

# THE INTERNATIONAL HANDBOOK ON INNOVATION

Edited by Larisa V. Shavinina



Pergamon  
An imprint of  
Elsevier Science

ELSEVIER SCIENCE Ltd  
The Boulevard, Langford Lane  
Kidlington, Oxford OX5 1GB, UK

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First edition 2003

#### Library of Congress Cataloging in Publication Data

A catalog record from the Library of Congress has been applied for.

#### British Library Cataloguing in Publication Data

The international handbook on innovation

1. Creative ability - Social aspects 2. Creative ability

3. Creative thinking 4. Creative ability in business

I. Shavinina, Larissa V.

306.4'2

ISBN 008044198X

ISBN: 0-08-044198-X

© The paper used in this publication meets the requirements of ANSI/NISO Z39.48-1992 (Permanence of Paper).  
Printed in The Netherlands.

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This handbook is dedicated  
to my parents  
Anna Shavinina and Vladimir Shavinin,  
to Professor Marina Kholodnaya,  
and to my wonderful husband and son  
Evgueni and Alexander

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**Larry Vandervert** is a theoretician, writing in psychology and the neurosciences for the last two decades. He co-founded The Society for Chaos Theory and the Life Sciences in 1991. In the past two decades he has authored many articles on a brain-based theory and epistemology. Dr Vandervert proposes that the true fundamentals of science must eventually be stated in terms of brain algorithms. In recent years, Dr Vandervert has published a series of papers that describe how he believes that mathematics arises from collaborative functions of brain areas. He believes that mechanisms in the brain that generate and manipulate patterns are responsible for both the discovery of mathematics and the processes that lead to innovation.

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# Preface

There is no doubt that innovations were, are, and will be extremely important for the individual and society. One way to understand the history of human culture is via its inventions and discoveries. All human cultural development builds on the amazing technological, scientific, educational, and moral achievements of the human mind. Today, people increasingly realize that innovations are even more critical than in the past. Thus, industrial competition is increasingly harsh and companies must continuously bring innovative products and services to the global market. To survive, companies need creative and inventive employees whose novel ideas are, to a certain extent, a necessity for the companies' continued existence and future success. Consequently, modern society desperately requires highly able citizens who can produce innovative solutions to current challenges and contribute new ideas that aid in the development and growth of the market for a particular product or service. People of exceptionally innovative ability thus remain as extremely important source of innovation and renewal. Hence, the new millennium is characterized by the need for innovative minds. Contemporary society, without doubt, is highly reliant on innovations. The future will be synonymous with innovation, since it will need an extremely high saturation of innovations in all areas of human endeavour. Despite the quite evident importance of innovations in the life of any societal 'organism', one should acknowledge that the phenomenon of innovation is far from well understood. Because of this, a handbook on innovation is an exceptionally timely endeavour.

The field of innovation is lively on many fronts. For the most part, it is studied today by many different disciplines as one of their components. However, contemporary demands on innovative ideas, solutions, products, and services mark an imperative of a special unified, multifaceted and multidimensional discipline: science of innovation. It was a combination of my interest in the topic of innovation with my perception of the field as needing unification that encouraged me to initiate the present project. I came to believe that the time was ripe for an *International Handbook on Innovation*—a volume that would help guide research in innovation during at least the next decade and, therefore, would advance the field.

The purpose of the handbook is multifold: (a) to pose critical questions and issues that need to be addressed by research in a given subfield of innovation; (b) to review and evaluate recent contributions in the field; (c) to present new approaches to understanding innovation; and (d) to indicate lines of inquiry that have been, and are, likely to continue to be valuable to pursue. This handbook does not provide the kind of literature reviews usually found in textbooks. The conventional understanding of handbook—as a compendium of review chapters suggesting a guide to practice—seems to be very restricted in the context of the field of innovation. The 'handbook' title suggests a guide to practice only in cases where the body of knowledge is understood to be complete and more or less unchanging. For example, 'Handbook of Mathematical Formulae', or 'Handbook of Motorcycle Repair'. However, the study of innovation is a body of knowledge under dynamic theoretical development, and so I prefer to use the 'International Handbook on Innovation' instead of the 'International Handbook of Innovation'. I hope readers will find the present chapters lively and provocative, stimulating greater interest in the science of innovation.

The handbook covers a wide range of topics in innovation. The handbook offers a broad analysis of what innovation is, how it is developed, how it is managed, how it is assessed, and how it affects individuals, groups, organizations, societies, and the world as a whole. The handbook will therefore serve as an authoritative resource on many aspects of theory, research, and practice of innovation. In short, the handbook can be considered as the first serious attempt to unify the field of innovation and, consequently, as the beginning of unified science of innovation. I hope that readers of this handbook will view it as serving that function.

The target international audience for this handbook is broad and includes a wide range of specialists—both researchers and practitioners—in the areas of psychology, management and business science, education, art, economics, technology, administration, and policy-making. Non-specialists will also be interested readers of this handbook, and it will be useful in a wide range of graduate courses as supplementary reading. Because the coverage of the handbook is so broad, it can be read as a reference or an as-needed basis for those who would like information about a particular topic, or from cover to cover either as a sourcebook or as a textbook in a course

dealing with innovation. In short, anyone interested in knowing the wide range of issues regarding innovation will want to read this handbook.

The handbook hopes to accomplish at least four things for readers. First, the reader will obtain expert insight into the latest research in the field of innovation. Indeed, some of the world's leading specialists agreed to contribute to this handbook. Second, the handbook will present many facets of innovation including its nature, its development, its measurement, its management, and its social, cultural, and historical context (most books are devoted to only one of these facets). This breadth will allow the reader to acquire a comprehensive and panoramic picture of the nature of innovation within a single handbook. Third, based on this picture, the reader will develop an accurate sense of what spurs potentially creative and innovative people and companies toward their extraordinary achievements and exceptional performances. Fourth, and perhaps most importantly, the reader will be able to apply the ideas and findings in this handbook to critically consider how best to foster their own innovative abilities and innovative performance in their organization.

There are many people to thank for helping this handbook come to fruition. Most important are the authors: I thank them for their willingness to undertake the difficult and challenging task of contributing chapters. I am particularly grateful to Professor Marina A. Kholodnaya, my former Ph.D. supervisor, who to a great extent 'made' me a researcher, developing my perception of scientific problems. She continually inspires me to undertake innovative endeavors. I am also grateful to my editors at Elsevier Science—Gerhard Boomgaarten and Geraldine Billingham, Publishing Editors, Lesley Roberts, Marketing Editor, and Debbie Raven, Senior Administrative Editor—who provided just the right blend of freedom, encouragement, and guidance needed for successful completion of this project.

I also wish to acknowledge my debt of gratitude to my parents, Anna Shavinina and Vladimir Shavinin, who aroused a passionate intellectual curiosity in me. Finally, I owe my biggest debt of gratitude to my husband, Evgueni Ponomarev, and our four-year-old son, Alexander. In countless ways, Evgueni has been a true colleague, critic, and friend throughout the four years of the project. He provided the moral, financial, and technical support, and—more importantly—the time I needed to complete this project. He did so by performing a number of great tasks, from cooking and administering PC problems when I worked at nights, to assuming the lion's share (and the lioness's, too) of child care for our Alexander, who was born during the course of this project. Very simply, this is his handbook, too.

I especially wish to thank Alexander, whose entry into the world taught me more about innovation and the need for it than has any other single event in my life. He demonstrates everyday that innovation is constantly possible. I sincerely hope that today's children from around the world will grow up to be innovative individuals—in both professional and daily life.

Larisa V. Shavinina

# **Part I**

## **Introduction**

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# Understanding Innovation: Introduction to Some Important Issues

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**Abstract:** This introduction provides an overview of the multidisciplinary and multi-faceted research on innovation presented in the following chapters of this handbook. The main contents of each chapter are summarized, and approaches taken by chapter authors are described.

**Keywords:** Innovation; Creativity; Approaches to understanding innovation; Management; Business science.

## Introduction

Most scholars and decision-makers will agree that innovations are necessary for individuals, groups, and society as a whole. There is also a consensus that human beings must advance in their study of innovation in greater detail. But there are a relatively small number of individuals around the world who study innovation. My goal in bringing them together in this handbook is to present a comprehensive picture of contemporary innovation research by integrating the quite diverse findings obtained by scholars from highly specialized and frequently remote disciplines, and to outline directions for further research, thus advancing the field. In choosing chapter authors, I was particularly interested in those new models, theories, and approaches, which they proposed. My deepest belief is that any handbook on any scientific topic should not only report the current findings in the field, but must also advance that field by presenting challenging new ideas. In one way or another each chapter in the handbook adds something new to our existing edifice of knowledge about innovation. This is the main merit of this handbook, which is international in scope, reflecting American, Canadian, Asian, European, and global perspectives. The chapter authors take a number of different approaches, both empirical and theoretical, reflecting a variety of possible perspectives and research methods aimed at understanding innovation. These range from case studies and autobiographical and biographical methods to experimental methods. I will briefly describe these approaches below. The handbook is divided into XV parts. The first part provides a general introduction to the work. Parts II to

XIV, consisting of 69 chapters, represent distinctive, although sometimes overlapping, approaches to understanding innovation. The final part of the handbook integrates these approaches.

Part I comprises just the present chapter, Chapter 1, which sets the stage for understanding innovation. This chapter describes the various approaches used by authors of this handbook in understanding innovation and briefly summarizes the main contents of each chapter.

Part II of the handbook describes work aimed at the understanding the multifaceted nature of innovation, its basic mechanisms and its various facets. This part presents neurophysiological, psychological, philosophical, sociological, economic, management and business science perspectives on innovation. This part comprises 15 chapters.

In Chapter 1 of Part II, *The Neurophysiological Basis of Innovation*, Larry Vandervert describes for a broad audience how the repetitive processes of working memory are modeled in the brain's cerebellum. He argues that when these models are subsequently fed back to working memory they are experienced as new, more efficient concepts and ways of doing things. As this process is repeated, the resulting degree of generalization (abstraction) increases. When multiple pairs of models are learned in working memory, they may give rise to sudden experiences of insight and intuition. To illustrate the working memory/cerebellar process of innovation, Vandervert walks the reader through three of Albert Einstein's classic subjective accounts of discovery. This is the only chapter in the handbook, which sheds light on the neuropsychology

logical nature of innovation. The neuropsychological foundations of innovation is a promising new direction in research on innovation.

Chapter 2, *On the Nature of Individual Innovation*, by Larisa V. Shavinina and Kavita L. Seeratan, introduces a fascinating theme, which also will be discussed in other chapters of the handbook from various angles. The theme is why some individuals are exceptionally able to generate new ideas, which lead to innovation. The chapter presents a new psychological conception of individual innovation. According to the conception, individual innovation is a result of a specific organization of an individual's cognitive experience. This organization is, in turn, a result of the protracted inner process of the actualization, growth, and enrichment of one's own cognitive resources and their construction into an unrepeatable cognitive experience during accelerated mental development. The direction of this process is determined by specific forms of the organization of the individual cognitive experience (i.e. conceptual structures, knowledge base, and mental space). The unique structure of the mind, which makes possible the creative ideas leading to innovation, is being formed on the basis of this process. The uniqueness of innovators' minds expresses itself in objective representations of reality; that is, in their unique intellectual picture of the world. This means that innovators see, understand, and interpret the world around them by constructing an individual intellectual picture of events, actions, situations, ideas, problems, any aspects of reality in a way that is different from other people.

In contrast to one of the psychological understandings of innovation presented in Chapter 2, Dora Marinova and John Phillimore's *Models of Innovation*, Chapter 3, reviews a number of models developed by economists, management and business scholars, sociologists, geographers, and political scientists that are used to explain the nature of innovation. Their overview includes six generations of models: the black box model, the linear model, the interactive model, the systems model, the evolutionary models, and the innovative milieu model. The authors view innovation mainly as a process leading to generating new products. Marinova and Phillimore analyze each model, its explanatory power and related concepts, and draw further research directions. A comprehensive review of the six models of innovation provides readers with a panoramic picture of the evolution of researchers' views on the nature of innovation.

In Chapter 4, *Evolutionary Models of Innovation and the Meno Problem*, Thomas Nickles proposes a philosophical view of innovation. He presents universal Darwinism as a new approach to understand innovation. According to this approach, innovation is the product of blind variation plus selective retention (BV+SR) and is thus a kind of adaptation, that is, a selective-adaptive process. In Nickles' view, accepting

BV+SR enables human beings to recognize sources of innovation other than new ideas of creative and talented individuals. He, however, points out that the human design model is not entirely wrong, but it turns out to be based on previous applications of BV+SR.

Chapter 5, *Three-Ring Conception of Giftedness: Its Implications for Understanding the Nature of Innovation*, by Joseph S. Renzulli, is the chapter where an author was given an explicit assignment; in this case, to apply his well-known conception of giftedness toward achieving an understanding of innovation. According to the conception, giftedness that leads to innovation emerges from the interaction and overlap of three clusters of traits; high ability in a particular domain, task commitment, and creativity, and occurs in certain individuals, at certain times, under certain conditions. This is another psychological attempt to address the intriguing issue about where innovation 'comes from'. Renzulli's Three-Ring Conception of Giftedness focuses on creative/innovative productivity, which differs from academic giftedness, and is thus appropriate for understanding forces leading to the appearance of innovators.

In Chapter 6, *Innovation and Strategic Reflexivity*, Jon Sundbo presents a strategic innovation theory, which explains activities that lead to innovations in firms. His theory, in which strategic reflexivity is the core concept, is based on evolutionary theory. According to the theory, market conditions and internal resources are the drivers of the innovation process. Firms manage their innovation process and market position through the strategy. Reflexivity is considered as a process during which managerial staff and employees define their strategy. Sundbo presents case studies of innovation in service firms, which support his strategic innovation theory.

Chapter 7, *The Nature and Dynamics of Discontinuous and Disruptive Innovations from a Learning and Knowledge Management Perspective*, by Elias G. Carayannis, Edgar Gonzalez and John Wetter, discusses the nature and dynamics of innovation as a socio-technical phenomenon. Specifically, these authors analyze the evolutionary and revolutionary dimensions of innovation, that is, discontinuous and disruptive types of innovation, respectively. They claim, and provide evidence to support that claim, that the key to organizational competence for generating and leveraging discontinuous—and especially disruptive—innovations is in the individual and organizational capacity for higher-order learning and for managing the stock and flow of knowledge. This chapter is the first in the Handbook to introduce important topics of organizational learning and knowledge management and their growing role in the emergence of innovation. This role is so significant that it is generally recognized today that we live in a society, which is largely based upon a knowledge-based economy.

In Chapter 8, *Profitable Product Innovation: The Critical Success Factors*, Robert G. Cooper analyzes the critical success factors that underlie new product performance, relying upon his and other's research into hundreds of new product launches, probing the question: 'what distinguishes the best from the rest?' Ten common denominators or factors appear to drive new product success, profitability and time-to-market. The chapter outlines these ten critical success factors, and notes the management implications of each.

Chapter 9, *Types of Innovations*, by Robert J. Sternberg, Jean E. Pretz and James C. Kaufman, describes various innovative forms, each representing a different kind of creative contribution. Based on Sternberg's propulsion model of creative contributions, the authors present the following eight types of innovation: replication, redefinition, forward incrementation, advance forward incrementation, redirection, reconstruction, reinitiation, and integration. For example, a conceptual replication is a minimal innovation, simply repeating with minor variations an idea that already exists (e.g. when Mercury puts the 'Mercury' label on what is essentially an already-existing Ford car). Forward incrementations represent next steps forward in a line of progression (e.g. the 2001 version of a 2000 Ford car). Redirections represent a totally different direction for products that diverges from the existing line of progress (e.g. electric cars). The authors discuss these types of innovations and the circumstances under which they are likely to be more or less successful.

In Chapter 10, *Problem Generation and Innovation*, Robert Root-Bernstein further extends our understanding of innovation. Following Albert Einstein and many other innovators in the sciences and engineering, Root-Bernstein argues that problem generation or problem-raising is far more critical to innovation than problem solution, involving not just a thorough grasp of what is known (epistemology), but of what is not known (nepistemology). The key thesis of nepistemology states that we must know what we do not know before we can effectively solve any problem. People are creative and innovative only when they need to do something that cannot yet be done. Root-Bernstein explores strategies used by successful innovators to generate productive problems.

In Chapter 11, *The Role of Flexibility in Innovation*, Asta S. Georgsdottir, Todd I. Lubart and Isaac Getz, define flexibility as the ability to change, emphasizing that innovation encompasses different types of change. Innovation is essentially a science about change, so it is not surprising that 'innovation' is frequently considered synonymous with 'organizational change'. The authors analyze different types of flexibility, particularly concentrating on adaptive flexibility (the ability to change as a function of task requirements) and spontaneous flexibility (the tendency to change for intrinsic reasons, to try out a variety of methods). The

issue of how these types of flexibility are important at different stages in the innovation process is also considered.

In Chapter 12, *The Effect of Mood On Creativity in the Innovative Process*, Geir Kaufmann focuses on creativity aspects of innovation, discussing a recent stream of new research on the importance of mood and affect in the process of creativity. He addresses the issue of the effect of mood states on creative problem-solving as part of the process of innovation. Kaufmann criticizes the dominant opinion that there exists a positive causal link between positive mood and creativity. He analyzes research findings, which demonstrate that under certain conditions positive mood may in fact impair creativity, while negative and neutral moods may facilitate searching for creative solutions to existing problems. Finally, Kaufmann presents a new theory of mood and creative problem-solving and provides data supporting it.

Chapter 13, *Case Studies of Innovation: Ordinary Thinking, Extraordinary Outcomes*, by Robert W. Weisberg, presents another approach to understanding the nature of innovation. He challenges the existing view that innovation is the result of extraordinary thought processes, such as Wertheimer's productive (as opposed to reproductive) and Guilford's divergent (as opposed to convergent) thinking. Weisberg asserts that innovation is the result of the use of ordinary thinking process; creative thinking is simply ordinary thinking that has produced an extraordinary outcome. The author uses quasi-experimental quantitative methods to examine case studies of innovators in the arts and science to support his approach. A sampling of case studies includes Picasso's development of his painting *Guernica*, Edison's electric light, Mozart's compositions, and the Beatles' stylistic innovations.

In Chapter 14, *Innovation and Evolution in the Domains of Theory and Practice*, James R. Bailey and Cameron M. Ford claim that innovation appears when individuals produce novel solutions, and members of the relevant domain adopt it as a valuable variation of current practice. The authors assert that at the individual level, creative or innovative actions are adoptive responses to tensions between the person and situation. In domains such as the arts or sciences, person-situation tensions are best resolved by favoring novelty, whereas in domains such as business, the same tensions are best resolved by favoring value. Bailey and Ford employ a neo-evolutionary view of creativity to propose that these within domains tensions create intractable tensions between domains.

Chapter 15, *E-Creativity and E-Innovation*, by Keng Siau, is about developments in the field of artificial intelligence, which provide researchers another means of analyzing the creative process. The author reviews germane work and discusses the existing approaches to e-creativity and their application for understanding e-innovation. He concludes that we can build creative

programs, which have the potential to shape the future of innovation.

Although many of the above-mentioned chapters consider individual differences in innovation to some extent, Part III of the Handbook, *Individual Differences in Innovative Ability*, concentrates directly on this issue. This Part consists of one chapter, *The Art of Innovation: Polymaths and Universality of the Creative Process*, by Robert Root-Bernstein, that discusses individual differences in innovative ability, which are caused by human innovative thinking. The author takes an interesting approach to the topic: he focuses on polymaths, that is, those innovative artists who have made scientific discoveries, innovative scientists who have made artistic contributions, and those who bridge both sets of disciplines without claiming allegiance to one the other. Root-Bernstein argues that examples of such scientists and artists are unexpectedly common. He concludes that it is precisely those polymaths, that is, those people who incorporate modes of thinking belonging to many cognitive domains that are those most likely to become innovators. Root-Bernstein's analysis of the most innovative polymaths leads him inevitably to the consideration of sciences–arts interactions from the viewpoint of their mutual contribution to innovation.

Part IV of the Handbook, *Development of Innovation Across the Life Span*, is aimed at understanding innovation mainly from the viewpoint of developmental psychology. It thus reflects developmental perspectives on innovation, showing how it develops in individuals from early years through late adulthood and until the end of the personal life. The developmental approaches to innovation explain many of the individual differences in innovation caused by the specificity of human development.

Chapter 1, *Young Inventors*, by Nicholas Colangelo, Susan Assouline, Laurie Croft, Clar Baldus, and Damien Ihrig, analyzes a special kind of innovation in children and adolescents, namely inventiveness. The authors briefly review the history of the study of young inventors. They further describe research on the young inventors who were part of the Invent Iowa program and who have been evaluated as meritorious inventors at local and regional invention competitions qualifying for the State of Iowa Invention Convention. This research revealed a wide range of important findings regarding perceptions of young inventors about the inventiveness process, their attitudes toward school, toward students, and an analysis of their inventions. It is interesting to note that boys and girls have equally strong interest and equal participation in inventiveness programs.

In Chapter 2, *Exceptional Creativity Across the Life Span: The Emergence and Manifestation of Creative Genius*, Dean Keith Simonton connects major innovations in the arts and sciences to the output of creative geniuses. He addresses the two main questions: “How

do great innovators appear?”; and “How does their creativity manifest itself?”. Considering the first question, Simonton analyzes the early experiences that contribute to the development of extraordinary creative potential. Those factors include family background, education, and professional training. In order to address the second question, Simonton focuses on the typical career trajectory of great innovators. He discusses the ages at which geniuses tend to produce their first great work, their best work, and their last great work.

Chapter 3, *Innovations by the Frail Elderly*, by Tomas Heinzen and Nancy Vail, presents an exceptional approach to understanding innovation. The authors point out that the study of extreme, unusual, or unlikely populations represents one seldom-used yet insightful research strategy. In their opinion, non-normative populations can provide insights about innovation that may generalize to larger populations. One such population that appears to be unlikely to demonstrate significant innovation is the frail elderly. The nine innovation principles presented in this chapter are abstracted from research, naturalistic observation, and clinical experience of the ‘pre-hospice’ population of frail elderly people living in nursing homes. Heinzen and Vail’s principles state that ‘the impetus for innovation may be external, unpleasant, and unwelcome’; ‘innovation does not require a ‘creative personality’; ordinary personalities in extraordinary circumstances will innovate’; ‘both frustration and suffering can inspire innovation’; ‘frustration will not lead to innovation unless it is sufficiently annoying to force new ways of thinking about a problem’; ‘innovative behavior is both externally and internally self-rewarding’. ‘changing ourselves represents one form of innovation’. Analyzing situation-driven and personality-driven kinds of innovation, Heinzen and Vail conclude that maximal probability of innovation is the product of the interaction between external stressors such as necessity, desperation, and perceived threat combined with internal capabilities such as habit, preparation, and motivation.

I would like to note that one of the aims of the handbook is to extend the existing understanding of innovation. For the most part, within the psychological science, the term ‘innovation’ is perceived as referring specifically to ‘innovative ideas’. Within the business and management science, the concept of ‘innovation’ is highly associated with ‘new product development’ or ‘innovation management’. I believe, however, that ‘innovative behavior’, ‘innovation in daily life’, and other similar phenomena should be explored, and this is another focus of the Handbook. In this light the Heinzen and Vail chapter definitely extends our understanding of innovation, pointing out a new promising direction in research on innovation.

Part V of the Handbook, *Assessment of Innovation*, comprises just one chapter about the measurement of

innovation. In this chapter, Ronald E. Goldsmith and Gordon R. Foxall analyze the assessment issues from a marketing perspective. Innovativeness refers to individual differences in how people react to innovations and accounts for much of their success or failure. Their conceptualization of innovativeness includes global, consumer, and domain-specific levels of innovativeness. Goldsmith and Foxall present many of the current perspectives on innovativeness and describe a variety of measures that reflect them.

Taking into account today's ever increasing demand for innovative ideas, solutions, products, services, and the commensurate demand on the creative, gifted, and talented individuals able to produce them, Part VI of the Handbook, *Development of Innovation*, consists of chapters with clear educational implications. Their authors analyze a variety of psychological methods, creativity techniques, and educational strategies best suited for the development of human abilities to innovate. The term education is broadly interpreted in the context of this Handbook. It refers to: (a) school and university education for innovation devoted to the development of students' innovative abilities, innovative behavior, and innovative attitude to the world around them; (b) organizational learning; (c) creativity and innovation training; and (d) teaching of innovation. This Part discusses what should be done to encourage the appropriate development of innovative abilities in children and adults, and how this can be accomplished within and outside of traditional education frameworks.

Chapter 1, *Developing High Potentials for Innovation in Young People Through the Schoolwide Enrichment Model*, by Sally M. Reis and Joseph S. Renzulli, presents the Schoolwide Enrichment Model (SEM), developed during 20 years of research in programs for gifted students, which enables each school to develop unique programs for talent development and creative productivity based upon local resources, student demographics, and school dynamics as well as upon faculty strengths and creativity. The major goal of SEM is to promote challenging and enjoyable high-end learning across a wide range of school types, levels, and demographic differences. The idea is to create a repertoire of enrichment opportunities and services that challenge all students. Any individual student does better in a school when all students appreciate creativity and innovation. SEM is one of the excellent ways to develop the creative potential of students within a traditional educational setting and inspire in them a spirit of innovation, inquiry, entrepreneurship, and a sense of power to effect change.

In Chapter 2, *Towards a Logic of Innovation*, Gerald F. Smith asserts that though it is affected by the organizational and social context, and by the individual's personality and motivation, the generation of innovative ideas depends to a considerable degree on

consciously controlled mental activities. His chapter discusses how an aspiring innovator can utilize specific mental activities and exercises in order to improve the prospects for successful idea generation. Smith points out that traces of such logic can be found in the many idea generation methods that have been proposed, but rarely tested, in the creativity literature. He also analyzes the logic of scientific discovery, another component of such logic that has been the target of philosophical and psychological development for the past half century. In Smith's view, the final and most promising stream of research is recent work that tries to develop useful prescriptions for innovation through the analysis of past cases of innovative activity. The most significant of these efforts is TRIZ, the theory of inventive problem-solving developed by Genrich Altshuller.

Chapter 3, *The Development of Innovative Ideas through Creativity Training*, by Maria M. Clapham, examines the effectiveness of various creativity training programs in enhancing innovation. In order to develop innovative thinking and to increase human ability to generate new ideas, creativity training programs of various types have become widespread in educational and business settings. Clapham provides an overview of various types of creativity training programs, which vary widely in methodology and scope, and analyzes recent research findings regarding their effectiveness for stimulating the development of innovative ideas.

In Chapter 4, *Intuitive Tools for Innovative Thinking*, Robert Root-Bernstein and Michele Root-Bernstein consider the role of intuitive thinking skills in the appearance of great innovations in the arts and sciences. The authors identified 13 non-verbal, non-mathematical, non-logical thinking tools that innovative individuals in a wide variety of disciplines say they use and discuss these tools in detail. The tools are: observing, imaging, abstracting, recognizing and forming patterns, analogizing, body thinking, empathizing, dimensional thinking, modeling, playing, transforming and synthesizing. R. Root-Bernstein and M. Root-Bernstein conclude that private, unarticulated insights generated by means of these tools are then translated in an explicitly secondary step into verbal, mathematical and other modes of public communication. Educational efforts to promote creative thinking must thus recognize and exercise intuitional thinking skills and directly address the process of translating idiosyncratic subjective thought into objectified public forms of discourse.

Chapter 5, *Stimulating Innovation*, by Ronald N. Kostoff, describes how innovation can be increased through the discovery by cross-discipline knowledge transfer. The author's approach entails two complementary components: one literature-based, the other workshop-based. The literature-based component identifies the science and technology disciplines related to

the central theme of interest, the experts in these disciplines, and promising candidate concepts for innovative solutions. These outputs define the agenda and participants for the workshop-based component. An example of this approach is presented for the theme of Autonomous Flying Systems.

In Chapter 6, *Developing Innovative Ideas Through High Intellectual and Creative Educational Multimedia Technologies*, Larisa V. Shavinina and Evgueni A. Ponomarev examine how human innovative abilities can be increased by the means of contemporary educational multimedia technologies. They analyze innovations in instructional technology and their implications for developing an individual's intellectual and creative abilities. The authors present high intellectual and creative educational multimedia technologies (HICEMTs) as a special kind of psycho-educational multimedia technology, which are aimed at the development of people's innovative abilities. They argue that a real goal of education should be seen not in knowledge transfer, but in the development of the individual intellectual and creative potential.

Part VII of the Handbook, *Innovations in Different Domains*, is aimed at understanding domain-specific innovations. One of the facets of the uniqueness of the Handbook and its fresh perspectives should be seen in analyzing the specificity of innovation(s) in various areas like science, art, education, management, business, technology, finance, and so on. In other words, the chapter authors reflect a domain-specific view of innovation, considering scientific innovations, technological and industrial innovations, financial innovations, innovations in education, and so on. In this regard, the Handbook addresses the exceptionally important question: Does the uniqueness of each domain predetermine the specific mechanisms of innovation within it?

Chapter 1, *Dimensions of Scientific Innovation*, by Gerald Holton, concentrates on scientific innovation of geniuses. The author describes essential but largely hidden mechanisms of scientific innovation as they manifest themselves in works of Johannes Kepler, Henri Poincare, Enrico Fermi, and the discoverers of high-temperature superconductivity.

In Chapter 2, *Do Radical Discoveries Require Ontological Shifts?* Michelene T. H. Chi and Robert G. M. Hausmann claim that many great revolutionary discoveries in science may have occurred because the scientists have undertaken an ontological shift. That is, the scientists re-conceptualized or re-represented the problem (i.e. the phenomenon to which she/he is seeking an explanation) from the perspective of one ontology or ontological category to another ontology. Examples of the highest level of ontological categories are entities, processes, and mental states. Chi and Hausmann explain what this re-representation or shifting across ontological categories entails, and why it is unusual to undertake, therefore shedding light on

the low frequency of exceptionally revolutionary scientific discoveries. The authors discuss examples from contemporary science and the history of science, which provide evidence in favor of their radical ontological change hypothesis.

Chapter 3, *Understanding Scientific Innovation: The Case of Nobel Laureates*, by Larisa V. Shavinina, addresses an important issue in understanding scientific innovation, namely: 'Why are Nobel Laureates so capable of innovation?' The author demonstrates that scientific innovation of Nobel laureates is determined in part by specific preferences, feelings, and beliefs, which constitute a whole field of unexplored or weakly explored scientific phenomena. These phenomena constitute Nobel Laureates' extracognitive intelligence that accounts for their exceptionally developed tacit knowledge, which, in turn, significantly contributes to the emergence of scientific discoveries. Based on autobiographical and biographical accounts of Nobel laureates, Shavinina describes all of these phenomena in detail and shows that they predict scientific productivity of the highest level resulting into innovations and, as such, displaying an outstanding talent of Nobel caliber.

In Chapter 4, *Innovation in the Social Sciences: Herbert A. Simon and the Birth of a Research Tradition*, Subrata Dasgupta describes the cognitive-social-historical process of innovation in the realm of the social sciences. In his view, innovation presumes creativity but creativity does not necessarily result in innovation. The latter involves both the cognitive process of creation and the social-historical process by which the created product is assimilated into a milieu. Dasgupta analyzes how the American polymath Herbert A. Simon (1916–2001) was led to a particular model of human decision making which in turn gave birth to a radically new research tradition—the cognitive tradition or, more simply, cognitivism—first in organization theory and economics, and then in other domains of the human sciences. For his seminal role in the creation of this research tradition, Simon was awarded the 1978 Nobel Prize for Economic Science. In Dasgupta's view, the emergence of a research tradition in any science signifies a major innovation in that science.

