1969 Charge-couple device	1986 High-temperature superconductors
1929 Synthetic rubber	1947 Instant photographs	1969 Computer network	1987 Mevacor, cholesterol-reducing drug
1930 Jet engine	1947 Transistor	1970 Compact disc	1988 Digital cellular phone
1931 Videophones	1948 LP records	1970 Relational database	1988 Prozac
1933 Frequency modulation	1949 Magnetic core memory	1971 Microprocessor	1991 World Wide Web
1934 Nylon	1950 Credit card	1971 Answering machine	1993 Pentium processor
1937 Pulse-code modulation	1952 The pill	1972 Ethernet and UNIX/C programming	1995 Java computer language
1938 Xerography	1952 Thorazine for anesthesia	1972 MRI	1995 Protease inhibitors
1939 Automatic transmission	1953 Structure of DNA	1974 Catalytic converter	1995 Internet, e-com business
1939 Helicopter	1953 Blackbox flight recorder	1975 Board cast to quality camera	1995 DVD player
1940 Radar	1953 3D movies	1976 Recombinant DNA	1998 Viagra
	1954 Fortran, programming language	1976 Personal computer chip	2000 Automated sequencing machine
	1957 First nuclear reactor	1976 Ink jet printer	
	1954 Polio Vaccine	1976 Cash management account	
	1955 Fast food chain—McDonald's	1977 Magnetic resonance imaging	
	1956 Containerized shipping	1979 Cellular phone	
	1956 Disk drive	1979 Spread sheet	
	1956 Optical fibers		
	1956 Video tapes		
	1958 Modem		
	1958 Implantable pacemaker		
	1958 Laser		
	1959 Integrated circuits, microchip		
	1959 Genetic engineering		

theories contributing to innovation. There is, however, growing interest in affiliating innovation theories with systems theory, such as national innovation systems theory. The underlying knowledge base becomes critical in explaining the relationships and interactions between the various components and forces acting on the innovation process.

Innovation is regarded as a social process because of the external factors that influence both scientific and technological factors. These theories may contribute to two important factors: the entrepreneurship of individuals (who have the curiosity and drive to aspire for better and new things) and the economic value and commercial purposes of the outcomes of these innovative activities. This value may not necessarily be monetary and should also be regarded as arising from forces that transform social structures and living environments. Some innovation theorists propose a process theory for the understanding of innovation (Mohr, 1982). The process theory helps explain how and why innovation develops based on the probabilistic arrangement of discrete events over time.

Some new products and processes are generated due to market demand-and-supply conditions and the consumption of the products and services that contribute to the growth of industry. Without economic demand and scales, new products and services may not thrive (Aghion and Howitt, 2000). Technological development is the consequence of the search for new knowledge, and it maximizes efficiency and enables economies of scale in the production of goods and services. As technology and industry mature, the underlying sciences become interdisciplinary and sophisticated. Consequently, governments may introduce selective policies or let the market decide on inventive activities. In other words, some firms will be able to pursue innovation as a competitive strategy for profit maximization.

Profiting from innovation will involve the stage-growth model of development of products and process. Such models enter three distinctive phases: preinnovative, innovative, and postinnovative phases. The preinnovative phase is driven by values of knowledge creation and synthesis processes. Discoveries and inventive activities are valued according to technological, economic, and social gains. The values placed on innovation activities are driven by product and process utility. The perception of these values and the impacts of markets, together with originality and novelty, add further value to these functions. The value of the postinnovation phase is determined by rates of diffusion and market penetration of products, processes, and services. Figure 1-2 illustrates the level of value and the progression of different phases of innovation.