In Chapter 5, *Poetic Innovation*, George Swede points out that every artist wants his or her work to be considered innovative, in both historical and contemporary terms. A psychologist, poet and editor of poetry periodicals and anthologies, the author discusses how and why poets strive towards these goals. His results can also be applicable to other kinds of artistic innovation. Swede's analysis is based upon the findings of psychological research on poets and their poetry, literary theory, and upon his own rich poetic and editorial experience.

Chapter 6, *Dual Directions for Innovation in Music: Integrating Conceptions of Musical Giftedness into*

*General Educational Practice and Enhancing Innovation on the Part of Musically Gifted Students*, by Larry Scripp and Rena F. Subotnik, discusses what should be done for systemic and sustainable innovation in public school music education. Scripp and Subotnik's analysis of innovations in music education lead them to propose a five-step course of action, potentially resulting into future innovations. These steps are: reconcile perspectives regarding the purpose of music education, establish a framework for comprehensive, interdisciplinary programs intended to benefit all children, prepare advanced college-conservatory students to contribute to the development and sustainability of innovative programs as 'artist-teacher-scholars', form networks of college-conservatory, arts organization, and public school partnerships, and, finally, explore and promote new conceptions of giftedness that result from the implementation of innovative forms of comprehensive, interdisciplinary music education.

In Chapter 7, *Determinants of Technological Innovation: Current State of the Art, Modern Research Trends, and Future Prospects*, Vangelis Souitaris reviews various methodologies used to identify the distinctive characteristics of innovative firms in the field of technology, that is, determinants of technological innovation. He discusses a wide range of issues, including the diverse nature and non-standardized definition and measurement of innovation, non-standardized measurements of the determinants, interrelated variables, different characteristics of firms, and, finally, different economic regions where the surveys take place. The author also presents a portfolio model, which synthesizes the existing research results and may be used for country- or industry-specific studies.

As follows from its title, Chapter 8, *Innovation in Financial Services Infrastructure*, by Paul Nightingale, is a thorough review of the state of research on innovations in the financial services infrastructure. Despite their evident importance to the world economy, both innovations in services in general and in financial infrastructure in particular are essentially neglected topics within the academic innovation literature. Nightingale discusses how external infrastructure technologies between institutions improve market liquidity by increasing the reach of markets. The author also analyzes internal infrastructure technologies within institutions, which are used to coordinate the profitable allocation of resources. The heavy regulation of the financial industry, the software intensity of modern infrastructure technologies, the way in which they have multiple users and their increasing complexity create extra uncertainties in their design and development. All of these cause very different patterns of innovation in financial services infrastructure than is observed in traditional consumer goods.

In Chapter 9, *Innovation in Integrated Electronics and Related Technologies: Experiences with Large-*

*Scale Multidisciplinary Programs and Single Investigator Programs in a Research University*, Ronald J. Gutmann overviews advances in university research innovation in integrated electronics via his own many decades involvement in the field. The author distinguishes between discontinuous (or radical) and continuous (or incremental) university knowledge-based innovations. He discusses the impact of the Semiconductor Research Corporation (SRC) initiated in 1981, SEMATECH initiated in 1988 and the Microelectronics Advanced Research Corporation (MARCO) initiated in 1998 on the development of innovations in integrated electronics.

Parts VIII–XIII are about innovations in social context, broadly defined. The importance of social context in the development and implementation of innovations is widely recognized by innovation scholars. The aim of these Parts is to overview research in this direction. They comprise chapters on innovation in different group contexts, for example, companies, universities, and countries. They thus discuss innovation at the group, organizational, regional, national, and international levels. A wide range of topics such as the impact of innovation on organizational members, innovation management, innovation leadership, and national innovation systems is under consideration.

Part VIII, *Basic Approaches to the Understanding of Innovation in Social Context*, contains seven chapters. Chapter 1, *The Barriers Approach to Innovation*, by Athanasios Hadjimanolis, is a comprehensive review on the various types of barriers to innovation, including internal (i.e. strategy-related) barriers and external (e.g. market-related) barriers. The author analyzes the nature of barriers, critically examines their various classifications, discusses their impact on the innovation process, considers theoretical explanations of barriers, and overviews the existing empirical studies. He further describes the specificity of barriers in different social contexts. For instance, barriers have a particular impact in small firm innovation and in small countries. Finally, the chapter presents a set of suggestions regarding how to overcome barriers.

In Chapter 2, *Knowledge Management Processes and Work Group Innovation*, James L. Farr, Hock-Peng Sin, and Paul E. Tesluk present a dynamic model of work group innovation. The model integrates recent advances in taxonomies of work group processes and stages of the innovation process with a focus on the temporal nature of innovation. This model identifies transition and action phases with each of two major stages of innovation: a creativity stage and an innovation implementation stage. The transition phases both involve primarily planning and evaluation tasks that guide later goal accomplishment. The action phases involve primarily in acts that directly contribute to goal accomplishment. Within the creativity stage, the transition phase consists of interpretation of issues and problem identification and the action phase consists of

idea generation. Within the innovation implementation stage, the transition phase consists of the evaluation of the generated ideas as possible solutions and selection of the one(s) to implement and the action phase consists of the application of the idea(s) to the problem.

Chapter 3, *Innovation and Creativity = Competitiveness? When, How, and Why*, by Elias G. Carayannis and Edgar Gonzales, describes the circumstances within which creativity and innovation occur in organizations. Using empirical findings from public and private companies, the authors discuss how and why creativity triggers innovation and vice versa, and the resulting implications for competitiveness. Carayannis and Gonzales analyze the existing literature on the topic and field interviews on the practice and implications of creativity and innovation from the perspective of competitiveness.

In Chapter 4, *Innovation Tensions: Chaos, Structure, and Managed Chaos*, Rajiv Nag, Kevin G. Corley, and Dennis A. Gioia presents a framework for understanding the tensions that underlie an organization's ability to manage innovation effectively in the face of a turbulent competition. These tensions are: (1) the fundamental tension between the desire for structure and need for creative chaos, and (2) the on-going tension between technology-push and market-pull approaches to innovation. The authors discuss the nature and boundaries of these tensions and characterize them as four distinct 'innovation contexts'. Nag, Corley, and Gioia present a case study of one high-technology organization as an example that supports their approach. The authors examine the notion of 'managed chaos', a concept that helps understand the role of innovation in the maintenance and change of an organization's identity.

Chapter 5, *Innovation and Identity*, by Nigel King, continues the theme of identity and innovation within an organizational context. The author specifically focuses on how innovation processes shape people's work-related identities. King further argues that the concept of identity is useful for considering the relationship of the person to the organization in the context of innovation. He analyzes the potential contributions of Social Identity Theory and Constructivist/Constructionist accounts of identity to the field of innovation. The author also presents findings from case studies of innovations in the British health service to demonstrate the value of an interpretive approach to innovation and identity.

In Chapter 6, *Manager's Recognition of Employees' Creative Ideas: A Social-Cognitive Model*, Jing Zhou and Richard W. Woodman concentrate on organizational creativity as a basis for the appearance of innovation. They employ a social-cognitive approach to explaining the conditions under which a manager is likely to consider rewarding and/or implementing an employee's idea. The recognition and support of

employee creative ideas is a critical facet in organizational creativity. Zhou and Woodman present a model, according to which the manager's 'creativity schema' determines recognition of creative ideas in the organizational context. In the authors' view, the creativity schema is influenced by personal traits of the manager, by aspects of the manager's relationship with the employee, and by a number of organizational influences. Finally, Zhou and Woodman describe implications of the social-cognitive approach for innovation research and business practice.

Chapter 7, *Venture Capital's Role in Innovation: Research Methods and Stakeholder Interests*, by John Callahan and Steven Muegge, is a comprehensive review of how venture capital contributes to innovation. The important role of venture capital in innovation is widely recognized by innovation research literature. Callahan and Muegge begin with the history and current state of venture capital. They describe the process of venture capital financing and how it relates to the innovation process. The authors then review the research literature related to venture capital investment decision-making, the venture capital-entrepreneur relationship, and the fostering of innovation by venture capital. Finally, using a stakeholder perspective, Callahan and Muegge emphasize the value of current research for different stakeholders and call for more qualitative, longitudinal research that contributes better stories and richer data on variable interrelationships.

In Part IX, *Innovations in Social Institutions*, chapter authors analyze innovations along a broad spectrum of social institutions, including small and medium-size firms, multitechnology companies, transnational corporations, universities, network forms of organizations, and technopoles.

Chapter 1, *Encouraging Innovation in Small Firms through Externally Generated Knowledge*, by Edward Major and Martyn Cordey-Hayes, continues the topic of knowledge management previously addressed in the two other chapters. Specifically, Major and Cordey-Hayes analyze the conveyance of externally generated knowledge to small firms. The authors emphasize that successful innovation requires firms to draw on multiple sources of knowledge. Many small firms take little note of external sources, thus restricting their potential innovative base. Major and Cordey-Hayes present the concepts of knowledge translation and the knowledge translation gap to illustrate why so many small firms fail to access externally generated knowledge. The authors' findings from research into U.K. small firms and national innovation schemes demonstrate how intermediary organizations can be used to bridge the knowledge translation gap. Finally, they discuss implications for government innovation policy for intermediaries and for small firms.

In Chapter 2, *Linking Knowledge, Networking and Innovation Processes: A Conceptual Model*, Jacqueline Swan, Harry Scarbrough, and Maxine Robertson

present a model that relates specific kinds of networking to episodes of innovation, that is, invention, diffusion, and implementation and to knowledge transformation processes. The operation of the model is illustrated through three longitudinal case studies, each focusing on a different innovation episode. The authors' thorough review of the relevant literature demonstrates that the need for innovation is frequently cited as a major reason for the emergence of network forms of organization. Through networks, it is assumed, knowledge needed for innovation is transferred more easily. However, Swan, Scarbrough, and Robertson point out that relatively little research has addressed the links between networks and the development and utilization of knowledge during processes of innovation. Research that does exist tends to focus on networks, in the structural sense, as channels for the communication of knowledge, which is seen as relatively unchanging. This research provides a useful starting point but tends to be rather static in its treatment of networks and knowledge flows during innovation. It also tends to emphasize the diffusion episode of the innovation process. In contrast, there is relatively little research on the relations between networking, as a dynamic process, and the development of innovation. The authors' model provides a more dynamic account of the links between networking and innovation processes.

Chapter 3, *Innovation in Multitechnology Firms*, by Andrea Prencipe, is about the generation of innovations in companies specializing on complex multitechnology products. He identifies two major dimensions of capabilities of such companies: synchronic systems integration and diachronic systems integration. Within each of these two dimensions, multitechnology companies maintain absorptive capabilities to monitor and identify technological opportunity from external sources and generative capabilities to introduce innovations at the architectural and component levels. Prencipe concentrates on company's generative capabilities and shows that these capabilities enable a company to frame a particular problem, enact an innovative vision, and solve the problem by developing new manufacturing processes. The author concludes that frame-enact-solve is the primary feature of a company's generative capability. Prencipe presents the case study that support his approach.

In Chapter 4, *Innovation Processes in Transnational Corporations*, Oliver Gassmann and Maximilian von Zedtwitz describe innovation in transnational business settings. The authors identify two phases in innovation process: (1) a pre-project phase fostering creativity and effectiveness, and (2) a discipline-focused phase ensuring efficiency of implementation. Such differentiation enables transnational companies to replicate and scale innovation efforts more easily in remote locations, exploiting both economies of scale and of scope. The distinctive features of these phases are different,

however: a few companies mentioned by Gassmann and von Zedtwitz have consistent and differentiated techniques to manage and lead the overall innovation effort specific to each phase.

Chapter 5, *An Analysis of Research and Innovative Activities of Universities in the United States*, by Yukio Miyata, examines how American universities contribute to innovation through their research and collaboration with industry. Universities are an important component of the national innovation system: they supply highly qualified personnel and advanced scientific and technological knowledge to public and private industry. Therefore, the state of innovative activities in universities should be an essential topic in innovation research. In light of the leading role of American science, it is especially interesting to analyze innovative efforts in the American universities. Miyata shows that American universities with a high quality of research tend to be productive in generating academic publications and research results that are close to commercialization. However, license revenue results from a small number of 'hit' inventions that are often in the field of medical research. It is difficult for universities to finance their research by license revenue, so the role of the central government is critical to maintain research quality.

In Chapter 6, *Incubating and Networking Technology Commercialization Centers among Emerging, Developing, and Mature Technopoles Worldwide*, David Gibson and Pedro Conceição discuss the development of innovations at the regional and global levels. Technopoles (Greek for technology and city state) refer to regions of accelerated wealth and job creation through knowledge creation and technology use. Innovation is considered as the adoption of 'new' knowledge that is perceived as new by the user. The access to knowledge and the ability to learn and put knowledge to work is essential to regional economic development and for globalization today. The authors present the conceptual framework for leveraging knowledge through Internet and web-based networks, face-to-face communication, and training programs. The aim is to accelerate regional economic development through globally linked Technology Commercialization Centers (TCCs).

Chapter 7, *Science Parks: A Triumph of Hype over Experience?* by John Phillimore and Richard Joseph, considers the role of science parks in innovation. For example, such parks can serve as technology and/or business incubators thus fostering the growth of start-ups. Phillimore and Joseph emphasize that there is a disjuncture between the critical assessment of the academic literature about most science parks and their growing number worldwide. The authors analyze the skepticism frequently expressed about science parks in the literature and how it contrasts with their continued international popularity. Phillimore and Joseph also discuss possible new directions for science parks.

Part X, *Innovation Management*, is devoted to one of the most central topics within innovation research, that is, how innovation processes should be managed. Today academic and professional journals publish more articles on innovation management than on any other innovation topic. This fact alone highlights an important role of innovation management. Four chapters included in this Part are aimed at the analysis of various aspects of this role.

Chapter 1, *Challenges in Innovation Management*, by John Bessant, reviews the question of managing innovation and particularly looks at some of the key challenges, which must be addressed if company plans to manage innovation successfully. A need to understand innovation, to build an innovation culture, and to extend participation in innovation process, as well as continuous learning are among these challenges.

In Chapter 2, *Managing Technological Innovation in Business Organizations*, Ralph Katz was given an 'assignment' to consider technological innovations and innovation management issues in technological companies. The author thus analyzes the patterns of innovation that usually take place within an industry and how such patterns affect a company's ability to manage its streams of innovative projects along technological cycles.

In Chapter 3, *Towards a Constructivist Approach of Technological Innovation Management*, Vincent Boly, Laure Morel, and Jean Renaud describe a constructivist approach to the understanding of technological innovation management. The key aspects of this approach include the development of a value-oriented strategy and a systemic vision of innovation management through its three levels: strategy, piloting, and sparking. The authors present findings from technological innovation survey in French small and medium size enterprises (SMEs), which support the constructivist approach to technological innovation management.

Chapter 4, *Promoters and Champions in Innovations: Development of a Research Paradigm*, by Jürgen Hauschildt, considers a typology of those individuals within an organizational context who enthusiastically support innovations. The success of innovations depends to a great extent on the activities of such 'champions' or 'promoters'. The author analyzes 30 years of research in this direction. Hauschildt concludes that three types of champions or promoters are necessary for successful development of innovations. First, innovations need a technical expert who acts as 'promotor by expertise'. Second, innovations need top management's sponsorship by a 'power promoter'. Third, innovations need boundary-spanning skills of a 'process promoter'. The size of a company and the diversification of its products, as well as the complexity and newness of innovation, considerably influence this 'troika' model.

Part XI, *Innovation Leadership*, comprises just one chapter, 'Innovation and Leadership', by Jean Philippe

Deschamps. This chapter is about innovation leaders, those critical senior executives which top management sees as the linchpins of its innovation process and the 'evangelists' of an innovation and entrepreneurship culture. The author begins with a well-accepted list of generic leadership imperatives as they relate to innovation. He further describes the common traits of innovation leaders in terms of personal profiles and behavioral attributes. Finally, Deschamps discusses the beliefs and management philosophy on innovation leadership adopted by some innovative companies and their CEOs and CTOs.

Part XII, *Innovation and Marketing*, presents a marketing perspective on innovation. This Part includes two chapters. In Chapter 1, *Innovation and Market Research*, Paul Trott examines the debate about the use of market research in the development of innovative products and discusses the extent to which market research is justified. The author points out that market research can provide a valuable contribution to the development of innovative products. Trott presents the conceptual framework, which should help product and brand managers to consider when and under what circumstances market research is most effective.

Chapter 2, *Marketing and the Development of Innovative New Products*, by Robert W. Veryzer, further develops the market-based view of innovation. Specifically, he analyzes innovation from the perspective of marketing concerns and challenges. The author highlights the critical value of market vision for companies, that is, the ability to bridge technological capability and market need and opportunity. Veryzer emphasizes that market vision is particularly important for high innovation products because they typically involve a significant degree of uncertainty about exactly how an emerging technology may be formulated into a usable product and what the final product application will be. He presents the conceptual framework that can help to clarify the innovation and adoption context with respect to the marketing challenge(s). Marketing thus provides a necessary and useful function in helping to shape an innovative idea into a product offering that meets the needs and desires of the people who are intended to use it.

Part XIII, *Innovation Around the World: Examples of Country Efforts, Policies, Practices and Issues*, discusses innovation practices and innovation policy issues in different countries. The 11 chapters included in this Part are essentially about national innovation systems and describe the unique paths of various states to innovation. It is beyond the scope of this Handbook to include chapters about innovations in all, or even in most, nations. The solution therefore was the following: first, to describe innovations in a few countries whose systems of innovation are unique, or which include unique and useful aspects; and second, to describe innovation systems which are representative of several or many other countries. For example, in

Chapter 1, *Innovation Process in Hungary*, Annamária Inzelt discusses innovations in Hungary, the country, which is, to a significant degree, representative of other post-socialist countries, all of which are characterized by transition economy. Inzelt based her chapter on the analysis of findings of the Hungarian innovation survey and concludes that the level of innovation in the Hungarian economy is low. For instance, Hungarian companies are aware of the importance of developing new products and accessing new markets, but in practice they mainly do this within the limited Hungarian context. The author largely attributes this low level of innovation to the financial stringency imposed by the economic transition process.

In Chapter 2, *Innovation under Constraints: The Case of Singapore*, Hung-Kei Tang and Khim-Teck Yeo examine the specificity of innovation in Singapore, a young nation that has achieved outstanding infrastructural innovations. The authors point out that the real challenge of innovation lies not only in identifying opportunities and committing to action, but also in identifying and mitigating the internal and external constraints that impede the process of innovation. Using four case studies, Tang and Yeo explore how constraints of different types can give rise to innovation as well as cause innovation efforts to fail. The Singaporean government has recognized the need for a better environment for innovation and entrepreneurship and has embarked on several strategic initiatives aimed at fostering that environment.

Chapter 3, *Continuous Innovation in Japan: The Power of Tacit Knowledge*, by Ikujiro Nonaka, Keigo Sasaki, and Mohi Ahmed, describes how Japanese companies innovate. Management practices of the knowledge-creating Japanese corporations had attracted a great deal of attention worldwide. The authors consider the issue of what the basic pattern of innovation is in the knowledge-creating business organizations. Specifically, Nonaka, Sasaki, and Ahmed analyze the basic pattern of innovation at Nippon Roche. They conclude that learning and rule-breaking alone are not enough for continuous innovation. Rather, individuals as well as organizations need to possess tacit knowledge.

In Chapter 4, *Innovation in Korea*, Sunyang Chung reviews the Korean national innovation system. Korea is an innovative and dynamic country. It has implemented a relatively competent national innovation system in three decades. Korea has invested a lot of resources in order to enhance the efficiency of its national innovation system and increase the innovation capabilities of major innovation actors. The author concludes that the dynamic development of the Korean economy within the context of global economy is connected to its efficient national innovation system.

Chapter 5, *Regional Innovations and the Economic Competitiveness in India*, by Kavita Mehra, examines

the innovation process in India. The study of innovation in India is particularly interesting, given that country's dual position as both a developing nation, and one with an ancient, and rich, civilization. Mehra describes the case studies of regional innovations from diverse locations in India, which are very typical to those regions and bound to local culture, knowledge, and resources. She points out that India has a vast storehouse of knowledge in various fields, particularly in tacit form. For this reason the tacit knowledge based innovations are one of the main kinds of innovations in India. These innovations are territorially specific ones, because of their embodiments in individuals, in their social and cultural context. The author concludes that this is exactly what allows developing nations to retain their identity, and preserve local art and craft as the national heritage in the era of globalization.

In Chapter 6, *Innovation Process in Switzerland*, Beate Wilhelm analyzes the national innovation system in one of the most economically advanced countries in the world. She emphasizes that the primary role of Swiss innovation and technology policy is to foster the utilization of scientific knowledge via organized technology transfer from universities to industries. Despite the robust health of the Swiss economy, Wilhelm concludes that the national innovation system needs improvement. Specifically, the existing innovation policy must be developed in order to better coordinate science, industry, government and societal demands.

Chapter 7, *Systems of Innovation and Competence Building across Diversity: Learning from the Portuguese Path into the European context*, by Pedro Conceição and Manuel Heitor, considers the current Portuguese path towards an innovative society. It focus on Portugal within a European scene, considering a context increasingly characterized by uncertainty and diversified environments, which are particularly influenced by social and institutional factors. The authors present a conceptual framework that helps to understand the contemporary demands for being innovative. The concepts of learning society, knowledge accumulation, competence building, and systems of innovation are main components of this framework. Finally, Conceição and Heitor propose suggestions aimed at the further development of innovation policy in Portugal.

In Chapter 8, *Innovation in Taiwan*, Chiung-Wen Hsu and Hsing-Hsiung Chen examine the Taiwan innovation system, which contributes to a great extent to its accelerated technology-based industrial development. The authors consider the most representative characteristics of the Taiwan innovation system, including: (1) the Technology Development Program of the Ministry of Economic Affairs planning the industry innovation policy; (2) the research and development and technology diffusion strategy of the Industrial Technology Research Institutes; (3) the Hsinchu Science-Based Industrial Park's method of

technology commercialization; and (4) the recruitment of overseas experts and cultivation of talents. Hsu and Chen show the Taiwan innovation system 'in action' on the example of the successful development of the Taiwan integrated circuit industry.

Chapter 9, *Innovation in the Upstream Oil and Gas Sector: A Strategic Sector of Canada's Economy*, by A. Jai Persaud, Vinod Kumar, and Uma Kumar, is about the Canadian innovation system and innovations in oil and gas industry. The authors discuss the main facets of Canada's innovation agenda aimed at the advanced economic development. The government of Canada is interested in making Canada a highly innovative economy. Persaud, V. Kumar, and U. Kumar consider the Canadian innovation strategy and related policy issues. The authors focus on the oil and gas sector of Canada's economy—its strategic sector—and analyze the key aspects of innovation in this sector. Innovations in the oil and gas industry can make greater contributions to sustainable development and play a crucial role in reducing greenhouse gas emissions.

Chapter 10, *The National German Innovation System: Its Development in Different Governmental and Territorial Structures*, by Hariolf Grupp, Iciar Dominguez Lacasa, and Monika Friedrich-Nishio, is about innovation system in the united Germany. Germany existed as one country from 1871 to 1945. It existed as a large array of individual states before that period and was divided into West and East from the Second World War to 1990, with extremely different innovation policies. Since then, it was reunited again. Nevertheless, there are many indications of a national innovation system through all these periods, government structures and territorial changes.

In Chapter 11, *Frankenstein Futures? German and British Biotechnology Compared*, Rebecca Harding analyzes biotechnology policies in the U.K. and Germany. She compares and contrasts the market based biotechnology policies of the U.K. with the regionally engineered biotechnology policies of Germany in the light of the national and regional systems of innovation. The author demonstrates that innovation systems generally and regional innovation systems in particular are still useful concepts in explaining the clustering of biotechnology. Harding shows that German biotechnology policy has been particularly successful in

stimulating rapid catch-up with U.K. and global levels of research.

Part XIV, *Innovations of the Future*, consists of two chapters. *Future Innovations in Science and Technology*, by Joseph F. Coates, describes future innovations in genetics, brain science, information technology, nanotechnology, materials science, space technology, energy, and transportation. A scientist and futurist, the author presents a 25-year look into the future, considering scientific developments and their practical technological applications. He concludes that a general result of future innovations will be continuing enhancement of the quality of human life, leading to unprecedented richness, on a worldwide scale.

In Chapter 2, *The Future of Innovation Research*, Tudor Rickards presents his view of future advances in the field of innovation. He identifies a few research directions in which the main developments should be expected. Rickards also describes challenges, which will be faced by innovation scholars, and discusses the multifaceted impact of innovation research on practice.

Part XV, *Conclusion*, contains a single chapter, *Research on Innovation at the Beginning of the 21st Century: What Do We Know About It?* by Larry R. Vandervert, which serves to integrate the other chapters in the Handbook. This chapter points out common as well as unique features of the various accounts of innovation and suggests directions in which future research, practice, and policy might lead us.

The chapters of this Handbook therefore demonstrate that the phenomenon of innovation is inherently multidimensional, multifaceted, interdisciplinary, personally demanding, socially consequential, cross-cultural, and frequently surprising. As a result, understanding the scientific principles that underlie innovation requires a variety of research approaches. Authors presented a wide range of approaches to understanding the nature of innovation at the individual, group, organizational, societal, and global levels. This Handbook thus provides what is perhaps the most comprehensive account available of what innovation is, how it is developed, how it is managed, how it is measured, and how it affects individuals, companies, societies, and the world as a whole.

## **Part II**

# **The Nature of Innovation**

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# The Neurophysiological Basis of Innovation

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**Abstract:** It is proposed that: (a) the recursive processes of working memory (online consciousness) are modeled in cognitive control processes of the cerebellum; and (b) when these new, more efficient control processes are subsequently fed back to working memory, they are learned in a manner that facilitates innovation. Walking through this cerebellar-working memory sequence, Einstein's experiential accounts of discovery are examined. Methods of encouraging innovation are outlined. It is concluded that innovation is a recursive neurophysiological process that constantly reduces conceptual thought to patterns, thus constantly opening new and more efficient design spaces.

**Keywords:** Einstein; Cerebellum; Design space; Innovation; Mathematics; Mental models; Working memory.

## Introduction

Many scholars and researchers have described the close parallels between biological evolution on the one hand and the processes that govern innovation on the other (e.g. Ziman, 2000). This broad-based literature leaves little doubt that innovation is an integral part of overall biological and socio-cultural evolution. But what, precisely, is the primary evolutionary mechanism behind innovation? Why is human innovation so prolific? And why does the pace of innovation seem to be accelerating? The purpose of this chapter is to describe neurophysiological processes going on in the human brain that can address these questions. Understanding how the human brain extends itself into the production of new ideas and technologies will help build a basic science of innovation. Such a basic science will perhaps permit us to unleash more of the seemingly limitless potential of innovation.

An attempt will be made to keep the jargon of neurophysiology at a minimum. Technical terms will be used only in a manner that will likely be understood by readers from a broad variety of disciplinary backgrounds.

*The Neurophysiology of Mathematical Discovery  
Represents a Generalized Model for All Innovation*

Recently, I described a theory of how mathematical discovery arises through the collaboration of working memory and *patterns* generated in the cerebellum

(Vandervert, in press).<sup>1</sup> In the present chapter I provide: (a) a description of how the brain processes that lead to mathematical discovery represent a general neurophy-

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<sup>1</sup> Historically, mathematics has been defined first as geometry, and, later, as number. With the advent of high-speed computers, however, mathematics is seen in a new, more fundamental light. We realize now that mathematics is actually all about *patterns*:

Mathematics is the science of patterns. The mathematician seeks patterns in number, in space, in science, in computers, and in imagination. Mathematical theories explain the *relations* (italics added) among patterns; functions and maps, operators and morphisms bind one type of pattern to another to yield lasting mathematical structures. Applications of mathematics use these patterns to 'explain' and predict natural phenomena that fit the patterns (Steen, p. 616).

See also Devlin (1994).

Today, we understand that the core of mathematics is about *relations* (functions and maps, operators and morphisms) among patterns that, ultimately, fit *all* real-world phenomena. Mathematics, as we know it, consists of patterns among phenomena in terms of scientific operations upon which there is social agreement (scientific validity). It is a thesis of this chapter that the cerebellar models of movement, perception, and thought are coded in functions, mappings, operators and morphisms pertinent to all processes taking place in the cerebral cortex. Thus it is proposed that innovation in all fields can be modeled after the brain processes that lead to mathematical innovation.

biological model for *all* innovation; and (b) a walk-through of three of Einstein's classic experiential accounts of discovery that corroborates the neurophysiological model.

#### *Why the Cerebellum and Working Memory?*

During the course of repetitive bodily movement, a person becomes able to move more quickly and precisely. These increases in efficiency are the result of control models that are learned in the cerebellum and subsequently fed back to motor areas of the cerebral cortex. In this chapter, three interrelated arguments are presented. First, it is proposed that in the same way that cerebellar models for bodily movement are learned and fed back to the cerebral cortex, models for working memory processes are learned in the cerebellum and fed back to working memory, making its visuospatial, speech, and central executive functions significantly more efficient (see Desmond & Fiez, 1998; Doya, 1999; Ito, 1993, 1997; Leiner, Leiner & Dow, 1986, 1989 for the extension of cerebellar modeling to thought processes). Second, because the components of working memory contain the attribute of conscious awareness (Baddeley, 1992; Baddeley & Andrade, 1998; Baddeley & Hitch, 1974; Teasdale, Dritschel, Taylor, Proctor, Lloyd, Nimmo-Smith & Baddeley, 1995), it is argued that the newer, high-efficiency *patterns* of the cerebellar models learned in working memory provide the experiential basis for innovation. Finally, it is the contention of this chapter that the experience of innovative discovery is the result of the action of multiple paired cerebellar models (see Haruno, Wolpert & Kawato, 1999 for a description of such models).

Three general theoretical premises constitute the working memory/cerebellar theory of innovation.

- (1) Innovation is a process of evolutionary adaptation.
- (2) The selective advantages of innovation arise from efficiencies that accrue through the reciprocal learning relationship between working memory (i.e. the visuospatial sketchpad, the speech loop, and the central executive) and the perceptual-cognitive functions of the cerebellum.
- (3) The working memory/cerebellar processes that lead to mathematical innovation represent the generalized model of innovation (Vandervert, in press). Thus the neurophysiological model of mathematical innovation can serve as the fundamental model for the brain processes that lead to innovation in all fields.

#### *The Plan of this Chapter*

##### Working Memory

First, the components of working memory will be examined. Since the concept of working memory is widely understood and resources on the topic are easily obtained, only a brief account that relates its compo-

nents to selected areas of the cerebral cortex and cerebellum will be described.

##### The Cognitive Functions of the Cerebellum

Next, a review of findings from newer research on the cognitive functions of the cerebellum will be presented. Because much of the research on the cognitive functions of the cerebellum tends to be relatively new and is spread over many sub-areas of investigation, a more lengthy discussion will be presented.

##### A Demonstration of the Generalized Model of Innovation: Einstein's Experiential Accounts of Mathematical Discovery

Finally, the interaction of working memory and the cognitive functions of the cerebellum will be illustrated within the framework of three of Albert Einstein's classic experiential accounts of mathematical discovery. While the neurophysiological 'walk through' of Einstein's subjective accounts is admittedly tentative, it is an attempt to both round out and demonstrate the generalized model of innovation that is suggested by the behavioral studies of working memory, and the neurophysiological studies of the collaborative cognitive functions of the cerebellum and working memory.

##### Working Memory: The Ongoing Stream of Cognitive Consciousness

According to Baddeley (1992) the term 'working memory' refers to processes in the brain that provide temporary storage and manipulation of the information necessary for such complex cognitive tasks as language comprehension, learning, and reasoning. Working memory may be characterized as our 'on-line' cognitive consciousness (e.g. Baddeley & Andrade, 1998). Working memory may be thought of as 'working consciousness'. It will be important to keep this latter conception of working memory in mind when we examine Einstein's experiential accounts of mathematical discovery.

When our attention is on a particular stream of verbal and/or visuospatial consciousness, such as when I am writing this sentence, or when it is being read, the essential conscious, cognitive framework is working memory. Working memory consists of three interacting components: a central executive and two subsidiary slave systems—a visuospatial sketchpad and a phonological (speech) loop. To maintain information in a conscious, on-line state in the central executive, the visuospatial sketchpad and the speech loop are in a continual process of repetitive rehearsal and updating. We can use the above-mentioned writing of a sentence to conveniently illustrate the on-line, repetitive interplay of the three components of working memory. First, *attentional control* of the action of writing (or reading) the sentence is carried on by working memory's central executive functions. Attentional functions of the central executive supervise, schedule

and integrate information from different sources. The *visuospatial sketchpad* and the *phonological loop* are short-term memory stores/rehearsal processes for maintaining, respectively, visuospatial images and speech information that is needed for the on-line composition (or deciphering, if reading) of the sentence. Because the sketchpad and speech loop are *short-term memory* stores/rehearsal processes, they are within the ongoing grasp of consciousness, but additional and updating information continually enters working memory via the attentional functions of the central executive.

*The Evolutionary Birth of Human Working Memory and its Collaboration with the Cognitive Functions of Cerebellum*

The relationships among the three components of working memory are both phylogenetically and ontogenetically dynamic and interactive. Mandler (1988, 1992a, 1992b) proposed how image-schemas (conceptual primitives) drive the ontological development of language. Following in the vein of Mandler's description of the development of language from image-schemas, I proposed that image-schemas and language evolved in a yoked fashion due to the following two-part, compounding selective advantage: (a) their visuo-linguistic advantage as state variables for cognitive simulation and communication of possible future states of events in working memory; and (b) new, higher efficiency advantages in movement, thought and communication as a result of their being modeled in the cerebellum, and then being fed back to working memory (Vandervert, 1997). I believe that this is the substantial account of the evolutionary selection toward the constantly improving, reciprocal relationships among working memory's central executive, visuospatial sketchpad, and phonological (speech) loop.

There are three highly supportive lines of evidence that the activity of working memory is indeed modeled in the cerebellum. First, Ito (1993, 1997) points out that, at the neurological level, movements and thoughts are identical control objects:

In thought, ideas and concepts are manipulated just as limbs are in movements. There would be no distinction between movement and thought once encoded in the neuronal circuitry of the brain; therefore, both movement and thought can be controlled with the same neural mechanisms [namely, those of the cerebellum] (1993, p. 449).

Thus, the control of the components of working memory in solving problems is not different from the control of hands and feet in solving problems. And, as the use of the components is repeated, the cerebellum acts to make the manipulations smoother, faster, and more efficient. Second, as will be seen below in the sections on the cognitive functions of the cerebellum,

there is abundant evidence that *patterning* representing both visual and linguistic aspects of cognition is learned in the cerebellum (see, e.g. Desmond & Fiez, 1998; Houk & Wise, 1995). Third, it has recently been found that the cerebellum continually updates its models of variations in cognitive activity (Imamizu, Miyauchi, Tamada, Sasaki, Takino, Pütz, Yoshioka & Kawato, 2000). This newer evidence is critical to the argument here because, to be of selective advantage to the rapidly changing, online nature of working memory, the infusion of parallel, rapidly updated cerebellar models is required.

*Working Memory and Associated Brain Areas*

Functions of working memory can be related to brain areas. Before proceeding to this description it is important to note that the distribution of working memory functions across brain areas is likely quite complex. For example, there is strong evidence that storage and rehearsal functions involve differing brain areas (Awh, Jonides, Smith, Schumacher, Koeppel & Katz, 1996). Figure 1 is a simplified illustration of key brain areas involved in working memory:

- (a) The central executive functions can be tentatively thought of as spread over the SMA (supplementary motor area—long associated with 'will' or intentionality (e.g. Deecke, Kornhuber, Lang, Lang & Schreiber, 1985), Brodmann area 9, with overlappings in Broca's area (Brodmann areas 44/45), lateral and inferior parietal areas (Brodmann areas 39/40), and, I will argue below, the cerebellum (Desmond & Fiez, 1998; Fiez, Raife, Balota, Schwarz, Raichle & Peterson, 1996).
- (b) The phonological loop involves at least Brodmann areas 44/45, and the cerebellum (Desmond & Fiez, 1998).
- (c) The visuospatial sketchpad most likely involves, Brodmann areas 40/18/19 (Fiez, Raife, Balota, Schwarz, Raichle & Peterson, 1996).

In brief summary of this section, the brain areas described above and shown in Fig. 1 are those most fundamentally associated with working memory and, I believe, with the production of mathematical discovery and innovation. The next section describes the cognitive functions of the cerebellum in learning and feeding adaptive control models to the cognitive processes of working memory.

**The New Perception of the Cerebellum: The Cognitive Functions of the Cerebellum**

*Research and Theory on the Cerebellum: A Fast Computational System for Patterns of Both Movement and Thought*

Understandings of the cerebellum have moved far beyond the earlier, more traditional idea that its functions are limited to motor control (e.g. Kornhuber,

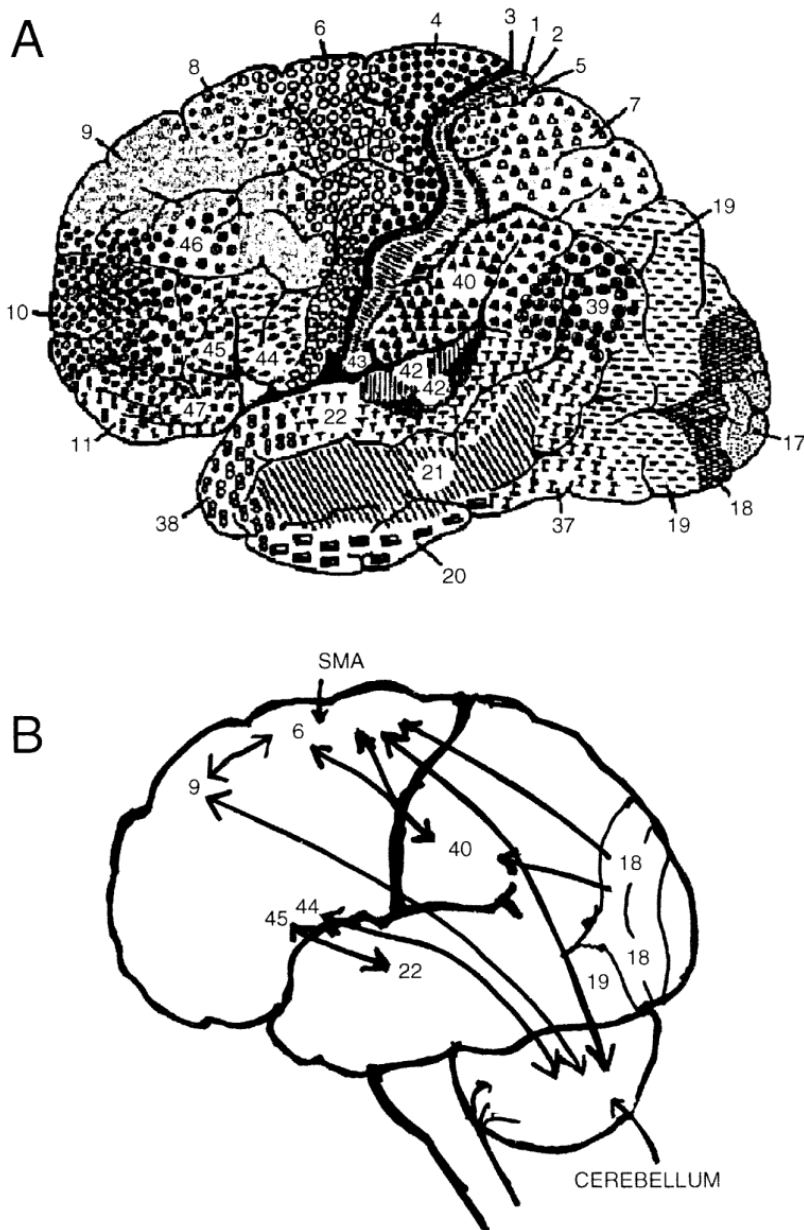


Figure 1. (A) Brodmann areas; (B) simplified connections among Brodmann areas, and between Brodmann areas and the cerebellum.

1974). A number of newer and converging lines of research and theory suggest that the cerebellum provides a fast computational system for the *patterning* of both motor and *cognitive* processes that take place in the cerebral cortex (Desmond & Fiez, 1998; Doya, 1999; Houk & Wise, 1995; Ito, 1993, 1993; Leiner & Leiner, 1997; Leiner, Leiner & Dow, 1986, 1989). This

newer knowledge about the cognitive control functions of the cerebellum was the thrust of Schmahmann's (1997) volume, *The Cerebellum and Cognition*. More recently, research on the cognitive functions of the cerebellum has been increasing at an accelerating rate. Table 1 contains a collection of chapter and paper summaries of such research that is particularly relevant

Table 1. Newer research and theory supporting cognitive control functions of the cerebellum.

Source:	Methods:	Conclusions:
Akshoomoff, N., Courchesne, E. & Townsend, J., 1997; Desmond, J. & Fiez, J., 1998	Human PET and functional MRI	The cerebellum is a master computational system that adjusts responsiveness in networks including those of declarative and working memory, attention, arousal affect, language, speech, sensory modulation and motor control
Doya, K. 1999	Mathematical modeling of the respective functions of the cerebellum, basal ganglia, and cerebral cortex	
Haruno, M., Wolpert, D. & Kawato, M. 1999; Imamizu, H., Miyauchi, S., Tamada, T., Sasaki, Y., Takino, R., Pütz, B., Yoshioka, T. & Kawato, M. 2000; Ito, M. 1993, 1997; Kawato, M. 1999; Kawato, M. & Gomi, H. 1992; Kawato, M., Furukawa, K. & Suzuki, R. 1987; Pribram, K. 1971, 1991	Mathematical and Physiological modeling of cerebellar cortex	During repeated thoughts in the cerebral cortex, faster-than-real-time (FTRT) model is transferred to cerebellum to allow that model later to be fed forward back to cortex circumventing need to check outcome of thought—thus, FTRT thought. FTRT cerebellar models are short-cut circuits (abstractions) of action and thought patterns of the cerebral cortex
Ivry, R., 1997	Physiological and behavioral modeling of cerebellar timing systems	Cerebellar timing system provides a near-infinite set of interval type timers that can become attached to perceptual tasking through learning
Leiner, H. & Leiner, A., 1997; Leiner, H., Leiner, A. & Dow, R., 1986; Leiner, H., Leiner, A. & Dow, R., 1989	Theoretical computer model of cerebellar anatomy and physiology	Computing capabilities of the cerebellum have expanded with the evolution of the cerebral cortex to specify ‘which’, ‘when’, and ‘where’ for sequencing cognitive processing (including the linguistic manipulation of ideas that precedes planned behavior)

to the purposes of this chapter. It can be seen in the right-hand column of Table 1, that the cerebellum is now understood to be a builder of *models* that govern the rapid manipulation of both motor and cognitive activities (including language and working memory).

*The Recent Evolution of the Relationship Between the Cerebellum and the Cerebral Cortex: Expansion Toward the Control of Cognitive Functions*

Before proceeding to specific cognitive modeling functions of the cerebellum, it will be helpful to briefly sketch the recent evolution of the cerebellum in its relation to the cerebral cortex. Leiner, Leiner & Dow (1986, 1989) proposed that the massive three- to fourfold increase in the size of the cerebellum (and not in the basal ganglia which concurrently enlarged at a very low rate) in humans arose in conjunction with parallel increases in size and cognitive complexity of the cerebral cortex:

A detailed examination of cerebellar circuitry suggests that its phylogenetically newest parts may serve as a fast information processing adjunct of the association cortex and could assist this cortex in the

performance of a variety of manipulative skills, including the skill that is characteristic of anthropoid apes and humans: the skillful manipulation of ideas (1986, p. 444).

Ito (1984, 1993, 1997) anticipated and later elaborated on Leiner, Leiner and Dow’s work by proposing *how* neurophysiological processes that take place in the cerebellum can apply equally well to both movements and mental processes:

This view may be justified in view of the common features of movement and thought as control objects . . . The cerebellum may be viewed in this way as a multipurpose learning machine which assists all kinds of neural control, autonomic, motor or mental (verbal or nonverbal) (1993, p. 449).

The cerebellum is now conceived as learning machine, as Ito put it, that facilitates the neural control of all information flows in the cerebral cortex.

Thus, the selective advantage of the greatly enlarging cerebellum was that its computing capacities were being harnessed as an ‘operating system’ (determining the which, when and where of information flows)

for the evolving yoked complexities of movement, language, and thought—including, of course, operating system control of the visuospatial sketchpad and speech loop of working memory. Leiner & Leiner (1997) have described the computing capacity of neural connections between the cerebellum and the cerebral cortex (some 40 million nerve tracts) in some detail. The details of this enormous amount of cerebellar connectivity with the cerebral cortex are beyond the scope of this article, but see Leiner & Leiner (1997, pp. 542–547) and Leiner, Leiner & Dow (1989). It is significant to recognize here that the influence of the cerebellum in the spatial and temporal control in the *internal* world of the brain rivals the influence of the nerve tracts of the visual system on the perceived spatial and temporal dimensions of the *external* world. It will be important to recall this idea, later in this chapter, when we examine Einstein's internal world.

### The Neurophysiological Basis of Innovation

In this section we will examine how the interplay between the cerebellum and the cerebral cortex leads to innovation.

#### Cerebellar Models

Biological *feedback* loops are relatively slow, and, therefore, rapid and coordinated movement and thought patterns cannot be smoothly or competitively executed through feedback control alone (e.g. Kawato, 1999; Kawato & Gomi, 1992). For example, the movements and thoughts of professional athletes would be disastrously handicapped if dependent only on feedback information. However, the cerebellum has evolved rapid control of such movements and thoughts by way of internal *feedforward models* that are acquired through learning (Ito, 1984, 1993, 1997; Leiner, Leiner & Dow, 1986, 1989).<sup>2</sup> As one learns to

<sup>2</sup> According to the *computational* scheme for *mental models* set for originally by Craik (1943) and extensively elaborated by Johnson-Laird (1983), thought processes construct mental models that are imitative, small-scale computational representations of the external world that retain the external world's relation-structure. Craik described how the preserved relation-structure of the model is computationally parallel to that which it imitates:

A calculating machine, an anti-aircraft 'predictor', and Kelvin's tidal predictor all show the same ability. In all of these latter cases, the physical process, which it is desired to predict, is *imitated* (relation-structure is preserved) by some mechanical device or model which is cheaper, quicker, or more convenient in operation (1943, p. 52).

Thus, the similarity of the relation-structure of the model captures the fundamentals of operation of that which it imitates, but makes the operations faster and cheaper, and in the case of cerebellar models, 'neurologically cheaper and simpler'. This abstractive-imitative modeling advantage, it is proposed, is precisely what takes place between working memory and the cerebellum.

play basketball or play the piano, for example, movement and thought strategies become smoother, quicker, and more efficiently executed.

More important to the premises of this chapter, cerebellar models also greatly increase the efficiency of purely *conceptual thought* (Doya, 1999; Ito, 1993, 1997; Leiner & Leiner, 1997; Leiner, Leiner & Dow, 1986, 1989). Leiner, Leiner & Dow (1989) described the processing of conceptual thought related to novel situations:

In confronting a novel situation, the individual may need to carry out some preliminary mental processing before action can be taken, such as processing to estimate the potential consequences of the action before deciding whether to act or to refrain from acting. In such decision-generating processes, the prefrontal cortex is activated. This cortex, via its connections with the cerebellum, could use cerebellar preprogramming [e.g. learned cerebellar models that involve rapid strategies of search, planning, pattern recognition, and induction] to manipulate conceptual data rapidly. As a result, a quick decision could be made. This could be communicated to the motor areas, including the supplementary motor areas (p. 448).

The foregoing account of innovative problem-solving clearly involves the visuospatial sketchpad, speech loop and central executive functions of working memory. But how, exactly, does such 'faster-than-real-time' cerebellar preprogramming lead to innovation?

#### Cerebellar Models are Dynamics Models

Cerebellar feedforward models are neural representations of the dynamics of movement and thought (Ito, 1993, 1997). A dynamics model learns the *dynamics* of control objects (e.g. hands, legs, or the components of working memory) instead of a specific motor command for a movement or a specific cognitive control for the manipulation of conceptual information (Ito, 1993, 1997; Kawato, 1999; Kawato & Gomi, 1992). This means that a dynamics model is a set of control instructions that *generalizes* to a broad variety of situations that could potentially occur in the state-space in which it was originally learned. This capacity for generalization, along with the speed advantage, permits a great flexibility of movement and thought, and it is why cerebellar dynamics models have powerful selective advantage when, as described above, the individual confronts novelty. The capacity for generalization that is inherent in dynamics models of the cerebellum is the key to innovation. But this is only the beginning of the story.

### *Manipulation of Thought: Unconscious Generalization*

In the process of learning, the cerebellum acquires two types of feedforward dynamics models, namely, dynamics models and *inverse* dynamics models. Dynamics (g) models are neural representations of the transformation from motor commands to movement and thought patterns in behavior and cognitive processing. However, the inverse dynamics (1/g, i.e. motor dynamics inversely equal to g) models are defined as neural representations of the transformation from the movement and thought patterns to the motor commands required to achieve them (see Ito, 1997, p. 481; Kawato & Gomi, 1992, pp. 445–446). In everyday language, this means that dynamics models are associated with rapid, skilled movement/thought while under conscious control, while cerebellar inverse dynamics models permit the motor cortex to be bypassed, thus allowing rapid, skilled movement/thought to take place at an unconscious level.

Ito (1997) provided an example of the respective operation of dynamics and inverse dynamics models that is highly pertinent to the learning of models of working memory activity by the cerebellum:

According to the psychological concept of a mental model (Johnson-Laird, 1983) [see footnote 2], thought may be viewed as a process of manipulating a mental model formed in the parietolateral association cortex (see Fig. 1) by commands from the prefrontal association cortex. A cerebellar microcomplex may be connected to neuronal circuits involved in thought [notably language processing] and may represent a *dynamics or an inverse dynamics model of a mental model* (italics added). In other words, a mental model might be transferred from the parietolateral association cortex to the cerebellar microcomplex during repetition of thought. By analogy to voluntary movement, one may speculate that formation of a dynamics model in the cerebellum would enable us to think correctly [and rapidly] in a feedforward manner, i.e. without the need to check the outcome of the thought. . . . However, an inverse dynamics model in the cerebellum would enable us to think automatically without conscious effort (p. 483).

The inverse dynamics model helps explain how generalizations can be formed outside a person's conscious awareness. This is one of the reasons that innovative insight may seem to leap out of 'nowhere'.

### **The Cerebellar/Working Memory Basis of Innovation: Details**

In this section I describe in more detail: (1) how the resulting new cerebellar patterns of operation are learned in working memory; and (2) why innovative discovery (actually the discovery of new cerebellar

patterns in working memory) is often experienced as intuition or insight.

### *Detail: How Cerebellar Patterning ('Innovation') is Learned in Working Memory*

What is the neurophysiological basis, in working memory, of 'seeing' (in the visuospatial sketchpad), 'hearing' (in the speech loop), and 'making decisions about' (in the central executive) innovative versions of conceptual information? Houk & Wise (1995) propose that the output from the cerebellum guides the frontal cortex by training its cortical networks toward more efficient use of problem spaces. I propose that the experience of innovation arises as cerebellar commands are executed toward broadened generalization in the conceptual thought of working memory (see also Vandervert, in press). Houk & Wise describe these cerebellum-initiated changes in the frontal cortex (and other modules of the cerebral cortex) as follows:

On the one hand, these alterations [arriving from the cerebellum] would serve to modify the collective computations being performed by the cortical network on a moment-to-moment basis. On the other hand, the same alterations would promote changes in the weights of the Hebbian synapses on pyramidal neurons, that, in the long run, would move the network's attractors closer to the points being forced by cerebellar and basal ganglia modifications. As a consequence, the frontal cortex would become trained to perform, in a highly efficient and automatic fashion, those particular functions being forced on it by its subcortical [cerebellar and basal ganglia] inputs (1995, p. 106).

The above training of the frontal cortex may involve the input of new efficiencies and generalization from either *within* a cerebellar dynamics space or *between* cerebellar dynamics spaces (see Haruno, Wolpert & Kawato, 1999). This would account for the fact that innovations may occur either within the narrow scope of a single technology or from diverse interdisciplinary efforts.

The alteration of cortical networks toward the experience of new ideas or technology may be experienced as an innovative insight, just as is, for example, an innovative hand movement that more efficiently renders a drawing, makes a signal, or throws a Frisbee. Since such alteration is a continuous updating process in working memory, innovation is a feature of learning that occurs regularly in everyone. What makes an innovation an 'important' innovation, or a deeply experienced 'insight' is a matter of its cultural or organizational context, and its degree of generalization.

*Detail: The Dynamics of Dynamics Models are Compounded: The Deepening of Generalization*

There is a rather profound corollary to the foregoing principle of dynamics learning in working memory. Once a new model of the cerebellar mental model is learned in working memory and given its new, more generalized expression, the newer expression in the neural networks of the cerebral cortex, under continued recursive processing in working memory, *itself* yields even more generalized dynamics—a deeper insight. Redrafting in writing, art or model-making is an example of this compounded recursive process. This ever-new level of realized generalization is one of the reasons, perhaps the most important reason, that ‘yesterday’s’ writing often appears to somehow be ‘sub-standard’.

Within the working memory/cerebellar theory of innovation, this ‘model-of-a-mental-model loop’ produces an ever-deepening level of generalization or abstraction. These new levels of generalization may be accomplished either by the individual who produced the initial level of abstraction or by importing generalized information from others that could be further ‘reduced’ in its recipient new ‘host’. I believe that this conceptually simple, selective mechanism is why the history of innovation is the story of continual refinement and an ever-deepening level of abstraction. It is an epistemological question as to how far this model-of-a-mental-model process may continue into the realm of abstraction. (See Constant (2000) for a discussion of recursive innovative processes at the socio-cultural level.)

**Einstein’s Experiential Accounts of Mathematical Innovation: The Generalized Case for All Innovation**

In preparation for the examination of Einstein’s subjective account of mathematical innovation, I will layout a summary diagram showing the hypothesized flow of information in terms of the collaborative contributions of recursive control patterns of working memory and the cerebellum. This articulated flow of brain functions provides a neurophysiological basis upon which to follow the mental steps to mathematical innovation as described by Einstein. In this way, we may assume for a moment that Einstein was perhaps describing actual, operationally specifiable milestones (within the general experimental framework of working memory developed by Baddeley and his colleagues, as it is influenced by the cognitive functions of the cerebellum) that constitute the gestation and birth, as it were, of mathematical axioms. Indeed, for Einstein, such a general assumption was the key to understanding how pure thought is directly connected to the axioms of science and mathematics (see Holton, 1979). Einstein took great pains on many occasions to tell us that the internal world of thought processes is

the epistemological nidus of axiomatic knowledge (Einstein, 1949, 1956; Holton, 1979).<sup>3</sup>

**A General Structure for the Analysis of Einstein’s Experiential Account**

Figure 2 is a summary illustration of the flow of information between working memory and the cerebellum that will be used to study Einstein’s experiential account.

While the mental processes that lead to the cognition of mathematical axioms are ultimately dependent upon the world of sensory experience, and such discovery must be verified in terms of tests in relation to the sensory world, the focus in Fig. 2 is upon events taking

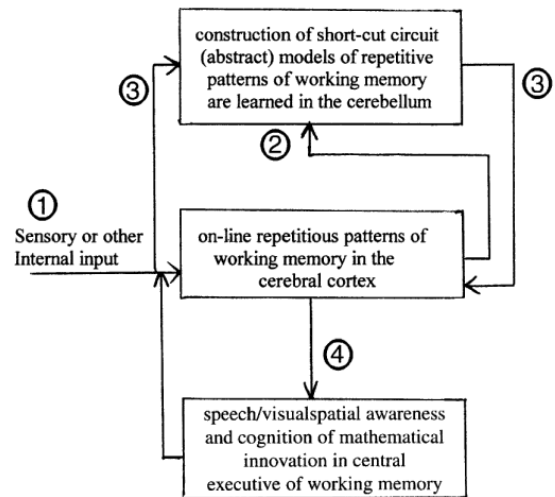


Figure 2. Flow between working memory functions of the cerebral cortex and their mapping representation in the cerebellum. Routing sequence: (1) sensory and/or other internal brain processes utilized by working memory; (2) mapping of patterns of working memory learned in the cerebellum; (3) upon elicitation by sensory, perceptual-motor, or other internal input, mappings fed forward from the cerebellum to facilitate smooth and rapid working memory processing, (4) awareness/cognition of innovation in the central executive. Since all innovations are based upon the cerebellar categorization and generation of patterns, mathematical discovery can serve at the basic model for all innovations (see footnote 1). Compare flow with simplified flows in brain areas illustrated in Fig. 1B.

<sup>3</sup> Similarly, it is the epistemological contention behind the theory of innovation presented in this chapter that the *patterns* that constitute mathematics (see footnote 1) arise from the reference frame of bodily movement in relation to perceptual-cognitive processing (Vandervert, 1993, 1997, 1999, 2001). This position does not deny the existence of a real world ‘out there’, but proposes that mathematics is based on patterns that are constructed in the brain as it adapts to its environment. See also the epistemological position on mathematics espoused by Lakoff & Núñez (1997, 2000).

place *within* the brain. Houk & Wise (1995, pp. 105–106) have presented an excellent overarching picture of brain functions that supports the processing plan proposed here. See especially their concluding section titled, ‘The Search for Intelligent Behavior’. It is important to note that Fig. 2 obviously does not represent an entire account of brain areas that may have a bearing on innovation. Such a detailed, full account is beyond the purposes of this chapter.

In Fig. 2, recursive patterns of the activity of working memory are learned in the cerebellum. Short-cut mappings (generalizations or ‘abstractions’) of these patterns are subsequently fed back to working memory’s central executive to facilitate more efficient on-line processing of conceptual thought as described in the previous section (Ito, 1993, 1997).

*Bringing Cerebellar Models to Awareness Within Mental Models Employed by Working Memory: Cognizing Abstract Predictive Mappings*

Baddeley (1993, 1998, especially chapters 6 and 18) has suggested that the central executive manages and comprehends available information by ‘running’ it within the predictive *mental model* frameworks proposed by Johnson-Laird (1983) (see footnote 2). According to Johnson-Laird, thought processes construct mental models that are *computational* representations of the external world. The selective advantage of such mental models is that they permit an organism to predict probable future states that may be critical to its survival (Vandervert, 1997). At the same time, Ito (1993, 1997) and Kawato & Gomi (1992) propose that the short-cut mappings generated in the cerebellum are also predictive mental models of the Johnson-Laird type. (See Ito (1997) on the subject of dynamics and inverse dynamics cerebellar models in the earlier section on the cognitive functions of the cerebellum.) In the brain-internal dialogue depicted in Fig. 2, then, the mental models employed by working memory and the cerebellum are computationally compatible predictive models. They would, of course, have to be compatible if cerebellar models were to act as short-cut circuits for movement and thought patterning (see Ito, 1997).

Thus within the flow depicted in Fig. 2, it is hypothesized that: (a) the *patterning* basis for mathematical innovation is contained in models generated by the cerebellum; and (b) the central executive has the capacities to bring these patterns to conscious awareness. We will now examine Einstein’s experiential accounts of mathematical innovation within the foregoing perspective.

*Einstein’s Inner World*

There are three classic sources that contribute to Einstein’s subjective account of mathematical discovery: (a) Einstein’s responses to Hadamard’s (1945) study of invention/discovery in the mathematical field;

(b) Einstein’s (1949) comments on the nature of thinking that appeared in his ‘Autobiographical Notes’; and (c) his model of the construction of axioms that appeared in a 1952 letter to Maurice Solovine (Einstein, 1956). (A thorough theoretical and epistemological discussion of the letter to Maurice Solovine appears in Holton (1979).) The above sources extend over several years and provide an excellent sampling of Einstein’s persistent views on the workings of his own experiential world. All three of the reports contain a great deal on how the structure of his thoughts evolved, and are therefore especially amenable to analysis in terms of the structure of processing depicted in Fig. 2.

*A View of the Central Executive*

Although we could begin with any one of the three sources on Einstein’s experiential world, we will begin with the earliest account. This is perhaps our best chance to view the operation of the central executive of Einstein’s working memory. The account was in response to a question in Hadamard’s (1945) survey of the habits and mental methods of mathematicians. The specific question read as follows:

It would be very helpful for the purpose of psychological investigation to know what internal or mental images, what kind of ‘internal world’ mathematicians make use of; whether they are motor, auditory, visual, or mixed, depending on the subject they are studying (Hadamard, 1945, Appendix I, p. 140).

Einstein answered this question in the following structured manner:

(A) The words or the language, as they are written or spoken, do not seem to play any role in my mechanism of thought. The psychical entities which seem to serve as elements in thought are certain signs and more or less clear images which can be ‘voluntarily’ reproduced and combined.

There is, of course, a certain connection between those elements and relevant logical concepts. It is also clear that the desire to arrive finally at logically connected concepts is the emotional basis of this rather vague play with the above mentioned elements. But taken from a psychological viewpoint, this combinatory play seems to be the essential feature in productive thought—before there is any connection with logical construction in words or other kinds of signs which can be communicated to others.

(B) The above mentioned elements are, in my case, of visual and some of muscular type. Conventional words or other signs have to be sought laboriously only in a secondary stage, when the

mentioned associative play is sufficiently established and can be reproduced at will.

- (C) According to what has been said, the play with the mentioned elements is aimed to be analogous to certain logical connections one is searching for (Appendix II, pp. 142–143).

Einstein says that, in the process of mathematical discovery, he consciously ('voluntarily') plays with combinations of psychical elements, but that they are not words or language as they are written or spoken. Because the search he describes was under voluntary control, it appears that Einstein was talking about ongoing awareness in the (his) central executive. However, because conventional words and other signs had to be 'sought for laboriously only in a *secondary stage*' (italics added), it sounds as if the essential combinatory play Einstein describes is a process of 'decoding' less conventionalized sources of information (and not simply retrieval processing). What might be the origin of such less conventionalized sources of information? Within the framework of this chapter, the only source of this type of information would be cerebellar inverse dynamics models of thought patterns that Einstein had repeated many times as he mulled over problems of mathematics. That is, these are perhaps cerebellar models emerging into the consciousness of Einstein's central executive. Recall Houk & Wise's (1995) description of how cerebellar patterns are learned in the frontal cortex.

But we need to know more about the *structure* of the 'signs and more or less clear images' (psychical entities) he mentions. The next source will greatly clarify that picture.

#### *Visualizing Automaticity in the Visuospatial Sketchpad: Decoding Cerebellar Models*

In his 1949 'Autobiographical Notes' Einstein focuses on the psychical elements and processing structure of his internal world. He offers a visual record of the combinatory play and structure that brings forth an ordering element. This ordering element provides the logical connections that he mentioned 'searching for' in his above response to Hadamard. Einstein referred to the process that unlocks the ordering element of combinatory play as 'thinking':

What, precisely, is 'thinking?' When, at the reception of sense-impressions, memory-pictures emerge, this is not yet 'thinking'. And when such pictures form series, each member of which calls forth another, this too is not yet 'thinking'. When, however, a certain picture turns up in many such series, then—precisely through such return—it becomes an *ordering element* for such series, in that it connects series which in themselves are unconnected. Such an element becomes an instrument, a concept. I think that the transition from free association or 'dreaming' to thinking is charac-

terized by the more or less dominating role which the 'concept' plays in it. It is by no means necessary that a concept must be connected with a sensorily cognizable and reproducible sign (word); but when this is the case thinking becomes by means of that fact communicable (Einstein, 1949, p. 7).