The Way to Do Things

Innovation introduces change by introducing new knowledge. However, increased competitiveness does not always follow. The way in which business and services are organized and arranged can also accelerate competitiveness. The adjustment to factors of production, sourcing low-cost inputs, and lowering

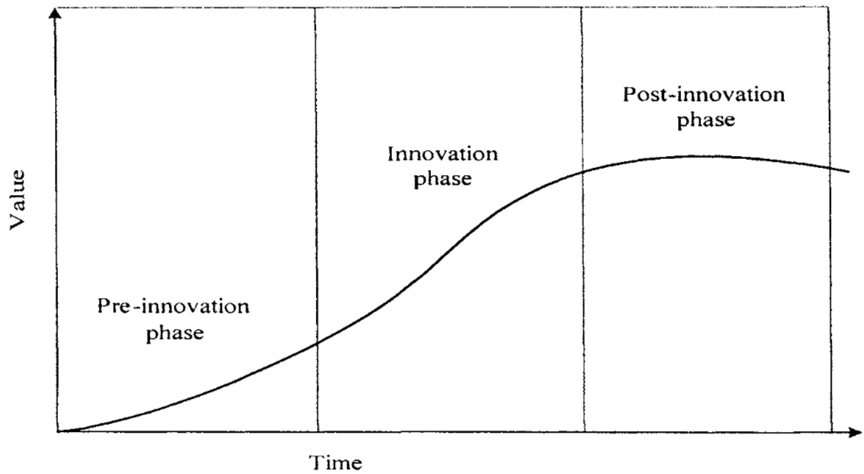

FIGURE 1-2. Value Creation in Innovation Phases

pricing strategies can also assist a firm's growth and competitiveness. Economic rationalism traces the progression of economic approaches to innovation theory but explains that there are other cultural, political, and sociological approaches to the process. For example, organizational innovations contribute to economic and productivity gains. "The way we want to do things here" distinguishes the uniqueness of each individual and organization. Just as no two individuals are the same, no two organizations are the same. Consider Coles and Woolworths supermarkets, both engaged in identical retailing businesses in groceries. Although they are engaged in similar business, their competitiveness depends on different strengths found in the value chain extending from direct customers to multiple suppliers and manufacturers.

As technology has entered the world of economic theory and production, economists and managers have attempted to provide explanations for change and innovation. Increasingly, as a result of innovative forces, society is confronted with greater consumerism—a variety of goods and services, more advanced and more technology intensive than existing products and services.

Market Power

Joseph Schumpeter (1934) pioneered the study of innovation and contributed much to the understanding of technological advances and the economic development of firms and industry sectors. His work suggested that large firms with considerable market power had the ability to engage in knowledge development and radical innovation that increased the economic advantage of these larger firms. The firms that engaged in research and innovation had the opportunities to capture the benefits of innovation for economic gain.

The efficiency of market structures determines the competitive advantage of nations and individual firms. The decisions on resource allocation to economic and technological activities, therefore, are important policy considerations. Government or public resources endowments have much to do with the development of some public sector knowledge and innovative capabilities as seen in the United States, Japan, and Europe (Ruttan, 2001). The role of governments may determine the success or failure of innovation policies that facilitate the development of products, processes, and services of a nation's firms.

Figure 1-3 shows that Schumpeter's ideas have provided a foundation that other innovation theorists have subsequently built upon. Additionally, there are other key innovation contributors who we consider in this book.

INNOVATION AND BUSINESS COMPETITIVENESS

Other theories have reinforced the argument that innovation constitutes two distinct stages of exploration and exploitation, in which the business activities are related but dependent on the exploitation stage. Within this consideration, innovation is a process of creating business values that have significant economic potential to an individual, a group, an organization, an industry, or a society (Higgins, 1995). Some critical observations are as follows:

- Innovation occurs in the generation of products, processes, services, management processes, and business systems that are new to the industry and new to the customers and that create value.
- Something new is not necessarily an innovation if it does not lead to value addition.
- The best idea in the world, if defeated in the marketplace by a competitor, cannot be regarded as an innovation.

These observations lead to the treatment of innovation as the process of transforming ideas into new or better commercial products, which adds value for the customer.

$$\text{Innovation} = \text{Invention} + \text{Commercialization}$$

However, this is a linear way of thinking about innovation. The invention to innovation process proceeds in a cyclical, longitudinal, and interactive manner and gives rise to intended and unintended innovations. The commercial failure of one innovation may be the success of another innovation. In this way, innovation is a complex, self-organizing, and adaptive system.