In his picture series, each picture calling forth another picture, and, as well, in the certain picture that turns up in many series, Einstein reveals the automaticity that underlies what he is referring to as axiomatic-level 'thinking'. (See Ito's (1997) comments on the automaticity of inverse dynamics models in the section on the cognitive functions of the cerebellum. See also Kihlstrom (1987) on automaticity in the cognitive unconscious.) The automatic flow of various series of memory pictures Einstein describes fits the computational architecture of *linked* multiple pairs of forward (predictive) and inverse (controller) models (Haruno, Wolpert & Kawato, 1999; Kawato, 1999). Within this architecture, a large number of separate but interconnected pairs of forward and inverse models cover a range of learning and control contexts. The paired models govern both conscious learning and unconscious control aspects related to various environment contexts, e.g. manipulation of physical objects, manipulation of language communication, and manipulation of working memory processes. A responsibility predictor function (forward model of a pair) automatically calls forth its context-appropriate inverse controller model. *In the case where working memory is mulling over several contexts, the responsibility predictor function would result in the calling forth of a series of inverse models and their visuospatial (and central executive and phonological) content (images or 'pictures')*. Thus the paired model computational architecture of the cerebellum appears to be a good candidate for the control of the automatic, each-picture-calling-forth-another portion of Einstein's description. I believe this is the selective strategy by which working memory forms new mathematical concepts (Vandervert, in press). But, we have not yet explained the crucial appearance of the ordering element that Einstein mentions.

#### *The Axiomatic Ordering Element: The Working Memory/Cerebellar Confabulation of Intuition and Insight*

Our final report from Einstein helps clarify *how* the ordering element, which would be an axiom in mathematical discovery, is 'constructed'. In a 1952 letter to his good friend Maurice Solovine (Einstein, 1956), Einstein described a complete diagrammatic model of the discovery of axioms. In the model, discovery begins with immediate sensory experience (E). Then, in the next step, Einstein shows an *intuitive leap* to axioms (A). In the letter he described the situation as follows:

A are the axioms from which we draw consequences. Psychologically the A are based upon the E. There is, however, no logical path from E to A, but only an intuitive (psychological) connection, which is always subject to ‘revocation’ (p. 121).

Einstein went on to say that once axioms were intuitively conceptualized, logical assertions could be deduced, and that, finally, these assertions could be tested against experience. The idea that axioms could *only* be arrived at by an intuitive leap was Einstein’s most persistent epistemological belief.

Einstein suggested that we prepare ourselves for the intuitive leap to axioms (concepts or ordering principles) by focusing our attention on “certain repeatedly recurring complexes of sense impressions” and “relating to them a concept” (Einstein, 1954, p. 291). This focus of attention (on the part of the central executive functions of working memory), I believe, is the basis of the confabulation and appearance of the ordering principle or ‘certain picture’ mentioned above in Einstein’s (1949) classic description of ‘thinking’.

But why would this new, common picture that Einstein mentions begin to turn up in many series? This new, common picture seems to be the key to intuitive discovery, and I think it is an expression of the *dynamics* principle described earlier in this chapter. That is, I believe that this picture is the result of *generalization* from a newly generated level of abstraction that has originated in the cerebellum (recall the recursive model-of-a-mental-model principle described earlier).

### *The Cerebellar Trigger of Intuition*

Why would the new picture appear *suddenly*, and *how* would it give new conceptual order to the several series? First, the appearance of the new picture would occur among many series as Einstein describes it, because the responsibility predictor functions of the several series (of multiple paired models) had simultaneously responded (via the neural computation of responsibility estimates)<sup>4</sup> to a newly generated level of abstraction as a *novel* control object. That is, since the new generalization had been recognized as a new control object by the series of multiple paired models, they would, depending on the coherence of their several contexts, simultaneously generalize their prediction and control *to* it. Such simultaneous generalized prediction and control would result in a new ‘picture’ in the visuospatial sketchpad that would appear ‘suddenly’ (either through simultaneous acquisition or through rapid recursion) in the many series mentioned by Einstein. Second, this new picture would be a synthesis based upon joint generalization in the

several impacted series of multiple paired models, and thus it would serve as an ordering element for otherwise unconnected series. When such simultaneous generalization among collections of multiple paired models occurs in working memory, it would be experienced as *insight* or *intuition*.<sup>5</sup>

### **Encouraging the Production of Innovation**

The neurophysiological process that leads to innovation works pretty much the same way in all people, although, due to a variety of learning and genetic predispositions, the emergence of innovation is perhaps not experienced to the same degree of clarity or of productivity. The main point is that everyone is born with, and carries throughout life, the neurophysiological ‘apparatus’ of innovation. And, like other cognition involving the cerebellum and working memory, this apparatus is highly educable.

The most fundamental product of the interplay between working memory and the cerebellum appears to be its boundless capacity for the deepening of abstraction. And, we can conclude from the earlier discussion of the subjective reports of Albert Einstein that the abstraction of pattern is the fundamental building block of innovation. Root-Bernstein and Root-Bernstein (chap. 5, 1999) have convincingly shown that abstraction is a product of a recursive ‘play’ involving some problem in art, science, poetry and so on. These authors show that when abstraction is achieved in this way, it is inevitably tied to discovery and innovation. Of course, in regard to the working memory/cerebellar theory of innovation, such recursive play is exactly what leads to the transfer of working memory information to the cerebellum for pattern abstraction, and then back to working memory where it may be consciously experienced. The reason that pattern abstraction produces something new is that an abstraction moves the system (physiological or mental) toward the fundamental rules, designs, and laws that connect collections of movements and thoughts. Abstractions thereby make new connections among disciplines and among topics within disciplines. Indeed, the deepest level of abstraction, which history seems to show we are neurophysiologically destined to achieve, may eventually lead humans to a verifiable grand ‘theory of everything’.

### *Steps That Will Encourage Abstraction and Innovation*

Root-Bernstein and Root-Bernstein (chap. 5, 1999) provide several classic examples, beginning with the art of Picasso, which illustrate how pattern abstraction

<sup>4</sup>Haruno, Wolpert & Kawato (1999) provide equations for the computation of the functions of each component of the multiple paired model architecture.

<sup>5</sup>Einstein’s example appears to involve mostly the central executive and visuospatial sketchpad of working memory. However, the same effects of multiple paired models, if arising in the other components or combinations of components of working memory, would lead to insight and intuition, although appearing in differing experiential form.

leading to innovation develops. To encourage the development of abstractions, in both children and adults, they offer the following advice:

Abstracting. . . is a process beginning with reality and using some tool (a personally-chosen, repetitive technique) to pare away the excess to reveal a critical, often surprising, essence. . . . Use one of the abstraction sequences discussed in this chapter—Picasso's *Bulls*, for example, or 'Observations on a Water-Worn Stone'—as a guide. Choose your subject and your abstracting tool; think about them realistically; play around with their various properties or characteristics; get at what might be most essential; then consider and reconsider your results from a distance of time and space. Say your abstraction, mime it, sing it, write it in prose, write it in poetry, extract a concept or metaphor. Practice with artwork, or, if you are scientifically inclined, practice with simple experiments or mathematical concepts. If you are a dancer, replicate the real movements of real people or of animals, then try to find the essence characterizing that personality or that species. Describe in music the distillation of birdness or windness or a carousel. Find the minimum vocabulary to convey a maximum amount of sense and sensibility (p. 90).

One can see the interplay of the components of working memory and its associative executive areas of the cerebral cortex on the one hand, and cerebellar model making on the other running all through the Root-Bernstein's approach to abstracting. Of course, their approach can also be looked upon as a guide to the improvement of the process of thinking in general. I will clarify this point in a moment.

I believe that the how-to-develop-an-abstraction plan that Root-Bernstein and Root-Bernstein have suggested is good, solid advice for systematically encouraging cerebellar/working memory processes toward generalization and innovation. And, as they say, it would be increasingly effective as it were carried out over longer periods of time. If we were to disassemble and examine Root-Bernsteins' recommendations as we did Einstein's experiential account of 'thinking' in the previous section, we would find that they both make use of the same cerebellar/working memory processes. In other words, processes very much like the abstract processes Root-Bernstein and Root-Bernstein describe are iterated automatically in the mind of, for example, an Einstein or a Picasso. The key to highly productive innovation would seem to be an approach that keeps a person (or an organization) at tasks that are contexted in such 'play' for an extended period of time.

### Discussion

Dasgupta (1996) argued that innovation is a lawful process that can be seen running across individual

innovators and across innovations in different disciplines. And, he says, the study of innovation can therefore be carried out in a scientific manner.

As a part of such a science, I have described how the recursive collaboration of working memory (online consciousness) and the cognitive functions of the cerebellum constitutes the primary evolutionary mechanism behind innovation. The repetitive activities of the visuospatial loop, speech loop, and central executive control processes of working memory are constantly reduced to new and more efficient spatio-temporal patterning in the cerebellum. These control patterns are subsequently fed back to working memory where neural networks constantly learn the new and ever more efficient control instructions for conceptual thought. Human innovation is prolific and its pace has accelerated, because constantly increasing levels of generalization are produced by the reciprocal relationship between the cerebellum and working memory. This process makes its appearance as ever-new levels and combinations of design space in working memory. (See Stankiewicz (2000) for a discussion of design space as implied here.)

Highly reduced patterning involving collections of multiple paired cerebellar models becomes the basis for the discovery of mathematical knowledge when it is learned in the neural networks of working memory. This cerebellar-working memory sequence of mathematical discovery was examined by way of three of Einstein's classic experiential accounts of mathematical discovery. The neurophysiology of the discovery of mathematics constitutes the general process of innovation in all fields and accounts for their unique subjective experiences of insight and intuition.

The transparency between mathematical discovery and innovation in other fields can be seen most clearly in technological innovation. This transparency becomes increasingly evident as technology has become increasingly electronic as in computing, communication and telepresence. At this advanced level of technological development, mathematics can be literally 'reverse engineered' from technology. In other words, mathematics is embodied in technology, just as it is embodied in the neurophysiological operation of the human mind. This is the essential theoretical-epistemological basis of cybernetics, as defined by Wiener (1948): "the entire field of control and communication theory, whether in the machine or in the animal" (p. 19).

### Acknowledgements

I would like to thank Marc Nagel for his help in securing the illustration of the Brodmann brain areas that appears in Fig. 1. The illustration was kindly provided by Hermann Strohmaier, Director of the Korbinian Brodmann Museum, Hauptstr. 43, 78355 Hohenfels, Germany.

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# On the Nature of Individual Innovation

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**Abstract:** In this chapter a new conception of individual innovation, seeking to explain its very nature, will be presented. Individual innovation refers to innovation at the level of an individual. This conception ventures to explore an issue of exceptional importance necessary for a scientific understanding of the inner essence of innovation, namely: why innovative ideas emerge in human minds. To successfully grasp this issue, we believe that mainly developmental and cognitive mechanisms must be taken into account. The internal structure of individual innovation is presented at five levels: (1) developmental foundation of innovation; (2) its cognitive basis; (3) its intellectual manifestations; (4) its metacognitive manifestations; and (5) its extracognitive manifestations.

**Keywords:** Innovation; Individual innovation; Giftedness; Talent; Creativity; Cognitive experience.

## Introduction

A growing body of literature suggests that innovation originates from within the individual, that is, from his or her new idea(s) (Amabile, 1988, 1996; King, 1990, this volume; Simonton, this volume). Various definitions, models, and theories of creativity and innovation include the 'generation of new ideas' as one of their components (Bailey & Ford, this volume; Clapham, this volume; Dugupta, this volume; Lubart, 2001–2002; Runco & Pritzker, 1999; Sternberg, 1999; Sternberg et al., this volume). For instance, many innovation scholars—including us—would agree with Kanter (1983) who states that innovation is the generation, acceptance, and implementation of new ideas, processes, products, or services. In this chapter, we focus on individual innovation, that is, innovation which appears at the individual level and which is mainly responsible for the generation of new ideas. In spite of advances in innovation research, determined mostly by studies of business scholars and management science specialists (Christensen, 1997; Katz, 1997; Leonard-Barton, 1995; Tidd, Bessant & Pavitt, 1997; Tushman & O'Reilly, 1997; Van de Ven et al., 1999), we do not know for certain why it is that some individuals are exceptionally able to generate new ideas and others not. An important goal of this chapter is to try to shed some light on this important issue by presenting a new conceptual framework for understanding individual innovation.

Individual innovation begins from the generation of new ideas, which is eventually externally manifested in the extraordinary innovative achievements we see in any field of human activity. According to our conception, individual innovation is a result of a specific organization of an individual's cognitive experience which functions as a carrier of all the manifestations of individual innovation (i.e. its traits and characteristics). Cognitive experience expresses itself in a specific type of the representations of reality (i.e. how an individual sees, understands, and interprets the world around), that is, in an individual's intellectual picture of the world.

The essence of individual innovation rests in the uniqueness of the individual's intellectual picture of the world. In other words, innovators' unique view, understanding, and interpretation of what is going on in the surrounding reality are keys for the scientific understanding of individual innovation.

In our view, the internal structure of individual innovation is presented at five levels: (1) a developmental foundation for innovation; (2) the cognitive basis of innovation; (3) the level of intellectual manifestations of innovation; (4) the level of metacognitive manifestations of innovation; and (5) the level of extracognitive manifestations of innovation. Below we consider each of them in detail.

Before beginning a presentation of our conception of individual innovation, it is important to note three

things. First, from our point of view, individual innovation belongs to a general construct of high abilities, which includes creativity, exceptional intelligence, giftedness, and talent. Thus, in this chapter we do not draw a distinction between individual innovation and creativity, talent, and giftedness. In our view, innovators are gifted, creative, and talented individuals.

Second, it should be emphasized that in this chapter we deal especially with individual innovation, which differs from the general understanding of innovation (e.g. Kanter's definition). Specifically, our chapter addresses the issue of *why* new ideas—from which any innovation begins—appear in the minds of only certain individuals. In this light, a range of questions arises such as: What is exceptional about the personalities of those people who are able to generate new ideas leading to innovations? Do they have extraordinary minds? Is their exceptionality a result of a combination of their unique minds and personalities? In order to successfully address these questions, one should recognize—as we have—that those individuals who are able to generate new ideas resulting into innovations (i.e. innovators) are gifted, creative, and talented.

Finally, since many chapters in this handbook provide comprehensive reviews of the existing literature on innovation appropriate in the context of our chapter (see, for example, Chi et al., this volume; Georgsdottir et al., this volume; Kaufmann, this volume; Root-Bernstein, this volume; Simonton, this volume; to mention just a few), we do not include our own literature review in this chapter.

## A New Conception of Individual Innovation

### *Cognitive Experience as a Psychological Basis of Individual Innovation*

As we previously mentioned, the nature of individual innovation is still an area of innovation research that has been left relatively unexplored. Although the traits, characteristics, features, properties, and qualities of innovation and innovative people (i.e. their external manifestations in any real activity) have been the subject of scientific research, the psychological basis (or psychological carrier) of these manifestations has not been investigated (Kholodnaya, 2002; Shavinina & Kholodnaya, 1996). Attempts to understand the nature of any psychological phenomenon based solely on listing and describing its external manifestations, including its characteristics, traits, features, qualities, and properties, are inadequate. Contradictions and crises in psychology testify to this (Vekker, 1981).

There is a need for a new direction for research that considers individual innovation as the sum of its two important aspects: its external manifestations and its

psychological basis. Consequently, there is a need to re-examine the question of the nature of individual innovation. Researchers should not simply answer the question 'What is individual innovation?' by merely listing its characteristics and traits (i.e. its external manifestations). Rather, they should answer the question: 'What is the carrier (a basis) of the characteristics and traits associated with individual innovation?' (Shavinina & Kholodnaya, 1996).

From this fundamentally changed viewpoint, scientists should study an individual's mental or cognitive experience—more precisely, the specificity of its structural organization. We assert that the individual cognitive experience is the psychological basis of individual innovation or the psychological carrier of its manifestations (Shavinina & Kholodnaya, 1996). Mental or cognitive experience is defined as a system of the available psychological mechanisms, which forms a basis for the human cognitive attitude towards the world and predetermines the specificity of his or her intellectual activity (Kholodnaya, 2002). Cognitive experience—that is the cognitive level in the structural organization of individual innovation—is formed by conceptual structures (i.e. conceptual thinking), knowledge base, and subjective mental space (Kholodnaya, 2002). These are all forms of the organization of the cognitive experience.

The importance of *conceptual structures* is determined by scientific findings, which indicate that conceptual thinking is the integrated cognitive formation, that is, a form of the integrated functioning of human intelligence (Kholodnaya, 2002). The more conceptual thinking is a form of the integrated work of intelligence, the better organization of an individual's intellectual activity will be. That means that intelligence will function perfectly (Kholodnaya, 1983; Vekker, 1981; Vygotsky, 1978). Chi & Hausmann (this volume) discuss the importance of conceptual structures in the context of their approach to understanding scientific innovation.

The *knowledge base* is the second form in the organization of the cognitive experience. Many researchers emphasize the role of the knowledge base in the development of an individual's intellectual resources as crucial (Bjorklund & Schneider, 1996; Chi & Ceci, 1987; Chi, Feltovich & Glaser, 1981; Kholodnaya, 2002; Pressley, Borkowski & Schneider, 1987; Rabinowitz & Glaser, 1985; Schneider, 1993; Shavinina & Kholodnaya, 1996; Shore & Kanevsky, 1993; Sternberg, 1985). Thus, the quantity and quality of specialized knowledge play a critical part in highly intellectual performance and in the process of acquiring new knowledge (Bjorklund & Schneider, 1996). For example, productive problem-solving cannot occur without relevant prior knowledge (Chi & Ceci, 1987). The knowledge base can facilitate the use of particular strategies, generalize strategy use to related domains, or even diminish the need for strategy activation

(Schneider, 1993). It was demonstrated that intellectually gifted people are distinguished by an adequate, well-structured, well-functioning, and elaborate knowledge base, which is easily accessible for actualization at any time (Kholodnaya, 1997; Rabinowitz & Glaser, 1985). Moreover, this rich knowledge base can sometimes compensate for overall lack of general cognitive abilities (Pressley et al., 1987; Schneider, 1993).

Conceptual structures and the knowledge base generate subjective mental space, the third form in the organization of cognitive experience. Individual differences in flexibility, differentiation, integration, and hierarchical structure of the mental space influence a persons' cognitive attitude to the world and, therefore, predetermine his or her intellectual and creative abilities, which lead to new ideas resulting into innovation. A more detailed review of the influence of flexibility on innovation can be found in the chapter by Georgsdottir et al. (this volume).

Cognitive experience expresses itself in a specific type of the objective representations of reality—that is, how an individual sees, understands, and interprets what is going on in the surrounding reality and in the world around him or her. Kholodnaya's (2002) investigations of the nature of individual intelligence have demonstrated that one of the basic phenomena (i.e. a proto-phenomenon) of an individual's intellectual life and his or her experience as a whole is his or her representations. Many psychologists have viewed representations to be important in understanding the essence of intelligence, intellectual giftedness, and innovation (Bamberger, 1986; Chi et al., this volume; Chi, Feltovich & Glaser, 1981; Klux, 1988; Oatley, 1978; Piaget, 1969). For example, Kholodnaya (1990) found that the main function of human intelligence lies in the construction of adequate representations of the world around.

In modern cognitive psychology, the expert–novice research paradigm also gives credence to the importance of the phenomenon of representations in the understanding of the nature of human intellectual abilities (Chi et al., 1981; Chi, Glaser & Rees, 1982; Kanevsky, 1990; Schneider, 1993; Shore & Kanevsky, 1993; Sternberg & Powell, 1983). For example, Chi et al. (1981) demonstrated that the main difference between experts and novices in physics has to do with their problem representations. They found that experts classified problems according to underlying principles and rules, but that novices tended to use superficial meanings of words and diagrams in their own classification of the same problems.

Therefore, cognitive experience manifests itself in the specific types of representations. This means that intelligent persons—and particularly innovators, who are intellectually gifted, creative, and talented—see, understand, and interpret the world around them by constructing an individual intellectual picture of events, actions, situations, ideas, problems, any aspects

of reality in a way that is different from other people. Because of that, their individual intellectual picture of the world (i.e. world view) is a unique one (Kholodnaya, 2002; Shavinina & Kholodnaya, 1996). One aspect of this uniqueness is connected with their objectivization of cognition, that is, they see, understand, and interpret everything in a very objective manner. Robert Root-Bernstein in his chapter, *The Art of Innovation* (this volume), emphasizes that sometimes perceiving the world differently is the key to making discoveries. Contributors to this handbook also highlight the importance of changing perspective for new ideas to appear (Chi et al., this volume; Georgsdottir et al., this volume).

It is important to note that scholars in the field of innovation point out that innovation does not necessarily imply acceptance and implementation of only objectively new ideas. Ideas can also be subjectively new ones—new only for some individuals or companies, but not for the rest of the world. As individual innovation deals mainly with the generation of new ideas, our conception of individual innovation emphasizes *objectively* new ideas, because the very essence of innovators—which, in our view, are intellectually gifted individuals—resides in their ability to see the world from an objective point of view. Kaufmann (this volume) also points out that novelty of ideas must be objective, and not only subjectively novel to its originator. Kholodnaya's (1990) understanding of human intelligence as the mechanism for structuring specific representations of reality—representations connected with the reproduction of 'objective' knowledge—suggests that the degree of development of the ability for the objectivization of cognition determines one's intellectual and creative productivity. She showed that one of the distinguishing features of gifted individuals' representations of reality is their objective character. In this respect the most important conclusion is that:

... the significance of *intellectually gifted individuals* in society should be seen not only in that they solve problems well and create new knowledge, but mainly in the fact that they have *the ability to create an intellectual (objective) picture of the world*, i.e. they can see the world as it was, as it is, and as it will be in its reality (Kholodnaya, 1990, p. 128; italics added).

The same is true in the case of innovators. Let us consider, for example, Albert Einstein, whose scientific innovations have been undeniable for decades. A countless number of people who came along before him tried to understand the fundamental questions of time, space, and relativity. However, the fact is that only Einstein was able to propose specialized and generalized theories of relativity—the monumental

achievements of the human mind of the 20th century. In our view, it was possible because Einstein saw the world—with its fundamental questions of time, space, gravity, and relativity—in its objective reality. That is—in accordance with Kholodnaya's (1990, p. 128) quotation—he saw the world as it was, as it is, and as it will be in its reality. Einstein's case as an innovator is especially compelling, because his ability to objectivize cognition was extremely pronounced (Shavinina, 1996).<sup>1</sup> Based on our study of Einstein, R. B. Woodward, Jean Piaget, and V. I. Vernadsky, we suggested that scientific innovations (i.e. new discoveries) are probably generated in the world of objectivization. In other words, the highly productive work of gifted, creative, and talented scientists—that is, their numerous discoveries and inventions—are made possible by their ability to objectivize cognition. Being active on a number of fronts and making important advances (i.e. formulating objectively new fundamental laws, rules, novel ideas, etc.) can be

<sup>1</sup> This is very clearly shown in his life ideal: "The *cognition of the world in its unity and its rational comprehension*" (as cited in Kuznetsov, 1979, p. 326; free translation from Russian, italics added). Being very young, Einstein wanted to go beyond various personal everyday problems to active work on *superpersonal* rational ideas, which take place in the *superpersonal world*, beyond the world of daily interests. Later, his desire to achieve objective and superpersonal cognition of the world became very strong. He was interested in general laws of the universe, nature, and existence. He wrote:

The most important level in the development of a person like me is reached then, when the *basic interest of life goes beyond the temporary and personal, and concentrates more and more on the desire to understand mentally the nature of the world* (as cited in Kuznetsov, 1979, p. 326; free translation from Russian, italics added).

Indeed, all Einstein's scientific activity was at the highest level of abstractness. His great theories are evidence of this. No doubt, such a level of abstraction was dependent on Einstein's ability to objectivize cognition. Probably only in the world of objectivization was it possible for Einstein to go beyond the known facts, principles, laws, and so on to the new constructive theories, which could adequately explain unknown phenomena of the universe and nature and move against the prevailing concepts in theoretical physics. As a whole, Einstein's productive work on the frontier problems of physics in 1905 depended on his ability to objectivize cognition. It is not therefore surprising that he preferred "to work alone and out of the academic mainstream" (Miller, 1988, p. 171), because only in the world of objectivization can scientists interact directly with their subject (i.e. experimental findings, ideas arising from their thoughts, and so on) to the maximum degree. As a result, Einstein was able to add fresh and unusual, objectively new ideas from his thought experiments to the information available, in order to formulate his innovative view of physical theory (Shavinina, 1996).

considered a result of their objectivization of cognition. It should be noted that despite its importance to the understanding of individual innovation, the phenomenon of the objectivization of cognition with regards to innovators has been, thus far, a relatively unexplored topic. Although we have begun to investigate this topic in the case of our studies of Einstein and other innovators in science (Shavinina, 1996), further research is needed in this direction.

We suggest that the ability to objectivize cognition is important not only for innovators in science but the same is true for innovators working in business settings (we will call them 'business innovators'). Why are some companies' employees able to generate ideas resulting into new products or services and others not? In our view, business innovators are able to objectively see either hidden consumers' needs, or potential developments in these needs, or changes in technology, or something else. Of course, everyone agrees that innovation in contemporary companies is a team sport, an endeavor of many players. Modern companies have Research & Development departments, marketing channels, and so on for successful development of new ideas and their transformation into new and profitable products. This is essentially what allows one to call innovation a 'team sport'. But one cannot deny that new ideas appear in the minds of certain individuals. It may be surprising that innovation is not a very frequent event in today's companies, in spite of its quite evident importance. In our view, one main reason is that companies do not have enough intellectual and creative employees and senior executives with the ability to objectivize cognition, that is, to objectively see every aspect of their business activity. In this light the study of the objectivization of cognition of business innovators—who are responsible for initial ideas for successful new products in today's companies—is a promising research direction for innovation scholars within management schools.

The whole structural organization of an individual's cognitive experience (i.e. its conceptual structures, knowledge base, and subjective mental space) determines innovators' unique intellectual picture of the world. As our previously mentioned study of Einstein and other Nobel laureates (Shavinina, 1996) demonstrated, the objectivization of cognition is one of the important aspects of this uniqueness. Our comparative experimental study of the individual cognitive experience of the 'gifted' high school students in physics and mathematics and those high school students who were not identified as 'gifted' (i.e. 'average') allowed us to shed light on other aspects of the unique intellectual picture of the world of gifted, creative, and talented people (Shavinina & Kholodnaya, 1996). In comparison with 'average' students, 'gifted' students' representations of the reality as a whole consisted of a predominance of categorical (generalized) cognition. The 'gifted' groups' representations of the future

focused on the differentiation of the ‘vision’ of future events. ‘Gifted’ students were also distinguished by more complex and rich conceptual representations (i.e. their representations are quite unfolded and a clearly articulated phenomena; Shavinina & Kholodnaya, 1996). Accordingly, the cognitive mechanisms of the construction of these representations play a key role in the organization of the experience of the gifted. These mechanisms are responsible for the construction of more categorical, differentiated, integrated and conceptually complex individual intellectual picture of the world. As innovators are gifted, creative, and talented individuals, then we can suggest, on the basis of these experimental findings, that their cognitive experience is a differentiated and integrated phenomenon. Correspondingly, their representations are generalized, categorical, conceptually rich, and complex. This allows innovators to have a unique intellectual picture of the world, which expresses itself in their exceptional performance and achievements (e.g. in their ability to generate new ideas).

Thus far, a few determinants, which constitute the uniqueness of an individual’s intellectual picture of the world, have been discussed. These are: (1) innovators’ objectivization of cognition; (2) their generalized, categorical, conceptually rich, and complex representations; and (3) their differentiated and integrated cognitive experience.

So far, the basis of individual innovation (i.e. an individual’s cognitive experience) was considered. In other words, the psychological carrier of its various manifestations (i.e. traits, characteristics, features, and properties) was described. We now briefly look at the three levels of the manifestations of individual innovation.

### *Manifestations of Individual Innovation*

The first level is the *level of intellectual and creative abilities* and it is composed of intellectual productivity, individual specificity of intellectual activity, and creativity (Kholodnaya, 2002; Shavinina & Kholodnaya, 1996). *Intellectual productivity* includes three types of the properties of human intelligence: *level properties*, *combination properties*, and *process properties*. In other words, all properties of human intelligence identified by psychological science were categorized into these three types (Kholodnaya, 1990, 2002).

Level properties characterize the achieved level of intellectual functioning—both verbal and non-verbal. These properties form a basis for such cognitive processes as rate of perception, capacity of short- and long-term memory, attention, vocabulary, and so on. Typical examples of the level properties of intelligence are those intellectual properties assessed by the Wechsler intelligence scales.

Combination properties characterize the ability to decipher various links, connections, and relations between different concepts or combination of concepts. In general, it is the ability to combine the components of experience in various ways (spatial, verbal, etc.). These intelligence properties are measured by tests of verbal analogies or the Raven Progressive Matrices Test, as well as reading comprehension tests and the so-called sorting tests.

Process properties characterize the elementary processes of information processing, as well as operations and strategies of intellectual activity. Piaget’s theory describes such properties of intelligence. Standardized intelligence tests may be used to measure process properties of intelligence (e.g. the Wechsler intelligence scales, the Stanford–Binet Intelligence Test, the Raven Progressive Matrices Test, and others).

*Individual specificity of intellectual activity* is the second component in the level of intellectual and creative abilities. This component manifests itself in the cognitive styles of an individual. Cognitive styles provide valuable information about individual differences in the functioning of human cognitive processes. For example, originally introduced by Kagan et al. (1964), reflectivity-impulsivity cognitive style displays individual differences in the speed and accuracy with which people propose and formulate hypotheses and make decisions under conditions of uncertainty. Today’s reality, in the fast-paced business world, is that a company’s employees and managerial staff must be able to propose and formulate new hypotheses and ideas and make informed, critical, high-staked decisions under conditions of uncertainty. Our experimental studies showed that intellectually gifted high school students are distinguished by a reflective cognitive style (Shavinina & Kholodnaya, 1996). Results from our administration of the Kagan’s Matching Familiar Figures (MFF) test also demonstrated that gifted students made fewer errors in the situation of multiple choices. From the viewpoint of basic cognitive mechanisms, it means that the gifted accurately analyzes visual space up to the moment of making decisions, that is, they are more careful in evaluating alternatives, hence making few errors. Average students, however, presumably hurry their evaluation thereby making more mistakes. The active character of visual scanning by the gifted indicates, in particular, a capacity to delay or inhibit a solution in MFF test performance containing response uncertainty, and also a capacity to differentiate unimportant and essential features of the external stimulus. When we assert that innovators are exceptionally able to generate new ideas, this also implies—in accordance with our conception—that they are able to carefully evaluate those ideas as well as the possible alternatives. This example of the reflectivity-impulsivity cognitive style demonstrates its significance for understanding individual innovation. Other cognitive styles (e.g. cognitive

complexity-simplicity) are equally important, since they shed light on the manifestations of the cognitive experience, which, as we propose, is a basis of individual innovation.

*Creativity* refers to the originality, fluency, and flexibility of thinking, and to the ability to generate original and appropriate ideas (Georgsdottir et al., this volume; Kholodnaya, 2002; Lubart, 2001–2002; Runco & Pritzker, 1999; Shavinina & Kholodnaya, 1996). Although creativity manifestations seem to be the most appropriate in the context of our chapter, we will not consider them in detail here, because there is a vast body of literature on this topic. In contrast to what many innovation researchers assert, a real novelty of our conception resides in our emphasis that the originality, fluency, and flexibility of thinking are not the basis of individual innovation. As we discussed previously, the real basis of individual innovation is an individual's cognitive or mental experience, which serves as a psychological carrier of all manifestations of individual innovation, including the creative ones. That is, the originality, fluency, and flexibility are derivatives from the individual cognitive experience. For example, flexibility, differentiation, and integration of an individual's mental space determine one's own creative abilities. The individual mental space is one of the above-mentioned forms in the structural organization of one's own cognitive experience.