Building National Capacity

National innovation capacity is the ability of a country to produce and commercialize a flow of innovative technology over the long term (Furman et al., 2002). The capability to innovate is gained by investing in knowledge and other

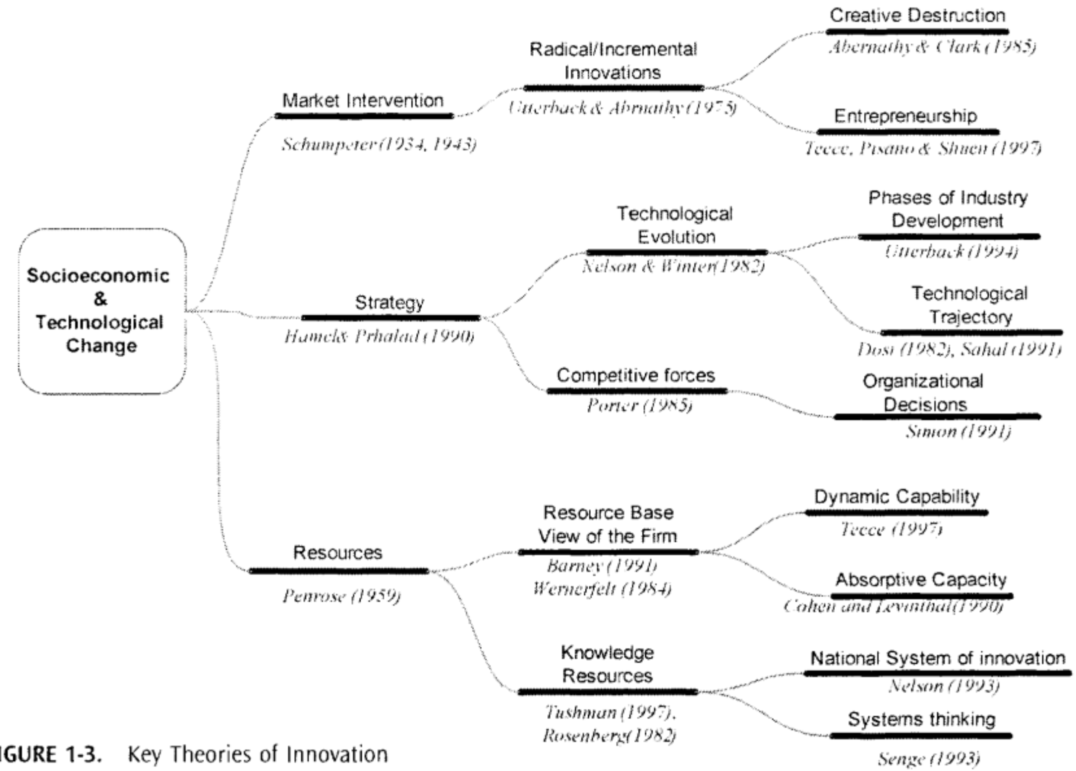

FIGURE 1-3. Key Theories of Innovation

infrastructure necessary to compete globally. There are distinct national advantages and competitiveness that are gained through the factors of production. Nations continue to enhance these national capabilities through internal capability building and the acquisition of technology from outside sources. Innovation, as observed earlier, is a collection of capabilities ranging from creating to commercializing a novel idea, concept, product, or process. The generation of useful innovations is partly a systematic accumulation of such capability that requires space and time to build such capacity among individuals and institutions. In these processes, the value is created across organizations, individuals, groups of firms, and industry sectors. Building capacity is evolutionary and to a certain extent can be directed. A continuous building and reshaping of innovation capacity is a collective effort in which government policies play a critical role. Such innovation capacity is also shaped according to global demands for goods and services and the conditions for technology transfer and diffusion processes.

As illustrated in Figure 1-4, the competencies and connections are formulated as distinctive segments connected in a network of pipelines to deal with

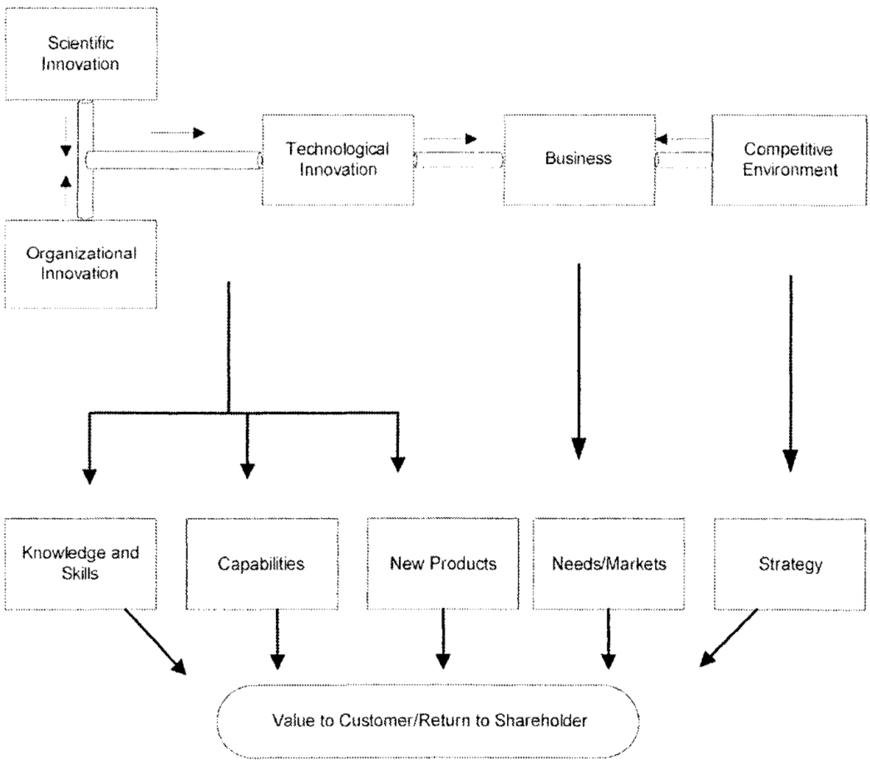

FIGURE 1-4. Process of Integrating Business and Innovation

innovative functions. In conducting inventive activities, there is a tendency to focus on a particular section of the pipeline rather than identifying the connections and composition of the entire system.

International and global movements of innovation activities have significant influence on domestic innovation development capability. Innovative efforts are therefore a matter of selecting appropriate strategies and adopting organizational structures, two of the four pillars identified earlier in this chapter. Competitiveness drives some innovations, which are time, circumstance, and outcome bound. Figure 1-5 shows how competition, vulnerability, and innovation are inextricably linked. In most cases, technology and market conditions facilitate the adoption of innovative products across several firms. As long as the wider marketplace allows, there exists a market for specific products and processes. An individual, group, or several groups may seek to achieve a certain outcome, but not all of these can achieve the same level of sophistication. As a result, firms may operate a particular technology with different competitive advantages.

Timing Is Critical

Timing of the introduction of new products or services is crucial. Leaders of innovation often reap considerable benefit from the introduction of a particular innovation. However, at the same time, pioneers are also subject to a greater degree of risk and have to spend considerable time and resources in market testing and gaining acceptance for the innovation, while latecomers may learn from others' early mistakes to profit from the same innovation. In business, the one who gets there first may not necessarily be the most successful in deriving the benefits. Although speed is important in introducing an innovation, other attributes such as quality, efficiency, ownership, and cost are also contributors to business competitiveness.