The second level of the manifestations of individual innovation is formed by *metacognitive abilities* (i.e. metacognitive awareness and regulatory processes). Metacognitive awareness refers to: (a) a system of knowledge about the basic manifestations of intellectual activity in general and about one's own individual cognitive possibilities; (b) the ability to evaluate the 'strong' and 'weak' aspects of his or her own intellectual functioning, including the ability to compensate for one's own weaknesses and rely on strengths; and (c) the ability to manage his or her mental work using various stimulation methods. Regulatory processes include planning, guiding, monitoring, and coordinating one's own cognitive processes (Kholodnaya, 1990; Shavinina & Kholodnaya, 1996).

According to many psychological accounts, metacognitive abilities are critical for the productive functioning of the human mind (Brown, 1978, 1987; Butterfield, 1986; Campione & Brown, 1978; Flavell, 1976; Sternberg, 1985). Knowledge about one's own intellectual creative abilities and the whole cognitive set-up, evaluating their efficiency, advantages and limitations, as well as planning, monitoring, and executive control are among important human abilities (Brown, 1978, 1987; Flavell, 1976; Pressley et al., 1987; Shavinina & Kholodnaya, 1996; Shore & Kanevsky, 1993; Sternberg, 1985). Moreover, research showed that less intelligent persons are characterized by a more superficial metacognitive understanding of

their own cognitive systems and of how the functioning of these systems depends upon the environment. It is also found that less intelligent people use executive processes that are not as complete and flexible for controlling their thinking (Butterfield, 1986).

Finally, the third level of the manifestations of individual innovation is presented by specific preferences, beliefs, and feelings, which can be referred to as *extracognitive abilities* (Kholodnaya, 2002; Shavinina, 1994). All of these abilities characterize the mental work of innovators. A special chapter in this volume by Shavinina analyzes this issue.

So far, we considered the second, third, fourth, and fifth levels in the internal structure of individual innovation. In the next section we are going to discuss its developmental foundation. Specifically, we will address the issue of what might happen in the individual development of certain people, which might eventually make them more open to innovations and consequently able to generate new ideas.

#### *Developmental Foundation of Individual Innovation*

Deschamps' (this volume) research on innovation leadership shows that innovation leaders are extremely fascinated and receptive to new ideas proposed by their colleagues and subordinates, which may potentially lead to new products or services. In our opinion, innovation leaders are open to innovation due to their sensitivity to everything new. Martindale (1999) noted that many creative and innovative people—in any field of human endeavor—point out that sensitivity is one of the essential characteristics of their personalities. We think that sensitivity as a personality characteristic has its roots in the specificity of the individual development of these people, particularly in their advanced development during childhood. In other words, if one wishes to know why it is that some individuals in, say, today's companies are able to produce new ideas resulting into innovative products and services or are open to supporting innovation in others (as in the case of innovation leaders), then one should look at their advanced childhood development.

We define advanced development as the development, which leads to the significant expression of an individual's potential—in the forms of innovation, giftedness, exceptional creativity, or extraordinary intelligence—and results in any socially valuable human achievement or performance (e.g. in new ideas leading to new products and/or services). According to our conception, the essence of advanced development in gifted, creative, and talented children—many of which will grow into adult innovators—can be seen in the specificity of a child's age. In the individual development—including cognitive, intellectual, emotional, personality, psychomotor, and social

aspects—of a child, there are certain age periods of heightened sensitivity, which are known as *sensitive periods*. The underlying mechanism of the advanced development in the gifted, creative, and talented that actualizes their potentially high abilities can be seen in sensitive periods.

Research demonstrates that human development is not a smooth process. Instead, it contains certain stages or periods, that is, it is ‘periodical’ in its essence (Ananiev, 1957; Case, 1984a, 1984b; Fischer & Pipp, 1984; Flavell, 1984; Vygotsky, 1956, 1972). For example, Piagetian stages of cognitive development reflect different ways in which the child processes information and interacts with the environment and also highlights specific age ranges within which these stages are likely to occur. Investigations into sensitive periods, in developmental psychology especially, indicate a periodical nature of human development (Bateson, 1983; Bateson & Hinde, 1987; Bornstein, 1987a, 1987b; Colombo, 1982; Gottlieb, 1988; Leites, 1960, 1971, 1978; Lewis, 1988; Oyama, 1979). Psychologists working in the field of high abilities also point out the periodical essence of gifted development (Feldman, 1986a, 1986b; Leites, 1985, 1988, 1996; Morelock, 1992; Shavinina, 1997, 1999; Silverman, 1997). For example, Feldman (1986a) sees giftedness as the “movement through the stages that leads to performance superior to that of most others” (p. 302). The Columbus Group’s approach to the understanding of giftedness as asynchronous development and Bamberger’s (1986) findings on ‘midlife crisis’ also provide strong evidence for the ‘periodical’ nature of development of the gifted, creative, and talented.

### *The Concepts of Sensitive Periods and Sensitivity*

*Sensitive periods* are defined here as special periods during human development when individuals show great openness to everything in the world around them. Specifically, *sensitivity* involves an individual’s idiosyncratic, personal, and heightened responsiveness to everything going on around him or her (Leites, 1971, 1996; Shavinina, 1997, 1999; Vygotsky, 1956, 1972). Such definitions of sensitivity and sensitive periods might seem rather general; however, they appear to be expedient on the contemporary level of the study of these phenomena in innovators, where the research, specific to the gifted, creative, and talented, is restricted.

The literature provides clear indications that age sensitivity takes a certain place in the advanced development of the gifted, creative, and talented (Feldman, 1986b; Jellen & Verduin, 1986; Leites, 1960, 1971, 1996; Kholodnaya, 1993; Piechowski,

1979, 1986, 1991; Shavinina, 1997; Silverman, 1994, 1995, 1997). For instance, Feldman (1986b) incorporated unusual sensitivity into his theory of prodigy phenomenon, in the “individual psychological qualities” component. Sensitivity is also one of the important elements in Jellen & Verduin’s (1986) conception of giftedness. Leites (1971) concluded that the child’s sensitivity and sensitive periods are critical phenomena in the development of prodigies. Piechowski (1991) considered sensitivity to be an individual’s heightened response to selective sensory or intellectual experiences—asserting that unusual sensitivity reveals the potential for high levels of development, especially for self-actualization and moral vigor (Piechowski, 1979, 1986). Sternberg (1986a) viewed “sensitivity to external feedback” as one of the metacomponents of his theory of intellectual giftedness. Kholodnaya (1993) considered child prodigies as the result of the specific development of a child during the early years.

Shavinina (1997) distinguished cognitive (i.e. sensitivity to any new information), emotional (i.e. sensitivity to one’s own inner world and to the inner words of other people), and social kinds of sensitivity, which intersect with one another, forming mixed kinds of sensitivity. Leites (1971) emphasized that each child’s age is characterized by one or numerous kinds of sensitivity. Vulnerability, fragility, empathy, and moral and social responsiveness are among some of the manifestations of sensitivity (Shavinina, 1999; Silverman, 1994, 1997). Cognitive sensitivity is extremely important in a child’s development in general and in the advanced development of the gifted in particular. Thus, the first years of a child’s life are characterized by the ease and stability of knowledge acquisition and of the development of many abilities, skills, and habits (for example, linguistic abilities; Leites, 1996). Shavinina (1999) suggested that because of cognitive sensitivity, children’s knowledge acquisition is very quick; it may take place even from the very first experience.

### *The Characterization of Sensitive Periods in Gifted Children, Future Innovators*

An individual’s sensitivity is not a constant—it varies in the course of development. At some points in the personal development the child is characterized by heightened sensitivity and these special age periods are called *sensitive periods*. At other points in his or her development the child’s sensitivity is low or even absent (Leites, 1971). There are exceptionally favorable inner conditions (i.e. conditions provided by the process of child development itself) and extraordinary possibilities for cognitive and intellectual development

during sensitive periods. Vygotsky (1956, 1972) specifically emphasized this issue. Introducing the concept of sensitive periods, he characterized their essence in the following way:

during these periods, certain influences have a big impact on the entire course of individual development by provoking one or another deep changes. During other periods, the same influences might have no effect or even an opposite impact on child development. Sensitive periods coincide fully with (. . .) the optimal times for learning (Vygotsky, 1956, p. 278).

Surprisingly, in light of Vygotsky's great impact on contemporary developmental theory, his view about sensitive periods appears never to have been translated into English, although it remains an important part of his developmental theory. Following Vygotsky, a general tendency in Russian psychology is to consider sensitive periods as an exceptionally productive time for learning (Leites, 1960, 1971, 1996; Shavinina, 1997, 1999) because they present extremely favorable internal conditions for mental development (Leites, 1985, 1988). In this respect, all human development—even in infancy—is characterized by individual periods of heightened sensitivity.

The years over which a child acquires language are one of the best-known examples of sensitive periods (Leites, 1996). Over a very short period of time, young children easily learn different forms and constructions of languages, but it becomes increasingly more difficult to do this in later years. It is fascinating and seems paradoxical that at a time when, for example, children are learning and speaking foreign languages with relative ease in the appropriate environment, adults who have a more developed mind—and therefore seem to be able to easily manage any linguistic difficulties—cannot do as well. Everyday life provides many examples of the difficulty with which adults learn and speak foreign languages. It seems clear that a certain age or age range—early childhood—is best suited for the specific mental activities involved in language acquisition. It appears that sensitive periods during childhood prepare and temporarily conserve favorable inner possibilities for advanced development. Elaborating further Vygotsky's ideas of sensitive periods, Zaporozhets (1964) asserted that “each period of a child's development has its age sensitivity, and because of that learning is more successful in the early years than in the elder ones” (p. 678). This is a key to the explanation of fast knowledge acquisition by gifted children that in turn leads to their advanced development. Cases of gifted, creative, and talented children at

sensitive periods support this assertion.<sup>2</sup> Taken together, the theoretical and empirical findings demonstrate that the changes of a child's age bring unique determinants of the advanced development: sensitive periods. Sensitive periods mean a qualitatively new strengthening of the possibilities for mental growth, which appear during the early childhood years. The strengthening of such possibilities leads to the general heightening of a child's cognitive resources.

#### *Sensitive Periods: Developmental Losses and Individual Acquisitions*

Favorable possibilities for individual development granted by these sensitive periods will weaken at a slow or fast rate—this is reality (Leites, 1971). Thus, the following question arises: can sensitive periods experienced by a child be predictors of his or her intellectually creative productivity in adulthood, which may eventually lead to innovation? We believe that the answer to this question will be ‘yes’ only if two important requirements are fulfilled during childhood. First, all *developmental* capacities (i.e. new abilities, habits, skills, qualities, traits, etc. acquired during a certain sensitive period) should be transformed into stable *individual* acquisitions. Second, these acquired

<sup>2</sup> For example, Alexander expressed his unusual abilities at a very early age. He started to read very well and to calculate before he was four years old. His interest in numbers probably indicated the first sensitive period. The boy continually demanded that all adults around him set up simple arithmetical tasks for him; he was hungry for them. In this period, he also liked to write various numbers. The number seven (7) was especially attractive for him: he wrote it everywhere in different forms and sizes painted in various colors. This ‘digital’ period eventually came to the end.

Just after his fourth birthday, Alexander entered a new sensitive period—the ‘geographical’ one. He read a lot about continents, countries, cities, seas, mountains, and rivers. All his questions to adults concerned only geographical issues. He asked his parents to buy geography books for him and he looked for related articles in newspapers. He watched TV programs that concerned travels around the globe and meteorological news (in this case, he could always see a map of his country). As a result, Alexander's acquired knowledge of geography was impressive. However, his new sensitive period did not consist only of the acquisition of new knowledge about geography. All of Alexander's cognitive activity was directed toward achieving one clear goal: to make a map of the world. All his time was devoted to this task. He prepared the map, conveying shapes and names of geographical objects (i.e. continents, countries, etc.) with amazing accuracy. Such an activity certainly required his artistic skills in drawing and painting, which were significantly developed during this period. In a few months, Alexander's second sensitive period—the geographical—was almost over (Shavinina, 1999).

individual capacities should, in turn, be transformed into unique cognitive experiences (Shavinina, 1999).

Although all stages of childhood can be distinguished by the heightened sensitivity (as compared to that of adults), sensitive periods have their own 'life story'. Sensitive periods emerge, exist, and even disappear during a child's development (Leites, 1971). What is important is what remains in the child at the end of sensitive period(s), as he or she grows older and favorable opportunities for advanced development weaken. It is important to note that although the favorable possibilities opened up by sensitive periods allow a child to advance significantly in his or her development by acquiring new and valuable knowledge, skills, and habits, he or she can also lose these acquisitions when a sensitive period ends. That seeming paradox is at the crux of, and is a real problem of, sensitive periods. Because of that Leites (1985, 1988, 1996) differentiates between *developmental* and *individual* aspects of sensitive periods.

If, at the end of a sensitive period a child loses almost all the exceptional capacities that he or she acquired during the given period, then one can assert that these capacities were mainly a *developmental* phenomenon (i.e. *developmental* capacities that disappear with age). This is key to understanding why so many gifted individuals who demonstrated exceptional abilities in childhood become ordinary adults who do not display extraordinary talents or outstanding creativity. Gifted children lose their unique abilities and talents in the process of their own individual development (Shavinina, 1999).

At the same time, sensitive periods are a true foundation for powerful *individual* gains. If new extraordinary capacities acquired during a certain sensitive period remain in the developing child after this period, then one can assert that these capacities have been transformed into *individual* acquisitions. Only in this case one can suppose, to a significant extent, that the child has the potential to be an intellectually creative adult, potential innovator.<sup>3</sup>

<sup>3</sup> In this context it is expedient to further consider the case of Alexander in detail. When Alexander was a five and a half, a seven-year-old girl began to live temporarily in their family. She was admitted to school and a new educational period started for Alexander. The children did exercises together, solved mathematical tasks, and learned poems by heart. Alexander started kindergarten. His teacher was impressed both by Alexander's mental development and by his ability to draw and paint. The accuracy of the presentation of even the smallest details was a distinguishing characteristic of his paintings. When he was seven, Alexander successfully passed all examinations and was admitted directly from the kindergarten into the fourth-grade class for 11-year-old pupils. All of his school grades were 'excellent'. At that time, the third

### *The Nature of Advanced Development in Today's Gifted Children, Tomorrow's Innovators*

Our analysis of the gifted at sensitive periods demonstrated the following tendency: their sensitive periods usually are linked sequentially or in chains (although the periods may overlap; Shavinina, 1999). This means that gifted children are always at sensitive period(s). In other words, the gifted's sensitivity does not disappear completely. In contrast to the previously mentioned opinion that sensitive periods emerge, exist, and disappear during childhood development (Leites, 1971, 1985, 1988), the chain of sensitive periods in gifted development testifies to the lasting sensitivity of gifted children. Research supports this conclusion. Thus, Silverman (1993) pointed out that "extraordinary levels of sensitivity and compassion do not disappear with maturity. A capacity for rich, intense emotions remains in the personality throughout the lifespan" (p. 642). Probably, this depends on the kind of sensitivity (i.e. cognitive, emotional, or social). Maybe emotional sensitivity, more than any other kind, remains in the individual during his or her life, whereas cognitive sensitivity changes periodically (but certainly it does not disappear in the gifted). Such characteristics of the gifted as sensitivity to a new experience and openness of mind—which are mentioned by many contributors to this volume as essential traits of innovators—can be regarded as evidence of this tendency of cognitive sensitivity. Perhaps the availability of cognitive sensitivity throughout the life span determines the exceptional mental abilities of an individual (Shavinina, 1999). Furthermore, if sensitivity remains in gifted children for a long time, then it is quite reasonable to state that new capacities acquired during a certain sensitive period will also remain in the gifted for a long time. These capacities are fortified and

sensitive period started, which can be called an 'ornithological' period (Shavinina, 1999).

At the age of seven, Alexander read three volumes of Brem's book for university students, *The Life of Animals*. This was the beginning of his interest in zoology; birds were especially attractive to him. The essence of a new sensitive period consisted of his writing (or, more precisely, creating) a book about birds. Alexander wrote down the summary of the corresponding chapters of Brem's volumes and made many illustrations for them. He also used two lengthy articles about birds that he found. The scale of his work was impressive: the manuscript ran more than 300 pages with more than 100 drawings. The text was divided into chapters, and all chapters were interconnected with an internal integrity. Alexander had an extensive vocabulary. His linguistic abilities were manifested in the absence of mistakes in the writing of his manuscript, which included many foreign words and biological terms. Alexander continued to read a lot, preferring scientific literature. He often used an encyclopedia and a dictionary of foreign words.

developed later, and finally they are transformed into true *individual* acquisitions that have a potential to remain in the person throughout the life span. In this case one can predict to a certain extent the transition of a gifted child into a talented adult innovator who will be able to excel intellectually and creatively.<sup>4</sup>

Moreover, the revealed chain of sensitive periods in the development of gifted children indicates a natural *overlapping* of age sensitivity. But to demonstrate that children may be continually in sensitive period(s) does not appear to be enough to explain truly advanced development. The overlapping of sensitivities is one of the keys to discerning the inner nature of advanced development. Such an *overlapping* of age sensitivities means that a child's sensitivity originates from different (i.e. previous, current, and subsequent) childhood periods.<sup>5</sup> Furthermore, the overlapping of a child's sensitivity predetermines *duplication* and even *multiple strengthening* of the foundations for the rapid intellec-

tually creative growth that results into advanced development of the gifted. The phenomenon of the overlapping of age sensitivity of gifted children also testifies to the above-mentioned fact that they are always in sensitive periods. In this instance the likelihood of the transformation of all *developmental* capacities into the *individual* abilities is getting significantly high. Being permanently in sensitive periods also implies the actualization of the gifted's immense cognitive potential and acceleration of their mental development. The latter implies rapid accumulation of the gifted's cognitive resources and the construction of those resources into the unique cognitive experience that continues to enrich itself in the process of the further accelerated development governed mainly by heightened cognitive sensitivity<sup>6</sup> (Shavinina & Kholodnaya, 1996). Their unique cognitive experience means their unrepeatable intellectual picture of the world. All the above written concerning sensitive periods demonstrates that they are not a factor, condition, characteristic, feature, or trait in a child's development. They should be understood as an inner mechanism of advanced development of the gifted, creative, and talented.

Sensitive periods, therefore, constitute a developmental foundation of individual innovation in that that they provide a basis for an extremely accelerated mental development in childhood. This intellectual acceleration leads to fast actualization and development of one's own mental potential and its transformation into the unique cognitive experience that, in turn, forms a cognitive basis of individual innovation.

### Summing Up

This chapter presented a new conception of individual innovation, which explains: (1) its developmental foundation; (2) its cognitive basis; (3) its intellectual manifestations; (4) its metacognitive manifestations; and (5) its extracognitive manifestations. The developmental foundation, the cognitive basis, and intellectual, metacognitive, and extracognitive manifestations constitute the first, second, third, fourth, and fifth levels, respectively, of the internal structure of individual innovation.

<sup>4</sup>In this context the example of Alexander should be considered briefly once again. At 14 and a half, Alexander graduated from high school with excellent grades. He was equally successful at the Department of Biology at Moscow State University and became a distinguished ornithologist. He participated in many expeditions, mainly to the north, related to the investigations of various birds. As an adult, he was characterized by the ability to work very hard, an intense interest in learning, the ability to draw well (especially birds), high ability in learning foreign languages, and an extremely clear and detailed memory. He was a competent, respected, and high-achieving scientist. Alexander's colleagues wrote: "He was distinguished by a combination of abstract thinking with deep knowledge of ecology and birds that he had learned during his numerous expeditions. He had strong will, excellent memory, and was able to work hard. He was also able to read in many European languages including Scandinavian languages; he was perfect in English. Alexander was an excellent scientist, untiring, purposeful, persistent. He could make an instant draft of a bird or landscape. He had an unlimited ability to work. He created his own scientific school" (Leites, 1996, p. 156).

What is remarkable is the complete coincidence between the description of 43-year-old Alexander, the talented scientist (by his colleagues) and the description of Alexander, the exceptionally gifted child (by the psychologist) (Leites, 1960, 1996). Alexander's life shows that his *developmental* capacities (i.e. those new capacities acquired during sensitive periods in childhood) were indeed transformed into powerful *individual* abilities that remained throughout the life span. In turn, Alexander, the profoundly gifted child, evolved naturally into Alexander, the highly creative researcher.

<sup>5</sup>The description of Alexander's childhood summers supports this assertion. At that time, he had at least two sensitive periods: the 'bird' period and the 'butterfly' period. His interest in birds can be considered as three distinct, yet overlapping, periods: the first (his intense interest at age seven), second (his summertime interest in the observation of birds), and third (his renewed intense interest, developing as a variation of his previous interest). A new—and partially concurrent—sensitive period was that of his interest in butterflies.

<sup>6</sup>The case of Alexander is quite appropriate again. Thus, although his 'ornithological' sensitive period was very long, his cognitive experience was different in each stage of childhood. For example, his initial drawings of birds were based on verbal descriptions from books because Alexander's first ornithological knowledge was from books, whereas his 'summer' drawings were based on his personal experience of natural observations. As mentioned above, at that time, his knowledge of birds reached a new level. Because of this, one can assert that Alexander had, in fact, a few 'ornithological' sensitive periods. These periods can be considered as previous, current, and subsequent sensitive periods sometimes simultaneously.

The developmental foundation of individual innovation is connected with the advanced childhood development of innovators that manifests itself in their accelerated mental growth, beyond which there are periods of heightened cognitive sensitivity. Specifically, during the childhood years, certain ‘temporary states’—or sensitive periods—emerge at each age stage, providing significant opportunities for advanced development. Sensitive periods accelerate a child’s mental development through the actualization of his or her intellectual potential and the growth of the individual’s cognitive resources resulting in the appearance of a unique cognitive experience. Such accelerated development further facilitates rapid and deep knowledge acquisition, intellectual functioning, and the creation of something new and original. This leads to advanced development of future innovators. In turn, cognitive experience expresses itself in the unrepeatably intellectual picture of the world of innovators and is responsible for their exceptional achievements and performance (e.g. generation of new ideas).

In our view, individual innovation is not a ‘gift’, chance event, or a consequence of socialization. Individual innovation is a result of a specific organization of an individual’s cognitive experience. This organization is, in turn, a result of the protracted inner process of the actualization, growth, and enrichment of one’s own cognitive resources and their construction into an unrepeatably cognitive experience during accelerated mental development. The direction of this process is determined by specific forms of the organization of a person’s cognitive experience (i.e. conceptual structures, knowledge base, and mental space). The unique structure of the mind, which makes possible the creative ideas leading to innovation, is being formed on the basis of this process. The uniqueness of innovators’ minds expresses itself in specific, objective representations of reality—that is, in their unique intellectual picture of the world—which can manifest itself in a wide range of intellectual, metacognitive, and extracognitive manifestations.

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# Models of Innovation

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**Abstract:** This chapter presents a historical examination of models used to explain innovation. It focuses on the attempts to describe innovation as a process generating new products and methods and outline the activities involved. The purpose of these models is to explain how all parties come together to generate commercially viable technologies. The overview includes six generations of models, namely black box, linear, interactive, systems, evolutionary models and innovative milieux. Each of them is explained by addressing the following issues: conceptualization background, the model itself and its elements, explanatory power, related models and concepts, and further research directions.

**Keywords:** Innovation; Black box; Linear; Interactive; Systems; Evolutionary models; Innovative milieux.

## Introduction

Technological change and innovation have become important factors in economic and policy debates. The qualitative nature of socioeconomic changes induced by innovation (in the form of new products, technologies, outputs, activities, actors, institutions and organizations, among others) also translates into quantitative measures, such as increased company turnover, profits, market shares, exports and GDP. While many people are aware of this phenomenon, our understanding of the process of technological innovation is still quite limited.

Since the 1960s, an ever-increasing number of researchers have tried to put together pictures of the process of generation of new products and production methods and outline the activities involved in this. Efforts to explain technological change have come from a variety of disciplines, including economics, management, sociology, geography and political science. The main aim of these models of innovation is to explain how all parties come together to generate commercially viable technologies. Four decades later, we can ascertain that there are a number of process characteristics, which we have come to understand. Nevertheless, the complete phenomenon is still covered under a veil of mystery, intuition and intelligent decisions in situations of risk, uncertainty and lack of information.

The main purpose of this chapter is to review the innovation models developed so far and in doing so

outline their explanatory powers and weaknesses. The focus is on technological innovation, as distinct from social, educational or organizational innovations, for example. The models examine innovation as a creative process engaging a variety of activities, participants and interactions<sup>1</sup> the outcome of which is a technological product or process.

This overview includes six generations of models, namely the black box model; linear models; interactive models; system models, including networks and linkages; technology learning and evolutionary models; and innovative milieux. After a brief explanation of the historical background, each generation of models is examined separately with references to the main related theoretical developments and publications. The concluding section of this chapter draws together the progress made so far in our understanding and description of innovation. Having done this, we also recognize the challenging task of capturing a snapshot of a phenomenon, which in each specific occurrence

<sup>1</sup> The innovation models discussed in this chapter specifically refer to innovation by firms. As pointed out by Beije (1998), this modelling activity does not concern individuals or not-for-profit organizations. Also not included are models representing the impact that innovation has on the economy and society (e.g. economic growth, comparative advantages or technology gap models). Nor does the chapter differentiate innovation by sector (see Pavitt, 1984) or by 'importance' or 'spread' of technological impact (see Freeman, 1982, 1984).

involves qualitatively different features, and where the exceptions constitute the rules.

### Generations of Models

In the early 1990s, Rothwell (1992) described five generations of innovation models: technology push; need pull; coupling model (with feedback loops); integrated model (with simultaneous links between R&D, prototyping and manufacturing) and systems integration/networking model (with emphasis on strategic linkages between firms). The approach taken in this overview reflects a similar chronology; however, it extends Rothwell's typology. The sections to follow cover six generations of innovation models, namely:

- (1) First generation—the black box model;
- (2) Second generation—linear models (including technology push and need pull);
- (3) Third generation—interactive models (including coupling and integrated models);
- (4) Fourth generation—systems models (including networking and national systems of innovation);
- (5) Fifth generation—evolutionary models; and
- (6) Sixth generation—innovative milieux.

Each of them is explained by addressing the following issues: conceptualization background, the model itself and its elements, explanatory power, related models and concepts and further research directions.

### The Black Box

#### *Background*

Irrespective of the widely acknowledged importance of resource allocation in all spheres of human activity, the economics of science, research and development and innovation has remained for decades an underdeveloped field of enquiry (David, 1994). The first attempt to incorporate technological progress in the economic equation was the influential mid-1950s production function study of Solow (1957) who analysed U.S. total factor productivity during the period from 1909 to 1949. His approach was that the component of economic growth, which changes in capital and labour could not explain, is due to technological advances. He concluded that about 90% of the per capita output could be attributed to technological change. This apparent invisibility of what happens when you invest in science and technology gave rise to the so-called black box innovation model.

#### *The Model*

According to Rosenberg (1982), economists have treated technological phenomena as events transpiring inside a black box. Although they have recognized their importance, “the economics profession has adhered rather strictly to a self-imposed ordinance not to inquire too seriously into what transpires inside that box” (Rosenberg, 1982, p. vii).

The black box model, borrowed from cybernetics,<sup>2</sup> states that the innovation process itself is not important and that the only things that count are its inputs and outputs. For example, money invested in R&D (input into the black box) will generate, as a rule of thumb, new technological products (outputs) but economists do not need to analyse the actual mechanisms of transformation.

#### *Explanatory Power*

The model places innovation as an important economic activity for firms. Although it does not explain research and development characteristics, it draws attention to the fact that “firms and industries that spend relatively large amounts on R&D may tend to have managements that are relatively progressive and forward looking” (Mansfield, 1995, p. 259). The black box coupled with the appropriate and timely management activities makes certain firms more successful than others.

#### *Related Models and Concepts*

The black box model of innovation arose along with, and sits neatly alongside, sociological theories of science that emphasized the importance of scientific autonomy and independence as essential for the flourishing of science (Merton, 1973). The threat to scientific freedoms under Nazism and communism, coupled with the astonishing successes of scientific and technological projects in the West (such as radar, the Manhattan project and nuclear energy), led to a strong belief in the power of science to produce radical technologies, if the scientific enterprise was given sufficient resources and ‘space’ with which it could be free to set its own methodologies and, to a large extent, its own goals. In such a climate, the fact that the actual innovation process was effectively a ‘black box’ was neither surprising nor particularly of concern; rather, it could be seen as a protective cover within which scientific inquiry could flourish. ‘All’ that was required was innovative outcomes in return for the input of resources. While this idea of ‘big science’ arose in the government funding of science, it translated easily into the management of innovation in large corporations, with the establishment and growth of corporate research laboratories, many of which became internationally renowned for their innovations, but whose inner workings were only partially understood by corporate management.

#### *Further Research*

The black box model and the reluctance of economists and other researchers to address the link between science, technology and industrial development were major factors in the lack of public policy encouraging innovation. The reliance on market mechanisms to

<sup>2</sup>A black box is any apparatus whose internal design is unknown.

support technological developments demonstrated the perception of a large number of economic analysts and policy-makers that there was little need to understand how innovation actually works.

The black box model also generally refers to the research and development component of innovation and/or has a tendency to equate the two. However, non-R&D activities, such as marketing, manufacturing start-up, tooling and plant construction, are crucially important for the introduction of new products and processes. The need to open the black box and explore its interior gave rise to a number of other models which are discussed in the sections to follow.

### Linear Models

#### *Background*

The 1960s and 1970s witnessed the opening of the black box of innovation with researchers becoming interested in the specific processes that generate new technologies and the learning involved in technological change. The expectations were that understanding innovation would also open the road to formulating policies, which would stimulate R&D and consequently the development of new products and processes. Innovation started to be perceived as a step-by-step process, as a sequence of activities that lead to the technologies being adopted by the markets.

#### *The Model*

The first linear description of innovation was by the so-called ‘technology push’ model, which was closely related to the ‘science push’ model of science policy advocated by Vannevar Bush in his groundbreaking *Science: The Endless Frontier* report. According to the report, “discoveries in basic science lead eventually to technological developments which result in a flow of new products and processes to the market place” (Rothwell & Zegveld, 1985, p. 49). The step sequence is as follows:

Basic Science ⇒ Applied Science and Engineering  
⇒ Manufacturing ⇒ Marketing ⇒ Sales.

The stages of the model may differ slightly (see, for example, Beije, 1998 or Feldman, 1994), but the focus is on technological newness as a driving force for innovation.

The ‘technology push’ model is also associated with the name and theoretical work of Schumpeter who studied the role of the entrepreneur as the person taking the risk and overcoming the barriers in order to extract the monopolistic benefits from the introduction of new ideas (Coombs et al., 1987).

The linear ‘need pull’ (or ‘market-driven’) model was developed not long afterwards in recognition of the importance of the marketplace and the demands of potential consumers of technology. It states that the causes of innovation are existing demands so that

the step sequence becomes as follows (Rothwell & Zegveld, 1985):

⇒ Market Place ⇒ Technology Development  
⇒ Manufacturing ⇒ Sales.

The main exponent of demand-led innovation is considered to be Schmookler who studied patterns in patents and investments (Coombs et al., 1987; Hall, 1994). His conclusion was that fluctuations in investments can be explained better by external events (e.g. demand) than by trends in inventive activities.

#### *Explanatory Power*

The 1960s and 1970s witnessed an enormous amount of research on success factors for innovation. The technology-push/need-pull dichotomy was used to explain not only a wide range of successfully introduced new technologies but also numerous cases of failure (see the description of some projects in Coombs et al., 1987).

Policy-makers around the world have also adopted much of the simplistic linear ‘technology push’ model because of its clear message and economic rationale (i.e. market failure as the main justification for public investment in research and development). However, funding R&D without supporting other innovation related areas often leads to disillusionment with research and criticism that researchers do not deliver the outputs that have been promised or expected.