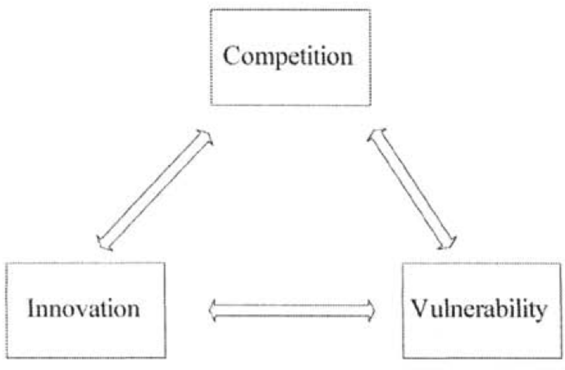

FIGURE 1-5. Connection Between Innovation and Business Competitiveness

Learning and Innovation

Learning is a fundamental requirement in adopting a particular innovation strategy and in building people, organization, and national competencies. There are areas in which developing innovation capability can be prohibitive due to costs, human resources, the level of educational and scientific knowledge, and intellectual property systems. Several fields of biotechnology, pharmaceuticals, and drug delivery are some of the potential areas requiring higher levels of organization. The resource requirements may exceed the capacity of firms and become a matter of national strategy. Singapore, for example, has decided to invest in biotechnology as a key sector of growth and is allocating resources to accelerate development. However, business strength alone is insufficient for major scientific breakthroughs, or for capturing the benefits from them. At the national level, the capacity of academic research institutions, the experience of the private sector institutions, and the level of absorptive capacity of national institutions act as a conduit in producing national innovations. As shown in Figure 1-6, a synthesis of endogenous and exogenous capacity may combine to develop new industry and strengthen existing industry in a given sector. The contribution to national productivity growth depends on the health of these industry sectors.

This leaves us to review the connectedness and interrelationships of the four pillars of innovation. Knowledge, people, strategy, and organization merge in regard to the innovation process as a unity, and these pillars are the powerful agents in the innovation system that interact with other components in the system. Each of these pillars has its own subsystems and agents. For example, knowledge is instrumental in the origins of innovation. Its construction, however,

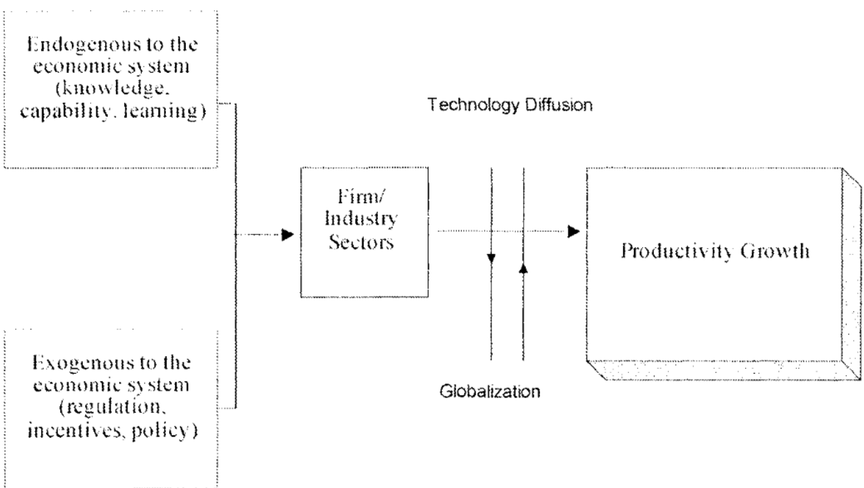

FIGURE 1-6. Sources of Innovation and the Process of Technological Change

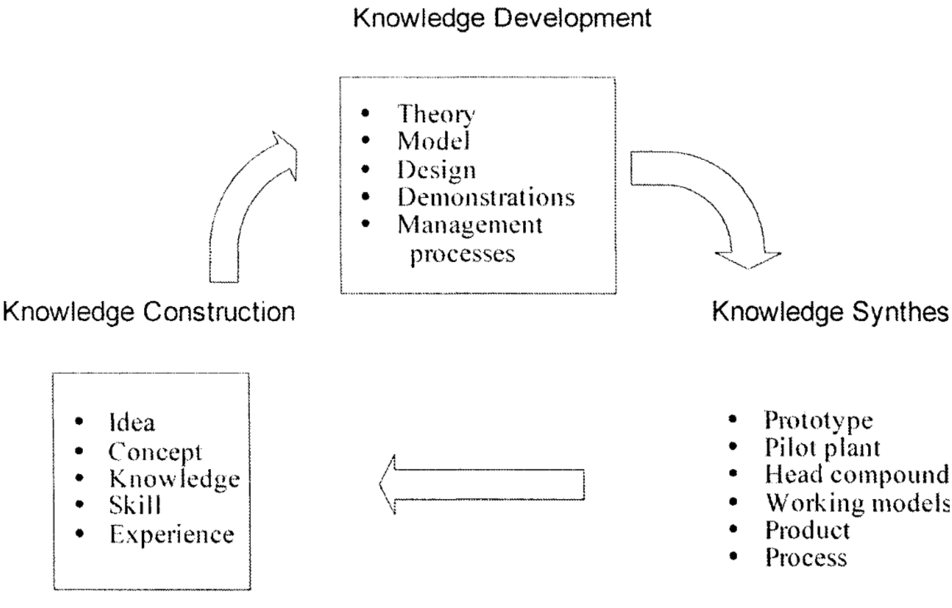

FIGURE 1-7. Origins, Growth, and Synthesis of the Knowledge Pillars

has many origins and routes. Figure 1-7 illustrates that knowledge comes from a variety of sources and that these combine to provide various methods of integrating and incorporating knowledge into products and processes. In the synthesis of knowledge, innovation activities draw from previous knowledge and integrate with new knowledge. In this sense, the knowledge pillar is constructed through continuous renewal and application of knowledge and does not necessarily follow a particular hierarchy of activities.

CONCLUDING REMARKS

Imagination and perseverance form the backbone of the concept of innovation that has revolutionized life on earth. Continuous production of artifacts, products, and processes builds core capability of firms and nations, elevating living conditions. Some inventions, such as the telephone, have transformed the world around us and remained powerful agents of change. Innovation is about creative synthesis and the combination of both new and existing knowledge. Knowledge alone, however, is insufficient. Innovation results from the nation's capability to translate this knowledge into a socioeconomic context.

The integration of core capability is a key consideration in treating innovation as an extended knowledge system that creates value for multiple stakeholders and across different layers of an organization. An understanding of the process of innovation requires foresight and vision as well as good models and theories. Drawing from systems theory and knowledge-based theories, the innovation process is described as a continuous evolutionary process. The treatment of innovation as a dynamic, rather than a static process is about connected thinking and imagining. In order to understand the interconnectedness, the process of innovation needs to be viewed as interconnected pillars of knowledge, people, strategy, and organization.

Innovation stems from good ideas and concepts, and these form the lifeline of "science-" and technology-based industries. Technological innovation brings tangible new products, processes, and services into markets to build capabilities and competencies that fuel new growth and maintain existing competencies. The exploration of good ideas is a never-ending journey. Scientists are engaged in the continuous production of premium ideas. Finding methods of continuous production of new and original knowledge is pursued with passion, involving strategic thinking by individuals and nations.

Inventions and innovation also bring inherent uncertainty to stable systems. Innovation disrupts a firm's routines and introduces new requirements. The most difficult task for managers is to maintain the innovation capability of the firm in the context of continuous technological change. Dealing with uncertainty requires systems thinking. Commercialization capability is often influenced by external factors such as finance, legislation, and maintaining customer relations, as much as by product and process development. Building capability to innovate is a composite activity requiring the creation of capacity to invent and use such inventions. The exploitation of innovations is a race and requires winning that race through the application of good business skills. Therefore, a combination of skills is required for commercialization of products and services. The general equilibrium in the innovation system arises from both inventive and commercial capabilities.

However, a nation can go so far only in inventing new products if there is no social and economic balance. The development of a product through an innovation process does not mean that the product launch will be successful. Many failures in products could eventually lead to the complete downturn of an organization. Innovation is often associated with high costs of development. It is not possible to innovate uncontrollably without an organization and a strategy. Therefore, diffusion of innovation needs to be considered in the evaluation of the effectiveness of an innovation process. The process of innovation needs to be viewed as a system of creating value across internal and external stakeholders. The route to innovation may well reside in external value creators and not necessarily in the internal value creators. As a result, the process of innovation is one of the least understood management fundamentals. The mastery of the innovation process provides a leading competitive edge to a firm. The four pillars of innovation provide a framework for this understanding and are dealt with in the following chapters, especially in relation to medical and health technologies.