#### *Related Models and Concepts*

A related concept to the linear model of innovation is the so-called ‘barriers to innovation’ or factors which impede the adoption of new technologies (see Hadji-manolis, this volume). Similarly, a lot of research has been conducted into defining the factors for successful innovation (Cooper, this volume; Freeman, 1982), such as understanding user needs, attention to marketing and publicity, good communications and the existence of key individuals within the firm. Any deficiencies or weak links in the causal chain could cause innovations or technologies to fail in the marketplace. Both barriers and success factors can be broadly classified as belonging to the push or pull side of the innovation process.

#### *Further Research*

Although very clear and easy to understand, the linear models have always been too much of a deviation from reality. They were soon replaced by more sophisticated concepts in theory but in practice they have developed firm ground in the way research is financed and in the outcomes expected by funding bodies and corporate management. The question of what comes first—technology or need—has turned out to be a chicken and egg question, and that field of research has remained relatively quiet.

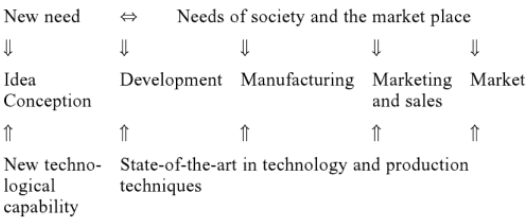
**Interactive Models**

*Background*

Both linear models were regarded as an extremely simplified picture of the generally complex interactions between science, technology and the market. There was a need for deeper understanding and a more thorough description of all the aspects and actors of the innovation process. The sequential nature of innovation has begun to be questioned and the process subdivided into separate stages, each of them interacting with the others.

*The Model*

According to Rothwell and Zegveld (1985, p. 50), “(t)he overall pattern of the innovation process can be thought of as a complex net of communication paths, both intra-organizational and extra-organizational, linking together the various in-house functions and linking the firm to the broader scientific and technological community and to the marketplace”. The stages are as follows (Rothwell, 1983):



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Beiji (1998) stresses that in such an interactive model, innovation is no longer the end product of a final stage of activity but can occur at various places throughout the process. It can also be circular (iterative) rather than sequential. An example of this was the ‘chain-link’ model suggested by Kline & Rosenberg (1986) which includes feedbacks and loops allowing potential innovators to seek existing inter- and intra-firm knowledge as well as carry out or commission additional research to resolve any problems arising from the market-design-production-distribution process.

*Explanatory Power*

The main power of the model is the explanation of the variety of interactions necessary for the success of innovation. Further studies expanded the number of boxes and provided insight into the iterative nature of innovation. According to Dodgson & Bessant (1996), the acceptance of the interactive model is now widespread. The original simple model has been extended in numerous variants to describe more players and organizations or to make it specific to a certain situation.

*Related Models and Concepts*

The interactive model drew the attention of researchers to the lag between new technological ideas and economic outcomes. Issues such as whether the innovation cycle is becoming shorter became a field of intensive research.

Another derivative of this model were the ‘technological gap’ studies that explored deficiencies in firms’ competences (Dodgson & Bessant, 1996) in relation to the various components and interactions required to make innovation happen.

*Further Research*

The interactive model was an attempt to bring together the technology-push and market-pull approaches into a comprehensive model of innovation. As a result, it provided a more complete and nuanced approach to the issue of the factors and players involved in innovation. However, it still did not explain what drives the engine of innovation and why some companies are better at doing it than others. Nor did it provide an answer as to how organizations learn or what is the role of their operational environment.

**System Models**

*Background*

The complexity of innovation requires interactions not only from a wide spectrum of agents within the firm but also from cooperation amongst firms. The well-established hierarchical mechanisms seem to break and in many cases are being replaced by new entities, which cross between organizational boundaries as well as market entities. Marceau (1992) calls this phenomenon ‘permeability’ of firms while Sako (1992) describes it as the existence of dynamic, industrial, strategic or innovation networks. The main focus of this approach is on innovation as a system, which includes emphasis on interactions, inter-connectedness and synergies.

*The Model*

The system model argues that firms that do not have large resources to develop innovation in-house, can benefit from establishing relationships with a network of other firms and organizations. Hobday (1991) summarizes the following advantages of such an organization for innovation:

- groups of small firms can maintain leading edge technologies by using the support of the other organizations within the network;
- skill accumulation and collective learning occurs within the network and benefits all participants;
- the network promotes flows of key individuals between firms;

- skills can be combined and re-combined to overcome bottlenecks;
- innovation time and costs can be reduced;
- the network provides entry into the industry for small innovative firms;
- individual firms within the network operate with high flexibility and in low cost ways, including small overheads.

The most well-known system model is the so-called national systems of innovation (e.g. Freeman, 1991; Lundvall, 1992; Nelson, 1993, 2000). It deals with the diversity in approaches to innovation in countries around the globe which differ in size, level of economic development, historical traditions or level of concern about specific policy problems (e.g. education or global warming). According to one study, this is reflected in the way the main actors in the innovation process (firms, public and private research organizations, government and other public institutions) interact and the forms, quality and intensity of these interactions (OECD, 1999, p. 22). A national system of innovation is defined as a set of institutions, which jointly and individually contribute to the development and diffusion of new technologies and provide a framework for the implementation of government policies influencing the innovation process (Metcalfe, 1995). The most important feature of this set is its interconnectedness, the way the various elements interact.

#### *Explanatory Power*

The main power of this model is in explaining the place and role of small firms in innovation and how they can survive the competition and pressures from large companies. The synergistic effect of the innovation networks explains their capacity to produce positive sum effects for all the participants (DeBresson & Amesse, 1991; Freeman, 1991). They are also flexible and can adapt more easily to the changing requirements coming from various clients and markets. They are better equipped to deal with technological risk and uncertainty. The systems facilitate communications (Tisdell, 1995), the flow of information and transfer of formal and tacit knowledge.

The national systems of innovation concept explains the differences between countries and the various role governments play. It highlights specific patterns of scientific, technological and industrial specialization, institutional profiles and structures and, most importantly, how different countries learn, “since innovation is—by definition—novelty in the capabilities and knowledges which make up technology” (Smith, 1998, p. 25). The concept is also not confined to the level of the nation state and can be applied worldwide or to regions and localities.

#### *Related Models and Concepts*

Related concepts are innovation chains (Marceau, 1992) and complexes (Gann, 1991, 2000). Chains refer to the relationships between core manufacturers and their suppliers and distributors (Dodgson, 1993). Complexes integrate not only firms but publicly funded institutions and specific industry-based research organizations (examples of this are the military or construction industry complexes).

Strategic networks (or alliances) is another related concept (Jarillo, 1988; Sako, 1992) which refers to long-term, purposeful arrangements between for-profit organizations in order to gain competitive advantage over players outside the network or alliance.

A particular case of networks is the regional network (Dodgson, 1993) in which geographic location has prime importance. In addition to physical proximity, regions share similar culture, industrial mix, economic and administrative homogeneity as well as political and governance environment, which can promote distinctive styles and modes of innovation within regions (Cooke, 1998). Regional systems of innovation are closely linked to the concept of innovative milieux, which is discussed further below.

#### *Further Research*

The potential of networks in promoting innovation compared to that of large firms is not always clearly understood. Networks are generally very dynamic, and there is not much evidence of how long they last. Their competitive advantages may be easily lost if (or when) some firms become larger, quit the network and/or take over other firms. Trust building is a crucial component in the networked innovation, and the ways to achieve and sustain this are not always clear. The mechanisms of simultaneous cooperation and competition within the network (be it in different areas or on different projects) also require further investigation and understanding.

Edquist (1997) lists nine characteristics of the systems models, which, as well as describing the approach, shed light on its weaknesses and the need for further conceptualization. They are: (1) innovations and learning are at the centre of the model; (2) it offers a holistic and interdisciplinary approach; (3) a historical perspective is natural; (4) there are differences between systems and there is no optimality; (5) it emphasizes interdependence and non-linearity; (6) it encompasses product technologies and organizational innovations; (7) it points to the central role of institutions; (8) there is a place for various kinds of ambiguities and diffusion of concepts; and (9) it provides a broad conceptual framework rather than formal theories.

Another aspect of networking which requires further investigation is the role of government, proactive policies and the regulatory environment in creating

favorable conditions for such linkages and interactions. For example, a special case of facilitating networking could be public encouragement of cooperation in the development of environmental technologies.

## Evolutionary Models

### Background

According to Saviotti (1996, p. 29), the need for an evolutionary approach in economics was proposed on the basis of a number of failures in neoclassical economics, including its inability to deal with dynamic qualitative changes, which are internal features of technological innovation. Hodgson (1993) argues that the mechanical metaphor adopted in orthodox economic thinking has weak explanatory power, as economics and innovation are products of living creatures. Hence, the biological metaphor is more useful and parallels can be made with the Darwinian evolution of species (more explanation on this approach is provided in the reviews by Nelson, 1995; Dosi & Nelson, 1994). More recently, evolutionary studies of technological change have combined fundamentals not only from biology, but also from equilibrium thermodynamics, organizational theory and heterodox approaches in economics.

### The Model

Saviotti (1996) explains the key concepts in an evolutionary approach to innovation as being the following:

- Generation of variety—innovations are seen as equivalent to mutations. They continuously generate new products, processes and forms and contribute to increased variety. Not all mutations (new technological developments) are successful, but the ones, which are often replace older products and processes consequently making them extinct.
  - Selection—selection processes act together with variety-generating mechanisms. The outcome is the ‘survival’ (which could also be interpreted as introduction or maintenance) of some products, technologies and firms as a result of their adaptation to the environment in which they operate, and the demise of others.
  - Reproduction and inheritance—firms are perceived as producing organizations and inheritance is expressed in the continuity in which organizations make decisions, develop products and generally do their business. Firms are learning entities but any developed expertise is difficult to inherit or transfer to other firms.
  - Fitness and adaptation—Darwin’s ‘survival of the fittest’ principle is represented by the propensity of an economic unit to be successful in a given environment.
- Population perspective—variation is an essential component for an evolutionary process. Hence, not only average values but also variances in the population of firms/products should be analyzed.
  - Elementary interactions<sup>3</sup>—these include mainly competition (between products or firms) and are the most studied interaction in economics. More recently, collaboration has also become a recognized type of interaction.
  - External environment—a key element in the evolutionary approach. It traditionally covers the socioeconomic (including regulatory) environment in which technologies are developed. It is determined by mechanisms such as patent regimes, market structures, standards and regulations. More recently (in the case of the green or ecologically friendly technologies) it has also started to include the link with the natural environment.

Nelson & Winter (1982) were the first to translate the conceptual evolutionary model into a computer simulation model describing business behaviour on the basis of the so-called ‘routines’ or regular and predictable behavioural patterns and habits of firms. This model was initially applied to data used by Solow (1957) who studied U.S. productivity. Nelson and Winter were successful in demonstrating that ‘realistic’ firm behaviour could account for macroeconomic outcomes at least as well as Solow’s growth modelling production function. With the further advance of computer technologies, the 1980s and 1990s witnessed further interest in evolutionary modeling (e.g. Kwasnicki, 2000).

### Explanatory Power

The evolutionary model challenged the central concept of economic theory, which traditionally focused on market equilibrium and complete information. This new approach explains that innovation by definition involves change, and decisions are made not merely on price. They evolve from historical context, social conventions and relationships between people and organizations. Metcalfe (1995, p. 26) concludes that in a “fundamental sense, innovations and information asymmetries are one and the same phenomenon”. In other words, imperfections are necessary conditions for technical change to occur in a market economy.

The uncertainty and imperfect information inherently associated with the innovation process is a departure from the ‘rational individual’ concept in neoclassical economics. The evolutionary model

<sup>3</sup> In biology, elementary interactions between species include competition (for a common resource in short supply), commensalisms (one species stimulate the growth of the other) and predation (one species inhibits the growth of the other).

stresses 'bounded rationality' (Dosi & Egibi, 1991) and the value of diversity (Dowrick, 1995). It also shows how, under meaningful economic values of certain parameters, such as technological opportunities, and established decision-making rules, firms can be dynamic self-organized systems (Dosi & Orsenigo, 1994).

The selection process and the importance of the surrounding environment shed light on the processes of failure of generally fit technologies and the success of technologies which are considered inferior (e.g. MS-DOS computer operation system or VHS videorecording system). According to Tisdell (1995, p. 128), "a fit technique... may fail to be selected because its surrounding environment at the time of its occurrence is unfavourable".

According to Bryant & Wells (1998), the evolutionary school of thought is likely to become very influential in policy considerations. Since World War II, governments have consistently funded outcome oriented research. What the evolutionary model emphasizes is that the process is as (if not more) important as the results from R&D. For example, a 1996 OECD report recommends governments to increase the population of innovative firms as a main policy goal rather than correcting market failure (OECD, 1996).

The evolutionary model also points out that outcomes are to a large degree determined by the evolutionary process, be it at the level of company or country. Shedding light on how decisions are made and how the various participants interact to produce innovations, is a major explanatory feature of this model. Therefore governments should be urged to create conditions conducive to the process of innovation by shaping relationships, encouraging learning, and balancing competition with cooperation. The model has less normative power, and is less focused on the implications for innovation strategy at the level of the firm beyond the need for firms to protect diversity and a range of competencies (of people, product ranges, technologies, etc.).

#### *Related Models and Concepts*

Related to the evolutionary model are a number of generalizations, which appeared in the 1970s and 1980s. They refer to technological imperatives (Rosenberg, 1976), innovation avenues (Sahal, 1981), technological trajectories (e.g. Biondi & Galli, 1992; Pavitt et al., 1989), technological (Dosi, 1982, 1988) and technoeconomic paradigms (Freeman & Perez, 1988; Perez, 1983). The main argument is that during a particular time period we witness certain regularities in the development of technologies (represented by the nature of the applied principles and practical solutions), but they are often hindered by the delays with which institutions adapt to the new potential of these technologies.

#### *Further Research*

In addition to explanatory power, an extremely important aspect of any model is its predictive potential. If a model is a relatively accurate representation of reality, the traditional scientific approach expects it to also deliver forecasts and predictions of future parameter values. The evolutionary model in general lacks such a capacity as it describes constant change, and hence, its parameters are always in flux. Nevertheless, there is some degree of predictability if we can explain the mechanisms supporting the continuity of the old and the introduction of the new and if we can characterize the turning points in between.

#### **Innovative Milieux**

##### *Background*

Since the 1970s, a large body of literature has developed dealing with aspects of the growth of regional clusters of innovation and high technology (Feldman, 1994; Keeble & Wilkinson, 2000). The importance of geographical location for knowledge generation gave rise to the innovative milieux explanatory model. The concept is the main contribution by geographers, regional economists and urban planners to a field, which traditionally has been studied by economists and sociologists. The real-estate rule of: 'Location! Location! Location!' started to attract attention to the natural, social and built environment surrounding establishments where technologies are developed. The model includes networking and linkages but goes beyond that to emphasize the importance of quality-of-life factors.

##### *The Model*

The innovative milieu model states that "innovation stems from a creative combination of generic know-how and specific competencies" and "territorial organization is an essential component of the process of techno-economic creation" (Bramanti & Ratti, 1997, p. 5). According to Longhi & Keeble (2000, p. 27), "the innovation process is not spaceless. On the contrary, innovation seems to be an intrinsically territorial, localized phenomenon, which is highly dependent on resources which are location specific, linked to specific places and impossible to reproduce elsewhere".

An early description of innovative milieux by Camagni (1991) lists the following components:

- a productive system, e.g. innovative firm;
- active territorial relationships, e.g. inter-firm and inter-organizational interactions fostering innovation;
- different territorial socio-economic actors, e.g. local private or public institutions supporting innovation;
- a specific culture and representation process;
- dynamic local collective learning process.

Camagni & Capello (2000) emphasize that the interactions creating the innovative milieu are not necessarily based on market mechanisms but include movement and exchange of goods, services, information, people and ideas among others. They are not always formalized in cooperative agreements or any other contracts. Major features of such an environment are the ease of contact and trust between partners, which reduce uncertainty in the development of new technologies and prove to be a source of exchange of tacit knowledge.

In addition to the components of a productive working environment, more recently other factors have started to impact on the capacity of locations to generate innovative firms. They relate to the social, cultural and natural characteristics of the place, such as proximity to recreational sites, climate and air quality, quality of life for family members, including children, to mention a few. The high density of links is also being expressed in relation to interactions with the local community (Willoughby, 1995).

#### *Explanatory Power*

The innovation milieu concept helps explain the success of small and medium-sized enterprises, which in general lack the resources to maintain aggressive R&D strategies and operate at the cutting edge of technologies. The existing supporting network compensates for that and provides an operational "microcosm in which all those elements which are traditionally considered as the sources of economic development and change within the firm operate as if they were *in vitro*" (Camagni & Capello, 2000, p. 120).

The model also explains why certain localities give birth to a large number of small innovative firms, which are situated in close proximity and share a similar cultural and business ethos. It also highlights the fact that different localities have different patterns and paths in knowledge development and transfer of high technology.

#### *Related Models and Concepts*

Porter's (1990) analysis of groups of firms located in geographic proximity is often referred to as 'innovation clusters'. According to the OECD (1999), the concept of clusters is closely linked to firms networking but it goes beyond that as it captures all forms of knowledge sharing and exchange within a specific locality. Many clusters have developed over extended periods of time and have deep historical roots. Often they are also linked to the particular natural, human and other resources available in the region.

Other closely related concepts are 'the learning region' (e.g. Florida, 1995; Kirat & Lung, 1999; Macleod, 1996; Simmie, 1977) and 'collective learning' (Keeble, 2000; Lawson, 2000). They stress that learning is the most important feature of any economy

and successful regions provide particular combinations of institutions and organizations to encourage knowledge development within the community and learning by local firms through conscious and unconscious mechanisms.

#### *Further Research*

The innovative milieu model has not so far addressed the links between innovation and ecology. It is still predominantly anthropocentric, and innovators rarely address the issues of harmony with the natural environment. Nevertheless, there is increasing evidence that the development of technologies is not a means of its own but a mechanism to achieve broader goals. An example of this is the Finnish environmental cluster research program (Honkasado, 2000), which covers projects encouraging cooperation between entrepreneurs who utilize the natural environment for eco-business and promotes innovative enterprises specializing in environmental technologies. The interest in the locality will hopefully result in increased consideration of issues such as ecologically sustainable development and social justice.

#### **Conclusion**

What becomes apparent from this overview of the six generations of innovation models is that the more we study innovation, the more we realize how complex a process it is and how difficult it is to 'master' it, whether at a corporate or government policy level. Hence while all the models discussed here stem at least in part from an interest on how innovation occurs in the firm, the explanatory factors have broadened out markedly. Innovation models have moved from a concentration on factors wholly or to a greater or lesser degree within the control of the firm (i.e. R&D management, marketing, financial resources, etc.) to factors external to the firm, so that networks of firms, government institutions and policies, and even culture and geography, have become relatively more important. The models studied here provide the basics of an explanation of the innovation phenomenon. Nevertheless, they leave a lot of questions unanswered. Every model is intrinsically a simplification of reality and as a rule omits the myriad details which make every innovation case so unique in its success or failure.

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# Evolutionary Models of Innovation and the Meno Problem

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**Abstract:** ‘Universal Darwinism’ is an innovation paradigm superior to the intelligent design and romantic paradigms. All innovation, including new knowledge, is the product of blind variation plus selective retention (BV + SR) and is thus a kind of adaptation. Yet many methodologists continue to regard BV + SR as a limited model of innovative problem-solving. I show how this clash can be (partially) resolved by exploring (1) the roots of the problem of innovation in Plato’s Meno paradox and (2) the implications of the ‘No Free Lunch’ theorems. The BV + SR paradigm recognizes sources of innovation other than novel ideas of creative individuals.

**Keywords:** Creativity; Innovation; Universal Darwinism; Universal evolution; Evolutionary epistemology; Design; Adaptation; ‘No free lunch’ theorems; Meno paradox.

## Introduction

Popular accounts of innovation in the sciences and the arts appeal to special powers of creative individuals. Da Vinci, Newton, Mozart, Einstein, Picasso, and perhaps also Napoleon, Thomas Edison, and Henry Ford, are said to be geniuses able to see into the future or into the deep-structure of the universe, to have special powers of intuition that transcend those achievable by mastery of one’s subject area. In one way or another, these intellectual heroes possess clairvoyance, prescience, or foreknowledge. In this chapter I reject all such accounts as nonexplanatory, question-begging, or even regressive in the sense that invoking them makes the explanation problem harder rather than easier. What we are left with on a thoroughly naturalistic account is the ordinary abilities of human beings (cf. Weisberg, this volume). To be sure, we humans vary tremendously, both in our natural abilities and in the expertise that we bring to various domains; but none of us have supernatural powers. None of us are gods, and not even the brightest of innovators can foresee or control the future implications of their work with guaranteed accuracy.

In avoiding the supernatural, my account agrees with others in this Handbook. However, my emphasis will be less on especially creative individuals (that is, on ‘great men and their ideas’) and more on general processes that constitute sources of innovation. I do not

deny that exceptional people exist, but here I am interested in the question: What are the implications of ‘going natural?’ Even the more sophisticated studies of canonical innovators tend to overplay the degree to which they knew enough about what they were doing to preplan their actions in accurate detail. Building on the work of Donald Campbell, Daniel Dennett, and others, I shall try to get to the bottom of the innovation issues in cognitive and epistemological terms.<sup>1</sup> Although I propound nothing worth calling a general *theory* or general *method* of innovation, I claim that the subject can be interestingly addressed at a general level. This will require thinking about innovation in a rather abstract way.

If I am successful, the overall result will be a framework, with some usable constraints, for thinking about genuine innovation of any kind—namely an evolutionary framework of a broadly Darwinian type. The major implication is that blind variation plus selective retention—an evolutionary process—plays an

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<sup>1</sup> See the references at the end of the chapter to Campbell and Dennett as well as to Richard Dawkins, Gerald Edelman, Henry Plotkin, Aharon Kantorovich, Gary Cziko, Dean Keith Simonton (who has a chapter in the present Handbook), and William Calvin. These authors are, of course, not responsible for the particular twist that I give to the BV + SR model of innovation.

essential role (although not the only role) in all innovative inquiry. This in turn implies that, at least to a first approximation, all innovation, all design, and, indeed, all knowledge can be construed as adaptation; and, contrariwise, in a broad sense, all adaptation can be construed as design or knowledge and, when new, as innovation. Insofar as a design is *fully* the product of intelligent planning, its production is routine, not novel, although the plan itself may of course be original and hence itself the product of prior trial and error.

Learning theories and, by extension, theories of innovation are sometimes classified into three types. *Providential* theories ultimately appeal to divine providence or some other transcendent process as the source of new knowledge or design, for example, a doctrine of innate a priori knowledge or a special capacity of clairvoyance. *Instructionist* theories claim that the world directly instructs the knowing agent by imposing its form on the receptive mind. The classical model is the signet ring impressing its pattern in wax. During the modern period we get the simple empiricist view that we can read the truth directly off nature, by passive induction, without any need for interpretive trial and error. One version of the modern view is British empiricist philosopher David Hume's psychological theory of learning or habit acquisition through mere repetition of an environmental contingency. Hume simply took for granted that the agent unproblematically *notices* the repetitive pattern.

Finally, *selectionist* theories postulate some sort of variation and selection process or iterative trial and error. In this chapter I defend the third approach, and I reject providential theories on the ground that they are question begging and viciously regressive. I shall not have space to critique instructionist theories (but see Campbell, 1974; Cziko, 1995).

At its core, Darwinian evolution consists of three mechanisms: a mechanism of blind or undirected variation, a mechanism of selection, and a mechanism of transmission or heredity, in short, BV + SR. Darwin appreciated that whenever these mechanisms operate in a reasonably stable environment with selection pressures, evolution of the species in question *will* occur. He elaborated a mechanism of natural selection but was ignorant of the precise mechanisms of variation and transmission. Although not a mathematician, Darwin thought statistically, in a qualitative sort of way, and thereby introduced populational thinking into biology more clearly than anyone had before. Moreover, his theory in effect introduced a new kind of control system into our thinking about natural processes, a kind of feedback mechanism of a subtle, indirect sort (one that is purely eliminative, with death or reproductive failure as the 'teacher'), operating over a distributed population of agents or processors responding only to their local conditions (Cziko, 2000, ch. 1 *et passim*). We should not consider evolution (and

BV + SR in general) as a mechanistic theory of a Newtonian kind.

It is no secret that evolutionary mechanisms can produce remarkably novel design. Indeed, biological evolution is surely the most innovative process that we know. What other process has produced anything as innovative and original as the biological world in all its amazing complexity and variety? This fact alone makes Darwinian evolution worthy of serious attention from students of creativity and innovation. What is it that enables such a blind- and dumb-looking process, one that completely lacks creative individuals in the human sense, to produce so much innovative design? Can we 'reverse engineer' this process and put it to human use? Have we already done that implicitly? While evolutionary processes are fascinating producers of innovation, I want to defend a stronger claim: they are the *only* truly innovative processes that we currently know!

I believe that an evolutionary process is implied by a thoroughly naturalistic treatment of innovation. At least there is no alternative account in sight at the present time, with the possible exception of self-organizing systems as a partial explanation. Yet many people interested in innovation find the selectionist model of learning and innovation highly counterintuitive. At the end of the chapter I shall reply to a few of the more frequent objections to the evolutionary model of innovation. Meanwhile, I shall maintain that, *since* it is the only innovative process that we really know and understand, we need to reconceive innovation, including learning and research. To a first approximation, we should conceive of all genuine innovation, including new knowledge, as a kind of adaptation.<sup>2</sup> And we should view all genuine design or fit as the product of an evolutionary process. This grand generalization of Darwinian evolution is often called 'universal Darwinism'. The label is convenient, but it misleadingly suggests too close a tie to Darwinian *biological* evolution. Accordingly, I shall often call it 'the BV + SR model of innovation' or 'Campbell's thesis'. I now motivate this generalization of the innovation problem and solution from an unexpected philosophical angle, namely, Plato's paradox of the *Meno*.

<sup>2</sup> Although this is a broadly biological conception of innovation and learning, I mean only that they are underlain by BV + SR processes, not necessarily strictly Darwinian biological processes. Still, my thesis can be viewed as an extension of the adaptationist paradigm in evolutionary theory. I do not commit myself slavishly to adaptation as the only possible origin for innovation (given such things as genetic drift and the possibility of self-organizing systems); hence my 'to a first approximation'. However, I believe that adaptation is the most important factor. And if a physical system in effect explores a phase space and hits on a stable, self-organized state or falls into an attractor basin, that is rather like blind search and selection, although it will not be iterative unless the state is self-reproducing or is shaken out of its basin with the possibility of finding an even deeper basin.

### Innovation, the Meno Paradox, and Darwinian Evolution

The Meno paradox presents us with the problem of how successful inquiry is possible. The paradox denies that inquiry is possible and hence denies that we can learn anything new. By two plausible extensions, the Meno problem can also be interpreted as: (1) the problem of how human innovation is possible; and (2) the problem of how novel design anywhere can emerge, whether or not that design is accomplished by the deliberate, conscious activity of intelligent agents. Indeed, taking a cue from Plotkin (1993) and Dennett (1995) as well as Campbell, I claim that all knowledge can be treated as a form of design and, conversely, that all adaptive design can be construed as a form of knowledge. The issues are too complex to defend in detail here, but I hope to make them at least intelligible.

The paradox, formulated in Plato's dialogue *Meno*, 80d-e, has the logical form of a dilemma. In its original form the problem is to show how successful inquiry is possible, that is, how is it possible to gain new knowledge. Meno (the character in dialogue with Socrates) concludes that it is not possible. For either you already know the answer (or problem solution) that you seek or you do not. If you do, you cannot really inquire, for you already have the answer. But if you do not know the answer, then you also cannot inquire, since you would not *recognize* the answer even should you stumble upon it accidentally. Ability to recognize is the key, and you have to know an item already in order to recognize it.

To many readers, the paradox is nettlesome word-play, to others an unnecessary abstraction. There is a bit of verbal confusion, to be sure; but in my view the paradox presents us with *the* core problem of innovation; and its solution possesses practical importance as well as intellectual interest.

As usual, there are two 'horns' to the dilemma. If you already know that magnetic monopoles exist, then you cannot genuinely inquire into whether or not they exist; and so you impale yourself on the first horn of the dilemma. This is true whether you had previously learned that alleged fact by empirical investigation, by reading a text, or by direct revelation by Providence. However, if you have no idea whether monopoles exist and even what exactly they are and what would count as detecting them, then you impale yourself on the second horn, since you would not recognize one even should you 'stumble upon it' accidentally. To change the example: Had Aristotle asked what makes salt flash yellow when tossed into the fire, and a twentieth-century quantum theory textbook had fallen out of the sky at his feet, he would have been incapable of recognizing that the text provides the answer to his question (namely in terms of electron state transitions

of sodium ions, which flash the familiar sodium yellow, as first proposed by Niels Bohr).

The Aristotle illustration is extreme. We all know that inquiry *is* possible, as is innovation. What, then, is the solution to the paradox? I take up this question more fully in Section 5, but to anticipate: As far as I know, the only viable solution involves an element of trial and error, that is, a process of blind variation plus selective retention (BV + SR). Of course, pure, blind or 'random' trial and error that simply discards all problem solutions that are imperfect, by some pre-established standard, is very inefficient. But things are very different if the standard of comparison is greater fitness relative to other members of an extant population, if the fitter individuals have a greater chance of selection, and if the retention mechanism involves transmission, with variation, to a new generation such that we get iterated 'cycles' of BV + SR. In that case we get gradual evolution. Darwin was the first to recognize this, and he further recognized that a BV + SR process, when it is in place, does not merely make evolution *possible*, it makes it (nominally) *necessary*, assuming a reasonably stable environment with selection pressures. As long as these conditions remain in place, there is no stopping evolution!

My claim is that human inquiry in the various sciences and the arts frequently satisfies the conditions that make evolution and hence innovation almost inevitable. So we have passed from puzzlement about whether and how innovation is possible at all to understanding why, under a variety of situations, it is inevitable—virtually necessary.

Although it is not news that human innovation is possible, the BV + SR model once again raises the question whether we can improve our innovative techniques by reverse engineering biological evolution, whether we can distill out the secret to its innovative powers, and 'bottle' it for our own use. 'Simulation of the evolutionary process is tantamount to a mechanization of the scientific method', wrote Lawrence J. Fogel, one of the founders of the field of evolutionary computing.<sup>3</sup>

This chapter and two companion pieces (Nickles, 2003 and forthcoming) can be viewed as an exploration of Fogel's claim. I believe that there is some truth in it. However, this does not mean that biological BV + SR is immediately applicable as a powerful scientific method (let alone as 'the' scientific method), for several reasons. One is that there are many kinds of BV + SR processes besides the biological family of evolutionary processes discovered by Darwin. Another is that the more powerful processes are highly domain-specific. It turns out that you cannot reliably or knowingly use a powerful method unless you already know a great deal

<sup>3</sup> L. J. Fogel (1999, p. 44), quoted by Jacob (2001, p. 3).

about the subject domain. So there remains this much truth in the Meno paradox. Roughly speaking, it takes knowledge to get knowledge, a claim that obviously raises ‘ultimate origins’ problems analogous to those faced by biological evolution. It also raises questions about how explicit that knowledge has to be and whether biological or mechanical processes can ‘know’ in this sense. I shall not be able to pursue such large questions in this chapter.

It was Darwin who first found the entrance to the vast space of BV + SR mechanisms and the new sort of control theory that accompanies them. In appreciating the potential of BV + SR to generate novel design, Darwin and Alfred Russel Wallace achieved the extraordinary but controversial insight that here is a process capable of producing more design (or at least apparent design) from less and hence a process that is genuinely creative. Still more controversial was Darwin’s insight that, ironically, the only previously known way of explaining design—the *intelligent design model*—actually explains no truly *innovative design* at all; and that, hence, the *evolutionary model* replaces it as the only game in town! Late nineteenth-century Darwin sympathizers such as Thomas Henry Huxley and William James already realized, to some degree, that there is no reason to restrict the evolutionary process to biology and to Darwin’s specific mechanisms—that bodies of knowledge claims and cultural practices may also be considered designs, designs that at one time were innovative and adaptive. Darwinian *biological* evolution is only one of many possible instances of BV + SR.