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2

Leading with Innovation

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I don't care what makes the grass green.
—Charles E. Wilson, Secretary of Defense
to President Eisenhower, 1953–57

Some people simply do not care how something is done as long as it *is* done. The stark reality in today's economy is the fast-changing technological and economic landscape, which has enormous implications for the world's growing population and the way we structure our lives. The impact of technological change cuts across several types of users and producers of knowledge and connects them through a series of activities and functions.

Technological change is the direct consequence of the innovation process and refers to both economic and social change (Schumpeter, 1949). Schumpeter suggested that the technological process is composed of three phases:

1. Invention—generation of new ideas
2. Innovation—the development of new ideas into marketable products and processes
3. Diffusion—new products and processes spreading across potential markets

Inventive steps, the process of innovation, and its diffusion processes closely interact with the four interrelated pillars: knowledge, strategy, organization, and people.

EVOLUTION OF INNOVATION CONCEPTS

Innovation ranges from the simple to the complex, and the interactions among the players in the process require significant resource commitment. Some simple ideas, such as those involved in the invention of the wheel, rudder, and printing machine, are now regarded as commonplace. On the other hand, more recent and sophisticated innovation includes developments in nanotechnology, electronics, and biotechnology. The innovation processes of science-based industry are complex (Nelson, 1987). This is partly because of the way knowledge capital is formed in a protected environment. Unless a degree of protection is available, the economic returns to those individuals and nations who were responsible for investing and developing such innovation will be limited. In the long run, innovation will diffuse and will ultimately be surrendered through absorption of such innovation into the global system via diffusion and imitation.

Innovation is also intricately associated with change. The process of change is associated with originality, which tends to feed the innovation process in a cyclical manner. Innovation usually fuels the change process with success and failure in some businesses and through systematic changes to agriculture, manufacturing, and the business sector. For example, the tractor has revolutionized agriculture, the production line has revolutionized manufacturing processes, and the advent of computers has revolutionized the way information, knowledge, and communication are distributed, stored, and retrieved. Failure, as well as success, is a defining possibility in innovation. New ideas always carry the risk of failure during their development and diffusion. Knowledge, both new and existing, is the preeminent force of change. In this chapter, we explore the pillar of knowledge and how knowledge capability contributes to the innovation process.

KNOWLEDGE—AS THE KEY DRIVER OF CHANGE

The quest for knowledge and the search for new ideas have accelerated over time. The flow of ideas has provided an array of new products and processes over the course of the past few decades, and these have been included as improvements in the technological content of many products. Innovation, as a general rule, progresses like a wave in industry—rising, swelling, and falling. Just as we thought the information technology bubble had burst, a new wave emerged in the form of digital communications technology, ushering in a new culture of mobile telephones and communications. But why innovate? Innovation is about responding to growing challenges, keeping ahead of the pack, shaping competitiveness, and, most of all, keeping a business alive. There are warehouses full of successful and unsuccessful products that are the result of more recent innovative processes. Some knowledge is never used. The stark reality, however, is that most patents that are filed are not necessarily commercialized, and still fewer are "successes" in the context of social and economic impact. Some areas where innovation has been a dominant contributing factor have received much attention as a result of their economic success. Some knowledge is purposefully selected and valued for its utility; Information and Telecommunications (ITC) technologies are among these. Advancement in the software industry has enabled the connectivity of technology products such as computers, printers, and modems, which have been extremely successful in their applications in numerous ways. The apparent slowing down of this industry's growth in the late 1990s highlights the inherent danger of economic and market impacts on continuous growth, rather than a lack of innovative ideas. At least in this case, new ideas have reached a plateau, and further development of premium ideas requires adjustment to markets and rethinking of the process of commercial exploitation of those ideas. Knowledge, often referred to as capability, is valued and transformed according to the scientific, market, and social values in ensuing innovations (Bozeman and Rogers, 2002).

SEARCHING FOR EXCELLENCE

The generation of successful ideas has always been a race for inventors. Financial, as well as intellectual, achievement has often been attached to such success. The search for excellence is a race for scientists to win the Nobel Prize as much as it is a race for business pundits to win market share. The Nobel Prize, which has been awarded since 1900, is the most valued prize in the scientific community. Alfred Nobel invented dynamite in 1866 and later built companies and laboratories in more than 20 countries around the world. Nobel's first company, and the world's first to produce nitroglycerin commercially, made a fortune, and part of his profits were invested in the pursuit of excellence in scientific fields. In his will, Nobel wrote:

> ...the whole of my remaining realizable estate shall be dealt with in the following way: The capital shall be invested by my executors in safe securities and shall constitute a fund, the interest on which shall be annually distributed in the form of prizes to those who, during the *preceding year*, shall have conferred the *greatest benefit on mankind*... (Alfred Nobel, November 1895)

The Nobel Prize has triggered many inventions since its creation, as winning it is the ultimate reward for a research scientist. Innovation is also associated with fame, and winning an Oscar for technical achievement or being selected as one of the best 50 innovative companies in the world or induction into the innovation hall of fame is an inducement adding to the creation of an innovative environment. Creation of an environment conducive to generation and, more important, acceptance of good new ideas are the critical success factors leading to successful innovation.

ROUTE TO SCIENTIFIC DISCOVERY

Some innovation evolves from the systematic and intense search for knowledge referred to as research and development (R&D). Some inventions have come about through backyard operations or "back of an envelope" solutions. Serendipitous discoveries, or the act of stumbling onto something while looking for something else, have been a feature of some major advances, including the discovery of penicillin.

Innovation requires building connections and relationships among different knowledge communities. In other words, it builds capacities, which are not confined to economic issues but a wide range of achievements of individuals, groups, and nations. Although the entire process can be complex, successes have also come about by focusing on the simple and most obvious solutions. The routes to successful innovations are numerous and range from individual to more organized efforts. In many cases, ideas are generated by people in everyday society. To generate and develop a new innovative idea, one needs to simply think, relate to a problem-solution, and, perhaps, have unwearying determination and commitment. Following a route to innovation is about building capacity and capability in individuals and institutions, which invariably involves all forms of learning, and developing and investing in human intellectual capital.

The routes to innovation can also be accomplished under different environmental conditions. Some conditions can be much more arduous than others. The presence of an innovation climate can considerably assist in facilitating the rate of invention. The absence of it can hinder and result in relatively barren innovative climates. The aftermath of the economic downturn in the 1990s has eroded the innovation capability beyond repair in Asian countries such as Indonesia. Once the systematic knowledge-generating activities in institutions are neglected, it is difficult to reestablish them, due to dilapidated infrastructure and difficulties in catching up with research developments made elsewhere. A conducive environment that supports creative skills is also required for the exchange of knowledge. Such conditions are generally created through a variety of political and economic conditions.

Innovation is not simply about conducting science-based development and turning the science base to technological products and processes. It is also combined with a social process where better products are championed through complex selection and diffusion processes. Introducing a new product to the market is often associated with the concept of innovation; however, there are many other categories involved in developing or improving existing products or processes. In addition, innovation is about doing something differently that has never been done before, and this can often be achieved by making incremental improvements. In general, innovation contributes to economic wealth as much as building knowledge reservoirs. Science and technological advances are considered to play a dominant role in long-run economic growth (Aghion and Howitt, 2000). In this economic process, innovation creates value throughout the industry process and builds an environment that feeds the generation of innovation through the building of intellectual and social capital.

KNOWLEDGE PILLAR

In an innovation context, the knowledge pillar consists of new and existing knowledge that combines to form an essential basis for effective action. New knowledge is a significant resource that is generated as a result of the exploration opment. He has in excess of 160 publications, has edited four books, and is co-inventor on four patents. Professor Hunyor has advised government on R&D policy and chaired Australia's first "Commercializing Health Innovations Forum" (CHIF '97). He established an Intellectual Property Unit for the state Health Department and also the North Shore Heart Research Foundation.

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