Now whether and how we can create more from less is precisely the knowledge problem of the *Meno*. Restated in our terms, the Darwinian claim is therefore that the intelligent design model does not really solve the Meno problem after all; only evolutionary models do. If this is correct, then, given the absence of viable alternatives, we can say that it is only within the last century and a half that we have been able to solve the Meno and hence learned the secret of inquiry, the key to innovation. Interestingly, even the young Darwin of 1838 had some notion of the relevance of his emerging ideas about evolution to the Meno problem. In response to a reference to Plato’s doctrine of innate ideas owing to the soul’s journey between lives, Darwin wrote in one of his notebooks ‘read monkeys for preexistence (of the soul)’.<sup>4</sup>

In our time, Donald Campbell and several other investigators (see Note 1) have revived and defended a *universal* evolutionary or selection theory—the claim that, ultimately, *all* innovative design is produced by

one or another variation-plus-selection-plus-transmission process.<sup>5</sup> This is the aforementioned ‘universal Darwinism’. Meanwhile, scientists such as Nils Jerne<sup>6</sup> and Macfarlane Burnet, founders of the ‘clonal selection theory’ of antibody formation in immunological theory have fruitfully applied generalized Darwinian models to areas of biology other than traditional evolutionary theory. More speculative applications include those of Gerald Edelman, author of an account of a semi-Darwinian brain development that he calls ‘neural Darwinism’, and William Calvin, with his clonal model of competing representations in the brain. Just as biological evolution can be considered a phylogenetic inquiry process or learning system, neural system development and the vertebrate immune system may be considered ontogenetic learning systems. Thus, evolutionary models are proving useful in developmental biology. Universal evolutionists extend the claim to learning theory and to all production of novel design.

Since the 1960s, founder John Holland and the many other contributors to the field of evolutionary computing have done more than anyone to extend the BV + SR methodology far beyond Darwinian evolutionary biology, to the extent that Darwinian biological evolution can now be represented as a single point or small region in a large space of BV + SR processes. In the past decade evolutionary computing has enjoyed explosive growth and is now employed in thousands of technical papers in dozens of disciplines every year.<sup>7</sup>

If the universal evolutionists are correct, then we have (or need) a new paradigm of innovation. For on this view *all* successful innovation, the emergence of all novel design, is the product of BV + SR. Not only is all adaptation design but also all design is a kind of evolutionary adaptation. This includes inquiry, where we need to think of problem solutions and other results as things that have evolved, grown, or emerged by a process of adaptation rather than as things that have simply been inferred by a logical process, whether deductive or inductive. In this sense the evolutionary paradigm supplants or transcends the old *logical*

<sup>4</sup> Desmond & Moore (1991, p. 263), quoted by Dennett (1995, p. 130).

<sup>5</sup> See the references at the end of the chapter. The BV + SR claim has other late-nineteenth-century sources that are not necessarily Darwinian, including Alexander Bain and Paul Souriau (Campbell 1960, 1974a). Also, by ‘universal Darwinism’, Dawkins (1976) originally referred to the Darwinian basis for life forms that may exist elsewhere in the universe.

<sup>6</sup> Interestingly, Jerne was led to his solution to the central problem of immunology by seeing it as similar to Plato’s Meno problem.

<sup>7</sup> Key references for this paragraph include Campbell (1960, 1974a, 1974b), Rechenberg (1965), Holland (1992), Plotkin (1993), Dennett (1995), Cziko (1995, 2000), Edelman (1987), Schwefel (1995), and Calvin (1996).

paradigm of innovation.<sup>8</sup> It also replaces the *romantic paradigm*, which relies heavily upon processes that are both nonnatural and nonlogical.

In insisting that all innovation involves an element of trial and error, the BV+SR paradigm incorporates at least a modicum of luck or chance. It thereby claims that all innovation involves an element of serendipity, normally many instances of scarcely recognized micro-serendipity rather than one big, lucky break. The BV+SR paradigm is not deterministic, but neither does it depend solely upon sheer blind luck. The process is iterative and cumulative and therefore builds on its previously established platforms (Dawkins, 1986, ch. 3). Nor need it be directionless, as biological evolution is. After all, Darwin himself was much instructed by the artificial selection techniques practiced by animal and plant breeders. However, according to the new paradigm of innovation, it would take *considerable* luck to realize the goals of a research program precisely specified in advance and adhered to religiously. As Campbell (1974, 435ff) points out, serendipitous discoveries depend upon having multiple selection criteria, upon being flexible and opportunistic. Ironically, then, it is the old design paradigm (the rigid, intelligent design or rational planning model) that actually requires luck in large quantities. The irony is doubled by the fact that the need for large chunks of luck arises out of the very attempt to eliminate the need for luck through detailed rational planning.

### What is Innovation?

It is impossible to define 'innovation' and 'creativity' precisely in a context-free manner. Clearly, what is innovative or creative for you may not be for your community, much less for the human race or the universe as a whole. The advanced inhabitants of Lagado or of the planet Zork may have achieved it already. Let us call 'the attribution problem' or 'the credit-assignment problem' the task of assigning credit for an innovation. Margaret Boden (1990, p. 32) distinguishes an individual's psychologically creative (P-creative) efforts, or personal firsts, from historically creative (H-creative) accomplishments, or historical firsts. (She limits the term to human history.) According to the naturalistic line that I am taking in this chapter, nothing is truly innovative if it is simply externally injected by an outside agency such as a teacher or even God. Good students are not necessarily creative students. They may 'get the point' without being able to improvise upon it. And if God gave Schrödinger and Heisenberg the laws of quantum

mechanics, then those two men are proportionately less creative, and their work is practically a form of plagiarism! (Recall the literal meaning of 'inspire'.) Similarly, simple instructive empiricism, according to which we can directly read the truth off Nature, diminishes attributions of innovation.

What about the apparently similar case in which someone or something arrives at a result by mechanically following an available recipe or method or algorithm? Isn't the result already implicitly contained in the method and so already implicit in the method-plus-user system? I would say so, but things become less clear when the methods are less specific and the algorithms complex. This latter issue somewhat resembles the question of whether you can get more out of a computer than you program into it. According to the 'Lady Lovelace objection', the computer deserves no credit for innovation.<sup>9</sup> I agree with Boden (1990, 6ff) and many others that you *can* get more out than you put in.

One issue is how we characterize what we put in. With simple, highly specific programs you do not get more than you put in, except, typically, more speed and accuracy. (These can make a real difference in performance, as the chess, checkers, and domino victories over human champions vividly demonstrate.) But with more general or complex programs the case is different. Here a distinction between potential and actual is necessary. From any set of statements or rules, an infinite number of logical consequences follow and are potentially recognizable by a rational cognizer. However, finite cognizers can actually recognize only a relatively small, finite set of these in any real-time situation. For this reason a purely deductive consequence can be *epistemically* novel, even though it is not *deductively* novel. Logically nonampliative inference can be epistemically ampliative. The computer, in exploring areas of consequence space that we have not explored, can produce something epistemically novel for us.

Similarly, by using a method we may be led to explore areas of search space previously unknown to us. Thus we cannot say that a method can produce nothing more than was explicitly built into it. Obviously, what its human designers built into it explicitly was already known and so cannot count as innovation. Here we encounter a tradeoff, to be further discussed below. Insofar as a method is both helpfully directive and warranted by domain knowledge, it relies upon knowledge already achieved in order to achieve a rather routine sort of problem-solving. And insofar as it is directive but unwarranted by domain knowledge, it is risky: it can lead us to major new results, but it will often fail badly. In this respect, such a method is hypothetical in character. So although I do not deny

<sup>8</sup> Logical inference often plays crucial roles in the BV+SR process. My point is that we should not essentially characterize innovation in terms of the old logical paradigm. There is a sense in which the BV+SR model also replaces the knowledge-based paradigm of artificial intelligence. See below and Koza et al. (1999).

<sup>9</sup> Ada Lovelace was the daughter of Lord Byron, who assisted Charles Babbage in the design of his analytical engine.

that methods can help us to innovate, the old view that methods are what produce discoveries is exactly backwards in my view. The methods routinely employed by the scientific community to solve already mastered problem domains are the final *result* of the discovery process, not the tool that produced the discoveries in the first place. A method is a final-stage streamlining of a trial-and-error process that was once full of false starts and blind alleys.

The credit-assignment problem can also be raised for the BV+SR model of innovation. Since BV+SR ‘only’ reorganizes and selects materials already present, with an occasional, exogenously caused chance mutation thrown in, does it really produce anything new? Isn’t all the ‘knowledge’ already built into the system consisting of population-plus-environment? Well, yes and no. Given the power of the process to explore vast regions of design space efficiently, and given the fact that the original designs were very simple (for probabilistic reasons), there remains a lot of novel design to be ‘found’ or generated.<sup>10</sup> Still, to count as genuinely novel design, it has to be something that did not actually exist before.

In some sense, then, “genuine originality must be a form of creation *ex nihilo*” (Boden, 1990, p. 29). Boden rejects this view, on the ground that it requires a miraculous explanation. However, there is a qualified sense in which evolution does just this. New design *emerges* from something that was not design, or at least not *that* design. But, of course, not even evolution creates something from absolutely nothing. Rather, as many authors in this volume point out, it works by adapting mechanisms or designs or resources already available. New design genuinely emerges from old. Novel design is an *emergent* phenomenon. It is precisely characteristic of emergent phenomena that they manifest novel features although resulting from combinations of ingredients already present. They reduce to what was already there, except for their organizational pattern or design, and thus do not require appeal to any distinct sphere of metaphysical reality; yet they are also nonreductive in manifesting that novel design. Any satisfactory solution to the Meno problem must show how genuinely new knowl-

edge can emerge from available resources, including old knowledge.

In speaking of design, I follow Dennett’s (1995) formulation of innovation as bringing new design into being. And so I have generalized the Meno problem as asking how it is possible that original design enters the world. Speaking of design does have the advantage that it embraces the arts and other human doings in addition to specifically scientific and technological innovation. However, I cannot claim more than a heuristic function for this move, since what counts as design in the relevant sense is also difficult to say. Clearly, not just any pattern counts as design in the relevant sense (as Dennett fully recognizes). Roughly speaking, to be a design, it must be adaptive to some context or purpose, it must display a degree of fitness.

Similarly, I agree with Robert Sternberg et al. (this volume) that creativity (or at least innovation) involves more than producing novelty. It must be useful novelty, in a suitably broad sense of ‘useful’. To this degree, ‘innovation’, like ‘discovery’, is a success term, an achievement term. For me such success requires recognition (part of the larger-scale Meno problem!) that can only be conferred by a community of people who can authoritatively locate the innovation as a contribution to their project. However, there can be attempted innovations that fail because, although verbally recognized, they are not integrated into the practices of the community. So in this respect, ‘innovation’ is not as definitive an achievement term as ‘discovery’.

Traditionally, credit assignment for innovation has been highly individualistic. I want to emphasize that social recognition and attribution are crucial, although they are not, of course, the whole story.<sup>11</sup> In my view, unlike that of many philosophers and psychologists, creativity and innovation tend to be highly distributed across communities, and this is especially true of deep innovation. At the frontier of research or of artistic production, no one can know the extent and magnitude of the ramifications (see below). A highly centralized

<sup>10</sup> Useful though it is, talk of search spaces and design spaces, as if all the possibilities already existed there waiting for us to discover them, can be misleadingly Platonic. It also threatens to reduce all discovery or recognition to the Columbus-discovers-a-new-continent model. And if we consider the knowledge to be already implicit in the population-plus-environment system, then one facet of the Meno problem becomes how to *transfer* this knowledge more explicitly to those members of the population that we call scientists (or artists or whatnot). See Section 5 for the Meno transfer and transformation problems.

<sup>11</sup> In short, I employ the term ‘discovery’ in a broad, non-realist sense that leaves room for social construction. For sophisticated accounts of the negotiation and construction of discovery attributions, see Brannigan (1981) and Simon Schaffer (1986, 1994), who point out that the attributions should not be naively accepted as accurate history of who did what. Thus Brannigan and other historical investigators have exploded the myth that Mendel was the neglected discoverer of modern genetics. More controversially, Thomas Kuhn (1978) has exploded the myth that Planck was the founder of quantum theory. I agree with the sociologists and social historians that social attribution is crucial, but I disagree insofar as they suggest that this is the whole story and that cognitive psychological accounts (for example) are beside the point.

cognitive process is not nearly efficient enough to account for the problem-formulating-and-solving successes we find in the sciences—and in the arts for that matter. Nor is innovation simply a matter of having new ideas, for inarticulate practices, institutions, social structures, and the like can also be creative. The gradual emergence of a market economy, from the Italian Renaissance on, was not the deliberate, conscious design of social planners. Not until hundreds of years later (Adam Smith in 1776) were some of the essential features even recognized.

According to the universal evolutionary paradigm, innovation does not flow directly either from logical inference alone or from the creative inspiration of a poetic individual alone, for it does not flow directly from anything. Although pieces of inquiry can be highly directed and the larger chunks directed somewhat more loosely, the process as a whole is quite indirect (but less indirect than biological evolution). No trial-and-error process in which the goals and problems themselves are initially only loosely defined can be very direct overall. And it is precisely characteristic of highly innovative work that the goals, standards, and problems themselves evolve and become sharpened during the course of the work.

So is trial and error essential to innovation or is it to be avoided? My answer in the remainder of this chapter will be Yes and No! According to universal Darwinism, yes, it is in some way essential. But no, this does not mean that all problem-solving and all productive practices are nothing more than blind, mechanical trial and error. My position is far from a simple reductivist one.

### The Evolutionary Design vs. Intelligent Design Models, Human and Divine

As indicated, the leading alternative model, which has dominated the explanation of innovation until recently, is the intelligent design model, according to which deliberate, directed, pre-planned inquiry is both necessary and sufficient for innovation, aside from the occasional, improbable lucky hit. The intelligent design model has two well-known versions: the human-design model and the God-design model. The central premise, or principle, of intelligent design models is that *there can be no intelligent design without an intelligent designer; no genuine innovation, or at least no systematic innovation, without an intelligent innovator; no genuine design without a rational planner*. This idea is familiar from old, natural theological debates about the design of biological organisms and the creation of biological species. However, the premise holds equally for the extension of the theological argument from design to human innovation. After all, as William Paley's (1802) example of the watch found on the heath reminds us, the human intelligent design model itself is the source of the God-design model and of the intelligent design

model of innovation in general.<sup>12</sup> Paley himself considered biological organisms and specific organs such as the eye to be artifacts, artifacts constructed by the Great Artificer. The God-design model is the human-design model writ large.<sup>13</sup>

While many students of innovation today steer clear of divine inspiration and the like, the human-design model still underlies many accounts of discovery and innovation in science and technology as well as in the arts. According to its proponents, trial-and-error methods are typically brought in only as a last resort, when rational planning fails. Yet the human-design model leaves us with a very poor understanding of human innovation, for it is plausible only insofar as its alleged applications remain vaguely stated. We never get enough detail to see how the model could really work. Indeed, the more detail we get for a given case, the easier it is to see that the *pure* human-design model gets no purchase at all. By contrast, a progressive scientific understanding yields better-defined models and/or stronger empirical confirmation the more closely the problems are examined.

Ironically, if the evolutionists are correct, it is the BV+SR model that is fundamental and not a mere stopgap, last resort when all else fails. The claim by Campbell and a host of other evolutionists is not that rational, informed planning and directed inquiry are impossible, but rather that all of the knowledge that those activities presuppose was originally acquired by means of BV+SR processes, and that even such planning, insofar as it goes beyond already available design, must resort to trial and error. Fully planned activities are not in themselves innovative.

If we do treat *knowledge* as a kind of design (as we did in our extension of the Meno problem), then the intelligent design model is committed to the thesis that there is no epistemically successful design without a *knowledgeable* designer, no intelligent inquiry without an at least equally intelligent and informed inquirer. But if the designer, or the intelligent method employed by the designer, already contains the design, then it is difficult to see how this process can produce genuine innovation, or more knowledge from less. Stated more explicitly in terms of knowledge, the point is that if the intelligent designer must already know everything necessary, then the new knowledge is not a genuine

<sup>12</sup> Very briefly, Paley's argument was this. Suppose that in walking on the heath you come upon something that looks and works exactly like a watch. What is the probability that this object is the product of a chance coming together of the natural elements rather than the product of intelligent human design? Answer: negligible. Well, we may conceive of the human body from head to toe as a machine that is far more complex than the watch. So the probability of intelligent design is even more overwhelming in this case.

<sup>13</sup> My purpose is not to construct arguments against God's existence but to study the conditions that can produce genuine innovation.

innovation at all but simply a routine application of what the designer already knows. There is no genuine inquiry, for the process is impaled on the first horn of the Meno dilemma.

This point parallels the criticism leveled by evolutionists against the God hypothesis: that appeal to God cannot really explain design, for creationists are merely positing more design (infinitely more!) to explain less, rather than the other way around.<sup>14</sup> Theists may reply that it is possible that such a God does in fact exist and that God is self-explanatory or is beyond human understanding. I will not argue here against such a possibility but only point out that although God then provides an in-principle explanation of all novelty, we are far short of a precise model or explanation, since an infinitely powerful being can do *anything* (possible). To be able to explain everything so easily in these terms, without having to provide a precise mechanism, is really to explain nothing. We understand no more about how innovations can emerge than when we began. The theistic account replaces the mystery of creativity by a much bigger mystery.

In its strong form, then, as a complete solution to the Meno problem, the intelligent design model turns out to be no solution at all, for it holds that general human intelligence or human reason already contains all possible human knowledge, at least potentially or implicitly, a view reminiscent of Plato's own solution to the Meno problem (see Section 5). One reason why this point is little noted is that traditional epistemology (theory of knowledge) has been conservative and retrospective, focusing on the justification of knowledge claims already in hand rather than upon the process of gaining serious new knowledge candidates at the frontier.<sup>15</sup>

Surprisingly, common accounts of scientific method are committed to the intelligent design model. For the method allegedly contains the general principles that define scientific intelligence—principles sufficient to mine scientific discoveries from incoming data streams and that, in this sense, already contain those discoveries. But how could a powerful method of discovery be warranted in advance?

Thus we encounter an exasperating clash of views. Just when we seem to have discovered the key to all

innovation, including the growth of knowledge, and hope to methodize this discovery as the only known solution to the Meno problem, that problem itself appears to deny us the ability to methodize or mechanize the secret. For the method itself would already contain the design, at least potentially, and hence would merely instantiate the old thesis of no design without a designer and, as a result, would impale itself upon the first horn of the Meno dilemma. This clash will be spelled out more fully below.

The thesis that BV+SR lies behind all genuine innovation has always met considerable resistance. Because it threatens traditional views about human nature, it has had to fight once again the old battles once faced by physicists and evolutionary biologists about the reality and explanatory power of *chance*, the possibility of genuinely statistical-probabilistic *explanation* (Lestienne, 1993). For example, we meet again the objection that appeal to chance only masks our ignorance, that if we could locate the underlying causes or (better yet) the logic or the specific inspiration, then we could discover the genuine springs of innovation. Unlike intelligent design, it is alleged, chance disappears upon closer inspection. Chance and design appear to be mutually exclusive. In my view, this objection has things exactly backwards.

Somewhat as God was invoked in the nineteenth century to account for the stability of social and physical statistics, many writers are tempted to invoke a special, non-natural intuitive power to explain how we humans hit on as many successful ideas as we do.<sup>16</sup> Likewise, there is a tendency to dismiss as mere bothersome noise the variation that we find in scientists' and technologists' beliefs and practices, their numerous misunderstandings<sup>17</sup> of one another's work, and the historical contingencies that often affect the direction of their work. This noise allegedly masks the true process of scientific innovation and is something

<sup>16</sup> These remarks should not be misconstrued. I am not saying that all appeal to chance, including the BV+SR account of innovation, essentially depends upon an underlying physical or psychological indeterminism.

<sup>17</sup> These misunderstandings often result from a scientist's reading the work of other scientists whiggishly, from the standpoint of his or her *own* problem. Thus Kuhn (1978) argues that Einstein and Ehrenfest in 1905 misread Planck's 1900 works as addressing *their* problem (which Ehrenfest dubbed "the ultraviolet catastrophe") rather than the Clausius-Boltzmann problems that Planck was actually addressing. Brannigan (1981) makes the same claim about the reception of Mendel's work. Dawkins (1986, p. 130) remarks: "Insofar as I can claim to have had any original scientific ideas, these have sometimes been misunderstandings, or misreadings, of other people's ideas". In this vein, Alfred North Whitehead supposedly quipped: "Everything has been said before, but not necessarily by someone who knew they were saying it".

<sup>14</sup> See Dennett (1995, chap. 3) for a version of this objection.

<sup>15</sup> See Dewey (1929, chap. 7). In virtually all of his major works (e.g. 1962), Popper has featured the problem of the growth of knowledge as his central problem, while denying that there is a method of innovation. For Popper the absence of a logic of discovery implies that the search for new theories must be, to some degree, blind. Popper explicitly developed a BV+SR methodology (see Campbell, 1974). I believe that a BV+SR model is also implicit in Thomas Kuhn's account of normal and revolutionary science. In any case, the preface to Kuhn (1962) indicates that he will not employ the discovery-justification distinction invidiously and that much of his work will concern discovery. See Nickles (2003) for details.

to be eliminated whenever possible—and certainly to be eliminated from our methodological accounts of scientific research. But according to universal evolutionism, this is again the wrong attitude, for variation is essential to the process (Edelman, 1987). Far from being ideal, a noiseless system would be completely uncreative.

Noise also enters the system at the selection and transmission stages of the evolutionary BV + SR process, so we should not see these as strictly temporal stages in which the variants are produced entirely antecedently to stages two and three. Whether someone's work catches hold depends upon audience reception and transmission (reproduction). While scientific recognition systems canonize a few 'greats', the actual authorship of deep developments is typically more distributed and more anonymous. Here the 'author function' largely disappears and can be regarded as a post-hoc social construction (Schaffer, 1986, 1994).

Insofar as the world at bottom is genuinely stochastic, the creationist 'model' is stretched even thinner, for then not even an omniscient being can create a specific world by setting up a deterministic causal system and letting its history unfold. Rather, such a being would have to survey in advance all possible probabilistic worlds, history and all, and then choose a particular world (whatever that could mean). For in a genuinely stochastic universe, as in a deterministic universe, not even an omniscient being is allowed to interfere to keep it on track. Furthermore, a being that is thus omniscient cannot really be creative in the sense of generating novel design, since it *already* possesses all possible design. Making the world is 'simply' applying what it already knows.

In what follows I shall unpack and defend a version of Campbell's BV + SR claim that somewhat reconciles the evolutionary model and the human-design model. Much of the debate has been spoiled by a tiresome polarization between two extremum positions, neither of which is held by any responsible writer today. At one extreme we have the view that scientific discovery (say) is determined by application of 'the' scientific method and leaves no room for chance. Such a view of discovery comes close to being oxymoronic. Meanwhile, advocates of evolutionary accounts are often characterized as committed to the opposite extreme, as saying that there is nothing more to creative work than totally random or mechanical trial and error.

Campbell and his precursors already insisted that the BV + SR thesis does not at all deny the existence of rational planning or of problem-solving or learning algorithms of other kinds, only that these are not yet known or justified at the frontier of research where genuine innovation occurs. Innovation has to do with pushing back the frontier, not with the routine application of known rules. While there is a grain of truth to the claim that trial and error is employed as a 'last

ditch' effort when intelligent design runs out of intelligence, the point is that, at the frontier, it always *does* run out. Since that knowledge itself was once a product of frontier research, the grand irony is that BV + SR processes ultimately underlie the knowledge presupposed by intelligent design. In this logical and empirical respect, trial and error is a 'first ditch' effort rather than last ditch.

While I defend Campbell's BV + SR thesis,<sup>18</sup> I do not share his tendency to conclude that, because they are blind, BV + SR processes are the very antithesis of method; and that, therefore, there is no scientific method or method of innovation in any field. In other words, I adopt a wider conception of method than the traditional one that is linked to the intelligent design model. The BV + SR thesis may thus have positive methodological significance after all.

Campbell is correct if he only means to say that any particular BV + SR learning rule is too weak to be considered an efficient *general* method of innovation, but he is mistaken if he denies that they are methods at all. For in fact, BV + SR methods can be powerful and creative search engines when tailored appropriately to a domain. Campbell himself deeply appreciated the creative power of evolutionary processes, but he perhaps underestimated their methodological possibilities. After all, Campbell's famous paper, 'Evolutionary Epistemology', was written in praise of Karl Popper, who adamantly rejected the possibility of methods of discovery. The same paper quotes Souriau's anti-methodological stance at length, with seeming approval (Campbell, 1974a, 428ff). The thesis of Souriau (1881) is 'le principe de l'invention est le hazard'. But in fact, the emerging field of evolutionary computing generalizes and methodizes the Darwinian insight.

As Campbell knew, there is also a certain vagueness in speaking so broadly of trial and error or even of BV + SR in the same breath as evolution. There are many such processes, ranging from 'random' guessing to highly directed search, that are not evolutionary in the full-blooded sense of selection from a *population* of competing variants, a selection that in turn will breed the next generation of the population. Consider a few of the many variations on the trial-and-error idea. A one-trial, all-or-nothing search clearly is not evolutionary. (E.g. you examine the first 28 characters formed by a monkey at a typewriter and 'select and retain' this string if and only if it perfectly matches 'Methinks it is like a weasel'.) Nor is an iterated version of this kind of search evolutionary (e.g. you give one monkey a thousand chances, or a thousand monkeys one chance

<sup>18</sup> Campbell himself usually wrote BVSR instead of BV + SR. I shall retain the 'plus' to distinguish my version from his.

each). However, if selection of partial matches is allowed and successful matches are allowed to accumulate,<sup>19</sup> then we approach the idea of an evolutionary process (albeit one based on goal-directed artificial selection rather than natural selection), even though we still have one trial at a time rather than a population of simultaneously competing individuals. For even in this simple sort of slow, serial evolution, success is allowed to ‘breed true’ into the next generation, while the incorrect parts are varied. Also, depending on how it is set up, a process that involves a population of competing and potentially crossbreeding individuals (trials) can amount to parallel processing.

This discussion makes clear that only a small minority of BV+SR processes are completely blind, let alone random in the above sense. Not even biological evolution is nearly random in this sense, because it involves: (a) highly constrained variation (the offspring of rabbits resemble their parents, not to mention other rabbits); (b) including nonrandom mutation and cross-over operations; (c) an iterated BV+SR process rather than a one-shot chance-arrangement of materials; and so on. In the field of evolutionary computation, specific choices of codings for individuals, choice of search operators, and of parameter values all represent departures from purely random search. In general, however, the weaker our domain knowledge, the weaker and less constrained (hence the more blind) the search procedures available to us. I shall develop this point below.

What then of the metaphor of monkeys at typewriters to describe the bare baseline of inquiry, the complete absence of method or direction? In the absence of cumulative selection, monkeys at typewriters are certainly inefficient producers of interesting novelty, but even here we could do worse. For example, a student who uses the ‘copy from my neighbor’ method of taking a true–false test but who gets the questions one number out of order may do much worse than chance!

Is the innovation process *convergent* or *divergent* according to the BV+SR model? The answer to this highly ambiguous old question is, Both! The production of variants is: in a sense, divergent, while the selection process could be said to be convergent. However, the question is misleading.<sup>20</sup> The degree of divergence and convergence will depend upon how tightly constrained the processes are. In biological

reproduction, for example, the production of variants is highly constrained: they result from such normal factors as sexual mating, noise in the system (copy errors and the like), and the occasional cosmic ray. And the selection process is convergent in weeding out the vast majority of variants that stray very far from the norm. As Campbell (1974, Section 4) points out, there is a tension between variation and selection. In effect, large variants are not recognized by the community-plus-niche system. Overall, this makes biological evolution a pretty conservative process in the short run. This tension corresponds to Thomas Kuhn’s ‘essential tension’ between innovation and tradition as manifested in normal science. He describes normal science as a convergent process even though it is a puzzle-solving process and, as such, involves the production of variant attempts to solve nonroutine puzzles (Nickles, 2003).

Both the Meno problem, with its two horns, and the BV+SR model predict that there will always be an essential tension between innovation and tradition. Innovation implies change, but changes that are too great will not be recognized as a contribution to *that* enterprise. In the case of human inquiry, decisions as to whether to include any significant change are socially negotiated (Schaffer, 1994). Is it art? Is it good science? Is it good solid-state physics? Does it really solve the original problem or does it change the subject?

### The Meno Problem Elaborated

What was Plato’s own solution to the Meno paradox? Plato’s Socrates concludes that learning is really only ‘recollection’ of knowledge already gained by souls between lives, when they supposedly enjoyed unencumbered epistemic access to reality, which knowledge was rendered subconscious by the rigors of childbirth. Thus learning, successful inquiry, is really only a matter of transforming this implicit, subconscious knowledge into explicit knowledge. That is, for Plato the only possible kind of inquiry is conversion of knowledge from one form to another. This amounts to a kind of conservation principle: the amount of knowledge (in all its forms) possessed by embodied human beings is a conserved quantity in the sense that normal human inquiry cannot increase it. (Notice that the God model of design also conserves knowledge at the cosmic level, since an omniscient God already possesses all knowledge in advance. Nothing can be gained or lost.) Plato’s solution begs the Meno question, of course, for he fails to explain exactly how it is possible for souls to learn between lives. But his solution does contain grains of truth.

The problem of whether and how knowledge can be converted from one form to another is extremely important. Many researchers today are investigating the relations of various forms of knowledge representation, knowledge embodiment, and knowledge

<sup>19</sup> Dawkins (1986, ch. 3), who gave the weasel example, convincingly demonstrates the power of accumulative BV+SR.

<sup>20</sup> If a research result decisively favors one theory or practice over another and thus reduces the set of competitors, is this convergence? Is it still convergence if the eliminated theory is the reigning paradigm?

engineering, including habit formation,<sup>21</sup> tacit knowledge, skills, procedural knowledge (knowing-how) vs. declarative, propositional knowledge (knowing-that), how items in short-term memory get fixed in long-term memory, how ignorance is transformed into a good problem, and so on.<sup>22</sup> Let us term this the *epistemic conversion* or *epistemic transformation* form of the Meno problem.

There are also fundamental problems in understanding the ‘transfer’ of knowledge from person to person (e.g. teacher–pupil), person to machine, and so on. This is the *epistemic transfer problem*. After all, the central question of the *Meno* is whether virtue can be taught by one person to another. In this case the recipient of the transfer clearly learns, but the system as a whole does not. Here, for example, we face the problem of understanding the transfer of scientific, technological, and artistic knowledge from one generation to the next, for it is by means of reproducing themselves in this way that disciplinary enterprises sustain themselves.

A third important Meno problem remains: how to acquire genuinely new knowledge (previously unknown to anyone or anything who could otherwise transfer it to you). Let us call this the *problem of epistemic innovation*.<sup>23</sup> This tripartite division of Meno problems is rather crude, but it is sufficient for our purposes. The three problems overlap, and the processes involved in solving any of them can be extremely complex, requiring much refinement of our ordinary talk about skills, habits, and the like.<sup>24</sup>

Even Plato’s original formulation of the Meno problem suggests (correctly, in my view) that explicit inquiry is a kind of *search* and that the Meno problem is basically a problem of *recognition* (or construc-

tion),<sup>25</sup> namely, how to recognize and select the (or a) correct answer, or at least a somewhat promising answer, out of a noisy background of zillions of potential alternatives.<sup>26</sup> Plato’s text also raises the crucial issue of the relevance of old knowledge to the search for new knowledge. It is on this second problem that Plato begs the question with his epistemic transmigration story. Within a normal human life, he seems to conclude, there is no answer to the Meno. In this life, genuine inquiry, and hence genuine innovation, are indeed impossible, and knowledge is conserved.

There are other kinds of learning discussed in the educational, psychological, and artificial intelligence (AI) literature. For example, improving one’s problem-solving skills certainly counts as one kind of learning even when the capacity to solve *new* kinds of problems does not increase. Much of AI has been concerned with developing problem-solving systems that operate more efficiently.<sup>27</sup> However, my focus here will remain on epistemic innovation as described above. In this case the Meno problem is ‘How is innovation possible at all?’ and not ‘What is the most efficient or optimal means to achieve it?’

Many nonnatural accounts of cognition suppose that we possess a kind of divine spark in the form of human intellect or a faculty of reason. But invoking a theological or supernatural account of knowing will not help here. The limiting case is an omniscient god, but, as noted above, such a being cannot inquire at all, given the first horn of the dilemma, for it already knows everything. The God model of knowing is not helpful to theory of inquiry—or even possible. Nor, for the same reason, is the intelligent design ‘theory’ of genuinely innovative design a viable model.

Ditto for the historical attempts to evade the paradox by positing special forms of human knowing such as the intellectual intuition of the rationalist philosophers, clairvoyance, precognition, or some other sort of

<sup>21</sup> In effect, Aristotle solved the problem of the Meno by means of his theory of potentiality, applied to habit formation.

<sup>22</sup> See Karmiloff-Smith (1992) and Root-Bernstein’s chapters in this Handbook for examples.

<sup>23</sup> I could have kept Popper’s old label, “the problem of the growth of knowledge”. There are other ways to parse the Meno problems. One could argue, I suppose, that even learning new things about actual natural phenomena is a kind of information-transfer problem (as simple instructionists from Aristotle to the British empiricists sometimes seem to have thought), whereas the full innovation problem concerns the creation of designs that previously were no part of the learning system (agent-plus-object) at all. Instructionist theories are clearly incapable of explaining this sort of innovation.

<sup>24</sup> Even simple verbal communication of an everyday sort (“I’ll meet you at the clock in Grand Central Station at the same time tomorrow”) is an extremely complex affair. See, Brandom (1994) for one recent account of how semantic content is constituted.

<sup>25</sup> For simplicity I shall characterize the Meno problem and the BV + SR selection problem in terms of recognition, which means that the system in question registers sufficient agreement with fitness criteria. The term ‘recognition’ can be contentious, for like the term ‘discovery’ vs. ‘construction’ or ‘invention’, it can beg questions of realism. In some contexts at least we do not discover (by recognizing) a solution just waiting there to be found; rather, we construct a solution. Moreover, whether discovered or constructed, the solution need not be optimal, as Simon (1947) emphasized in his discussion of satisficing.

<sup>26</sup> I do not mean that a search always must be literal, deliberate, conscious search for something predesignated, for I want to extend the idea of evolutionary biology to subconceptual human practices.

<sup>27</sup> See Simon & Lea (1979) and Dietterich (1986) for ‘classical’ discussions of these issues.

prescience.<sup>28</sup> Most of these solutions are as question-begging as Plato's own response to the problem of innovation. Some of them, e.g. prescience, again impale themselves upon the first horn of the dilemma. Typically, the 'mechanism' by which the extraordinary faculty works remains unspecified. Notice that if 'intuition' and 'inspiration' (whatever they might be)<sup>29</sup> are analogous to ordinary vision, then they, too, involve an element of blind search. As Campbell has shown convincingly, even systematic visual scanning, e.g. by a creature that may be both predator and prey, is blind in the specific sense that the animal does not know in advance whether predator or prey will show up at all, or where and in what form, in the region scanned.

The more promising attempts to solve the Meno problem all 'go between the horns', thereby dismissing the argument as a false dilemma. The basic idea is that there are grades of knowledge. Our epistemic situation is not that of completely explicit, justified knowledge or else nothing at all. Rather, we possess inferior grades of knowledge or quasi-knowledge that, through inquiry, can be upgraded or converted into a more usable form. Hence we have the possibility of search that impales itself on neither horn of the dilemma. We can search because, although we do already have the answer in one respect, in another respect we do not. Moreover, we can hope to recognize the thing sought, should we stumble upon it, since we already possess some knowledge of it, explicit or tacit. Despite the fatal difficulties, there is something right in Plato's account.

The power of the iterative, 'multi-pass' BV+SR solution to the problem resides in the fact that recognition need not be an all-or-nothing affair and in the fact that BV+SR processes can be massively parallel, with many agents exploring vast regions of the search space rather than a single agent, who is likely to get stuck on a local fitness peak. (This second point does concern efficiency but more than that, since the parallel nature of the process helps BV+SR avoid traditional difficulties of hill-climbing heuristics, such as getting stuck on a local maximum.) BV+SR can parlay even the coarsest, partial recognition or 'fit' by one or more candidate solutions into a series of better

solutions. That is, low-grade recognition by one or more candidate solutions or 'variants' triggers a new generation of variants parented by those first generation variants of above-average fitness. If there is a pattern or solution to be found or constructed, it is likely that some second-generation variants will achieve still higher fitness, and merit their selection for production of the third generation of variants; and so on. Stated somewhat differently, the earlier populations of variants provide a widely dispersed set of explorers of the fitness landscape. Those found a little higher on the hills or peaks of the landscape will have a higher probability of reproducing. As the process iterates from generation to generation, the exploratory focus on the more promising regions of the search space increases exponentially. According to the clonal selection model, this is basically the manner in which the vertebrate immune system can muster its limited resources to 'recognize' any of a vast domain of invading antigens and then can proceed to sharpen its criteria of recognition.<sup>30</sup>

It is this ability to utilize low-grade information as a pointer that makes iterative BV+SR *heuristically* powerful. The selection criteria at each stage function as a mechanism for heuristic appraisal, that is, evaluation of the promise of pursuing a line of investigation (Nickles, 1989). (Here we humans have an advantage over nature in that we can look ahead to longer-term goals and do not always have to worry about the immediate survivability of the present model in competition with more robust but less promising ones.) Thus heuristic appraisal does not reduce to standard confirmation theory as discussed by philosophers. Scientific survivability depends upon far more than empirical track record to date.

One implication of this gradualist solution to the Meno problem of recognition is that 'micro-aha' recognition experiences will vastly outnumber the 'macro-aha' experiences widely reported in the popular romantic literature on innovation (cf. Gruber, 1974). In fact, most of the microrecognition surely takes place at the subconscious level.

The Meno problem can also be parsed into two (or more) subproblems in a different way. First, assuming that a still unanswered question or unsolved problem has already been posed (which itself requires a sophisticated sort of recognition or construction), there is the *starting problem*, the problem of knowing where and how to search for an answer. Second, there is the *stopping problem*, the problem of knowing whether and when you have found a suitable answer, or at least

<sup>28</sup> It is remarkable how many people take seriously the 'predictions' of Nostradamus, for example. There are problems even if you seem to receive direct instruction from a crystal ball or the voice of God. How do you determine whether this crystal ball is veridical? And even if it is, do you have to use it as a scanning device? How do you know what you are seeing? In the other case, how do you know that it is the voice of God and, if so, what God's message means?

<sup>29</sup> Here I am speaking of intuition and inspiration of a transcendental kind. I have no objection to speaking of intuition and inspiration of a down-to-earth, naturalistic sort. Indeed, I believe that culturally acquired intuition and the intuitive flow we can acquire through skilled practice are important phenomena.

<sup>30</sup> Nowadays, the clonal selection model is no longer the last word in immunology. See, for example, Tauber (1994). However, later developments do not undermine my point.

an answer worth pursuing in order to achieve a still better fit.<sup>31</sup>

The process of solving at least the first subproblem would seem to require a degree of blind search in the form of trial and error. For even if you already possess some knowledge of where to look for the answer, you must still search for it once you get there; and, by definition, search involves an element of blindness in Campbell's sense. For if no search at all were required, then you would already have the answer. Of course, if you know where to search, this will be highly constrained search. Your search procedure will be 'biased' (in the good sense in favorable cases) by knowledge you already possess about which small region of a potentially much larger search space you need to examine. Of course, such biases can also be unfavorable in cases where an unexpected sort of answer is superior.

The second subproblem is just the problem of recognition. A third subproblem would then be what to do with the item(s) now recognized in terms of using them to conduct a more refined search, that is, how to conduct the iteration.

Taken together, these processes amount to a blind generate and test procedure. Thus the Meno problem itself points toward its own solution, a process of BV + SR. Only resistance to the idea of blind trial and error can explain why it took so long to recognize this path to solution. Yet this is not so surprising when we recall that, until Darwin, there seemed no way other than intelligent design to explain any significant design innovation, including the epistemological design that constitutes a body of knowledge.

### Search Operations: Generality and Efficiency

A look at developments in artificial intelligence (AI) over the past 50 years will reveal the importance of domain knowledge as a constraint on efficient evolutionary computation.

It has taken the AI community a long time to appreciate the need for, and power of, evolutionary adaptation as a search process.

The breakthrough results that got AI rolling were the Logic Theorist and General Problem Solver of Allen Newell and Herbert Simon, developed in the 1950s and 1960s. Their premise was the then-plausible idea that human reason or intelligence resides in relatively few general principles, namely, logical and heuristic princi-

ples that would do for problem-solving what the laws of mechanics do for physics. But despite the historical, revolutionary importance of this approach, it turned out not to have the problem-solving power expected.<sup>32</sup>

From the late 1960s on, prominent members of the AI community promulgated the informal truth that completely general, a priori, content-neutral, 'logical' problem-solving methods are inefficient at best and not very innovative, that inquiry can be highly focused only insofar as we already possess substantial knowledge of the domain in question.<sup>33</sup> It takes domain-specific knowledge to solve domain-specific problems (and thus to gain interesting knowledge) with any efficiency. As Edward Feigenbaum, a former student of Simon and one of the most enthusiastic leaders of the new movement once put it:

There is a kind of 'law of nature' operating that relates problem-solving generality (breadth of applicability) inversely to power (solution successes, efficiency, etc.) and power directly to specificity (task-specific information).<sup>34</sup>

Newell and Simon already recognized, of course, that the more highly constrained a problem could be, the more readily it could be solved. As Newell (1969) remarked:

Evidently there is an inverse relationship between the generality of a method and its power. Each added condition in the problem statement is one more item that can be exploited in finding the solution, hence in increasing the power.

But the new knowledge-based computation movement went considerably further in the direction of domain-specific knowledge by incorporating large quantities of domain-specific knowledge in the program itself and not only in the statement of the problem. The basic idea is that intelligence is a function of domain knowledge, not of general logic and heuristics alone. Thus we get a new paradigm of innovation: innovation flows from specific knowledge, not from logic or reason. It is sometimes quipped that the ratio of A to I in AI is very high. Be that as it may, it is surely an important insight that knowledge is artificial, something constructed (in various ways and to various degrees), and hence something that can, in principle, be engineered.

The lesson that it takes knowledge to get new knowledge at all efficiently was already implicit in

<sup>31</sup> Gigerenzer & Todd (1999) divide heuristics into search rules (what I am calling starting rules), stopping rules that determine when it is no longer cost-effective to continue searching, and decision rules that select an action decision among those options available at stopping time. My account is simplified. I also make no attempt here to extend this 'knowledge' and 'search' talk to biological processes, although I believe that it is fruitful to do so. In a sense nature solves problems that it does not pose.

<sup>32</sup> For their masterful summary of their previous work, see Newell & Simon (1972). For a fairly comprehensive 'insider' history of AI through the early 1990s, see Crevier (1993).

<sup>33</sup> Compare the rejection of traditional syllogistic logic as sterile because it is not ampliative, by Bacon (1620), Descartes (1637), and many others. Critics make the same point more generally against the rational, pre-planned design strategy of the human-design model.

<sup>34</sup> Feigenbaum (1969), repeated in Feigenbaum et al. (1971, p. 167).

Plato's treatment of the Meno paradox and is readily apparent in the history of any branch of science or mathematics—indeed, in the history of any major constructive endeavor, anything that results in 'design'.<sup>35</sup> The short history of AI merely recapitulates the history of science in this respect. Scientists themselves have recognized this characteristic of scientific inquiry. In his 1901 Presidential Address to the British Association, Lord Kelvin remarked:

Scientific wealth tends to accumulate according to the law of compound interest. Every addition to knowledge of the properties of matter supplies the naturalist with new instrumental means for discovering and interpreting phenomena of nature, which in their own turn afford foundations for fresh generalizations.<sup>36</sup>

Insofar as it is correct (and of course there are exceptions, as when all the major problems in a field have been solved and sterility sets in), the claim that problem-solving power depends upon appropriate domain knowledge has major implications for the debate about scientific method. For the idea of a completely general, content-neutral scientific method becomes oxymoronic. On the one hand, such a method would be too strong—already containing potentially any number of possible scientific discoveries across many fields. On the other hand, it would be such a weak search tool as to be practically useless.<sup>37</sup> The traditional idea of a general scientific method harbors a greedy desire for a one-step solution to the problem of the growth of knowledge, namely: Follow my method!

Incidentally, since the mid-nineteenth century, the most widely touted general method of science is the so-called hypothetico-deductive (H-D) method. This is the method of hypothesis and test, and it can be regarded as a slow BV + SR process: the H-D method typically considers hypotheses serially and in isolation instead of in parallel, as members of a population of simultane-

ously competing hypotheses.<sup>38</sup> Its complete, content-neutral generality renders it incapable of providing guidance to hypothesis formation in any particular case. But in specific domains in which we already possess knowledge, the process can be more directed. One way in which it can be more directed is by considering variants of a previous hypothesis that showed some promise. So it is better to regard the general H-D method as a high-level schema that includes domain- or problem-specific H-D methods as instances rather than as a specific method in itself. There are various H-D methods, depending on the modes of variation, selection, and retention and, specifically, the ways of modifying previous hypotheses.

Returning now to AI: the leading implementation of knowledge-based computation was and is that of 'expert systems'. The idea is to elicit the domain knowledge of human experts and then to incorporate this content into the problem-solving program, typically in the form of rules (e.g. if-then production rules). At first the possibilities for expert systems seemed unbounded, but progress on this front, while genuine, was also ultimately disappointing. Knowledge did not compound in anything close to Kelvin's manner. One difficulty was that the more knowledge that was incorporated into expert systems, the slower they ran.<sup>39</sup> Another was that of transferring problem-solving expertise (domain knowledge-how as well as knowledge-that) from human expert to machine. Among other things, this obstacle suggested that explicit rules might be the wrong way to represent most expert knowledge. So here we have both the epistemic transfer and epistemic conversion forms of the Meno problem that I distinguished above.

More serious for our study of innovation is that standard expert systems do not happily solve the innovation problem either, for they turn out to be innovative only to a limited degree. They can be

<sup>35</sup> The universal evolution thesis applies to any process that produces novel design, whether or not that process is conceptual or subconceptual, conscious or subconscious or nonconscious.

<sup>36</sup> Kelvin (1901, p. 114). Gigerenzer (1994) adds the reverse heuristic, which he calls 'the tools-to-theories heuristic'.

<sup>37</sup> I like to illustrate this point with my 'crowbar' or 'pry bar' model of method. A method is a tool that we use to investigate the world. Consider a crowbar as a representative tool. Now a crowbar is useful only insofar as it fits the world at one end and the human hand at the other. If the world were tomato soup or if we were fish, a crowbar would be useless. Similarly for methods in general: they are useful only insofar as they fit the world at one 'end' and human capabilities at the other. A good method cannot be totally out of kilter with the way the world is, and it must also sufficiently fit human capacities (which may be considered another part of the world). Thus we cannot regard usable or successful methods as content-neutral any more than hypotheses are.

<sup>38</sup> Another irony! Despite the historical resistance to BV + SR and to any suggestion that chance, luck, or serendipity could be an element of method, the dominant, H-D method itself turns out to be a slow BV + SR procedure. Proposals such as Chamberlain's (1897) 'method of multiple working hypotheses' and Paul Feyerabend's (1975, ch. 3; 1981, pp. 104ff and 139ff) theory proliferation methodology in effect turn the process into a fully populational one, although the populations will usually be rather small.

<sup>39</sup> Kevin Kelly (1994, p. 295) quotes Danny Hillis et al. as saying:

The more knowledge you gave them, the slower computers got. Yet with a person, the more knowledge you give him, the faster he gets. So we were in this paradox that if you tried to make computers smarter, they got stupider. . . .

There are only two ways we know of to make extremely complicated things. One is by engineering, and the other is evolution. And of the two, evolution will make the more complex.

immensely valuable, of course, in coordinating incoming information or queries with large databases, e.g. to give faster and more reliable medical diagnoses than human experts. But from the standpoint of genuine innovation, the popular old saw that a computer contains only that knowledge deliberately programmed into it remained too close to the truth in this case (Crevier, 1993, ch. 8). Even a perfect lateral transfer of routine problem-solving ability from human to machine would not necessarily endow the machine with significant creative powers, so there would be no overall gain in knowledge or creativity by the human-machine system. (Compare the knowledge transfer from professor to dependable but uncreative student.) Of course, once a machine with greater speed became available, that might give it a higher productivity and hence more creative ‘hits’ than the human investigator whom it simulates; and hit rate is one measure of creative potential (see Simonton, this volume).

In sum, knowledge-based computation of the traditional, expert-systems type runs into some practical and theoretical difficulties with the first and second Meno problem (the epistemic conversion and transfer problems) and into major difficulties with the third Meno problem (the innovation problem). Evolutionary epistemologists, including evolutionary computational theorists, believe that their approach will have more success.<sup>40</sup> Interestingly, some of them tout their approach as a new, general paradigm that does *not* depend heavily upon domain-specific knowledge (Koza et al., 1999).

### The ‘No Free Lunch’ (NFL) Theorems

Recently, the above knowledge-based insights have received formal backing. David Wolpert and William Macready (1997 and elsewhere) have proved a series of seemingly fundamental theorems, commonly called the ‘No Free Lunch’ theorems (NFL theorems), according to which there is no one, best, general, problem-solving algorithm. The proofs are highly technical results showing, basically, that the average performance, for any relevant performance measure, is the same for any two algorithms, when averaged over all cost functions and the space of all problems, or, as we might say, all inductive learning problems in all possible problem domains or possible worlds.

Although these results are still undergoing critical evaluation and interpretation, they are not totally surprising, certainly not to knowledge-based computation advocates and to those philosophers of science

who have noticed the domain specificity of powerful problem-solving methods and research techniques in the history of the various sciences. In fact, David Hume himself (1748, Section IV) vaguely anticipated such results when he wrote (among many similar things) that Adam, upon coming afresh into the world with full powers of reasoning but without any experience, would have no knowledge of anything in nature. In particular, Adam would be able to draw no inferences, either logical or psychological, about what would happen next. Hume’s argument was that, absent empirical knowledge of what the world is like, reason is powerless to provide an inductive projection rule that is either correct, or the best possible, or better than average, or even better than some specified rule. That is, there is no reason to think that any rule is best or even better than some other rule, when averaged across all possible worlds. Contrary to the rationalists, pure reason can teach us nothing about empirical reality. Stated differently still, the point is that, under a veil of complete ignorance about which world we inhabit, or of the problem domain in which we are now working, we have no reason to believe that any particular induction rule will dominate all others, or, indeed, *any* others. Nor is there any a priori justification for projecting any perceived pattern in a given data set. In this situation, one can only proceed by adopting a (so far unjustified) learning bias and seeing how well it works. Readers of Ludwig Wittgenstein’s *Tractatus* or Rudolf Carnap’s *Continuum of Inductive Methods* will come away with similar intuitions in sharpened form.<sup>41</sup>

It is these intuitions that the NFL theorems formalize and prove. In fact, Wolpert himself quotes Hume’s *Treatise* as the motto for Wolpert (1996), where he broadly characterizes the NFL theorems as follows:

(T)he implication of the NFL theorems that there is no such thing as a general-purpose learning algorithm that works optimally . . . is not too surprising. However, even if one already believed this implication, one might still have presumed that there are algorithms that usually do well and those that usually do poorly, and that one could perhaps choose two algorithms so that the first algorithm is usually

<sup>40</sup> Another approach was/is to train an inductive learning system on sets of examples rather than to try to extract rules from human experts. This method can be used with or without evolutionary algorithms. For a discussion of ‘Feigenbaum’s bottleneck’ in philosophical context, see Gillies (1996, pp. 25ff).

<sup>41</sup> For an introduction to these ideas, see Carnap (1950, 1952) and Salmon (1966, pp. 70ff), on Carnap’s use of state descriptions and structure descriptions in possible worlds. Assignment of equal weights to state descriptions corresponds to a world in which learning from experience is not possible. Unfortunately, Carnap’s logical conception of probability required a priori choices of weights. See also Mitchell’s insightful paper (1990), originally written in 1980. The Carnap sort of treatment also makes the issue simply one of inductive connectivity among phenomena, whereas it is also one of metaphysics—the nature of the underlying entities and processes that constitute a domain.

superior to the second. The NFL theorems show that this is not the case (Wolpert, 1996, p. 1362).

What implications, if any, do the NFL theorems have for our topic? Their interpretation is controversial, as some commentators deny that they seriously affect inquiry in our world. Here is the significance that I read into them, as a series of overlapping claims.

- (1) ‘No free lunch’ suggests that something is conserved, that you can’t get something for nothing, that it takes domain knowledge in order to warrant using any inductive rule with confidence, much less to establish that it is superior to another rule. This means empirical domain knowledge in the case of learning about the natural world. One way in which to state this idea is that the inductive success of any given rule will be zero when averaged over all possible learning situations. It will fail as often as it succeeds. C. Schaffer (1994) and Rao et al. (1995) provide technical discussions of conservation.
- (2) We cannot determine purely a priori the relative power or efficiency of learning rules for an arbitrary domain.
- (3) Efficient learning procedures are domain-specific and not general, regardless of whether or not anyone knows which rules or algorithms these are. The theorems themselves are ‘objective’ and not relative to the state of our knowledge.
- (4) There is no completely general scientific method (across all possible problem domains or ‘worlds’) that is more efficient than other possible methods or learning rules, let alone a method that can be justified a priori or even by convention, as methodologists from Descartes to Popper have supposed. Specifically, there is no maximally efficient hypothetico-deductive method, let alone a maximally efficient ‘logic of discovery’.
- (5) Available domain knowledge can be used to select ‘biased’ (in the nonpejorative, engineering sense) search procedures with superior efficiency. That is, we *can* know that a rule is more (or less) efficient than the average rule or some specific rule, in a particular domain, given relevant domain knowledge. Choice of an efficient learning procedure is justified only insofar as we possess relevant domain knowledge.
- (6) Conversely, the less domain knowledge we possess, the more ‘blind’ and general, and hence weak and inefficient, our search procedure becomes. For as long as significant domain knowledge is lacking, we have no way of knowing which of the possible rules is indeed more efficient.
- (7) Thus Campbell’s BV + SR thesis (the necessity of using BV + SR at the research frontier) is true.
- (8) For in a state of ignorance we can only proceed blindly, by trying this solution or rule or that one. Once we have determined that some rules or techniques work better than others, we can then try, *post hoc*, to *explain* this fact by attributing a particular structure to the domain. Confirmation of that attribution can then warrant the use of biased rules. This basic idea was already incorporated in the traditional method of hypothesis.
- (9) Thus at the frontier of knowledge, inquiry is consequentialist rather than generative, relative to the domain knowledge already available (see below).
- (10) It takes knowledge to get knowledge at all efficiently, yet, contrary to Plato’s version of the conservation of knowledge, we can still get more knowledge from less. This claim goes beyond the NFL theorems in assuming that the domain in question does have some structure and that a BV + SR process can find some of it. Under these conditions, creation *ex nihilo* is possible, not in the sense of innovation from absolutely nothing but in the sense of the emergence of more knowledge from less, of more design from less.
- (11) However, the more innovative the knowledge (relative to our ignorance of the domain), the weaker, more inefficient our search procedures will be and the more difficult the corresponding recognition problem.
- (12) Therefore no strong methods of discovery are possible in the sense of efficient methods for producing major innovations. However, weak discovery procedures are possible. And, when iterated, the ultimate result can be highly innovative.
- (13) Random trial and error is not the weakest of all methods. For, averaged over all possible domains, it is as strong (or weak) as any other method.

<sup>42</sup> See Thornton (2000, pp. 141ff). Of course, neither the NFL theorems nor the data-compression techniques that Thornton proceeds to promote ultimately *solve* Hume’s philosophical problem of induction. Inductive moves will always remain risky.

<sup>43</sup> I cannot address here the converse question of whether a sufficiently weak BV + SR procedure will work to produce learning if any rule will work.

- (14) Moreover, for any particular domain, there exist any number of methods (learning rules) that are worse than random trial and error.<sup>44</sup>
- (15) Given that there are many distinct varieties of BV + SR, not all BV + SR rules should be labeled 'mere' trial and error or 'random' trial and error.
- (16) Specific BV + SR methods will be more or less efficient than each other in a given domain but equally good (or bad) when averaged across all possible domains of problems.

A few words of explanation are in order. With reference to (7) and (8), the NFL theorems do not single out BV + SR rules as objectively special in any way. Given any particular domain, there is no reason to think that a BV + SR rule will be among the objectively more efficient rules for that domain. So, as objective existence claims, the NFL theorems offer no positive support for the Campbell thesis that innovative inquiry must employ some BV + SR. It may even appear that they undermine the thesis. However, they do not, for Campbell's thesis concerns inquiry under conditions of ignorance and not the mere mathematical existence of learning rules for a given domain. The relevance of the NFL theorems to this epistemic situation is the familiar Humean one: we have no a priori reason to prefer one rule over another. In this case, BV + SR rules of one sort or another become special in the sense that we have no alternative but to use one of them. A new scientific domain may be subject to very powerful search rules. The trouble is, the investigators first opening up the domain do not know what they are. They can only proceed blindly, according to the degree of their ignorance.

Obviously, even when a powerful rule happens to exist, you cannot use it until you hit upon it, and you cannot make justified efficiency claims for it until you have shown its superiority to other rules. To be sure, you may select any arbitrary learning rule or problem-solving procedure as a hypothesis, but, a priori, it will have as much or as little chance as any other rule. This choice in itself is therefore blind. You may subsequently try another rule and yet another. You are now implementing a BV + SR procedure at the level of rules.

Once your research community achieves some domain knowledge, you may graduate to a stronger form of inquiry. Suppose that previous BV + SR has produced sufficient domain knowledge to justify more direct procedures for solving problems in this domain.

<sup>44</sup> Writes Wolpert (1996, p. 1355):

In other words, one can just as readily have a target for which one's algorithm has *worse than random guessing* as one in which it performs better than random. The pitfall we wish to avoid in supervised learning is not simply that our algorithm performs as poorly as random guessing, but rather that our algorithm performs worse than randomly!

Now you may use these newly found rules to solve these classes of problems routinely, but of course this exercise is no longer seriously innovative. As I said before, discovery of efficient problem-solving methods is the *product* of innovation and not the original source and explanation of those problem solutions. The problem solutions are streamlined and methodized as the final stage of the discovery process, as it were. Meanwhile, research goes on at the frontier of the problem domain, where new problems remain unsolved. And here the conditions of the previous paragraph obtain: you can only proceed (more or less) blindly. Typically, your domain knowledge will place constraints on the candidates you generate, but, beyond that, you must grope for a promising solution. In the domain of mechanical problems, for example, it would be crazy to keep generating solution candidates that violate conservation of energy or momentum, once those principles become known. To take another sort of example, a systematic scan of a domain (e.g. a woodchuck scanning the horizon) requires domain knowledge in order for the scan to be systematic. In general, the more domain knowledge available, the more constrained or 'biased' the variation and selection mechanisms can be.

With reference to (9), a *consequentialist* methodology of innovation or discovery is one that proceeds by *post hoc* or consequential testing.<sup>45</sup> The old H-D method of science is an example: propose a solution and then check it by deriving testable consequences from it. Insofar as the solution goes beyond any previous knowledge and hence any epistemically justified selection criterion, it is selected solely on the basis of the success of its logical consequences. By contrast, a *generative* process proceeds from premises to novel conclusions and can, in principle, be deductive. However, if the universal evolutionists are correct, then even the process of finding deductive arguments to novel conclusions will involve an element of BV + SR. Nonetheless, this latter case shows that ultimate *justification* can be generative even when first selection or 'discovery' is not. A new deductive proof must be found by a BV + SR process, but, once found, it is, after all, a deductive proof. Finally, it is worth noting that neither a generative nor a consequentialist approach need restrict itself to deductive inferences.

The previous paragraph is misleading insofar as it suggests that inquiry is globally consequentialist, that is, consequentialist 'all the way down'. For domain knowledge that enables us to cut down the size of the search space and/or to select a more efficient learning procedure amounts to a generative contribution to inquiry. The fact that that knowledge itself is a former product of BV + SR does not prevent it from serving a generative role in the current stage of inquiry.

<sup>45</sup> For further discussion of consequentialist and generative methodologies, see Laudan (1980) and Nickles (1987).

With reference to (13), Campbell always insisted that blind search is not the same as purely random search.

It is important to realize that there are zillions of actual and possible BV + SR procedures available. The class of these processes or learning rules is not at all restricted to the one or relatively few operative in biological evolution. Depending on the kinds of individuals and populations one is considering, there are any number of different possible mechanisms of variation, selection, and transmission. So here, as elsewhere, the wise choice of particular learning rule will depend upon domain knowledge.

David Fogel, one of the leading researchers in evolutionary computing, applies the NFL results to his field thus:

[The NFL theorem shows that] there is no best algorithm, whether or not that algorithm is 'evolutionary', and moreover whatever an algorithm gains in performance on one class of problems is necessarily offset by that algorithm's performance on the remaining problems.

This simple theorem has engendered a great deal of controversy in the field of evolutionary computation, and some associated misunderstanding. There has been considerable effort expended in finding the 'best' set of parameters and operators for evolutionary algorithms since at least the mid-1970s. These efforts have involved the type of recombination, the probabilities for crossover and mutation, the representation, the population's size, and so forth. Most of this research has involved empirical trials on benchmark functions. But the no free lunch theorem essentially dictates that the conclusions made on the basis of such sampling are in the strict mathematical sense limited to only those functions studied. Efforts to find the best crossover rate, the best mutation operation, and so forth, in the absence of restricting attention to a particular class of problems are pointless.

For an algorithm to perform better than even random search (which is simply another algorithm) it must reflect something about the structure of the problem it faces. By consequence, it mismatches the structure of some other problem. Note too that it is not enough to simply identify that a problem has some specific structure associated with it: that structure must be appropriate to the algorithm at hand. Moreover, the structure must be specific (Fogel, 1999, p. 56).

Fogel notes that this result contradicts much conventional practice in evolutionary computing. Numerous investigators have sought general results as to which types of representations or codings of individuals in a population and which types and specific values of variation, selection, and heritability operators are more efficient than others. While specific claims of this sort

may still hold, they are false if made completely general.

In sum, the NFL theorems sharpen the intuitive remarks of Hume, Wittgenstein, and Carnap. Insofar as we possess relevant domain knowledge, a more restricted selection of BV + SR procedures is possible; but as long as there are important, unsolved problems beyond the limits of current domain knowledge, we can only proceed blindly. Here we may apply Hume's so-called method of challenge: If you remain unconvinced that we must resort to BV + SR procedures at the frontier of research, then, pray tell, what alternative procedure is there, and how do you justify it?

Having touted knowledge-based inquiry in the last two sections, a word of caution is in order. It is possible that our perspective may change as faster machines and machines of different architectures (e.g. parallel machines and neural networks) become readily available. For example, John Koza and associates (Koza et al., 1999) are developing, with some success, genetic programs capable of solving problems that are given as high-level problem descriptions without explicit instruction as to how to go about solving them. Their aim is to realize the dream of 'getting a computer to do what needs to be done without telling it how to do it'. Such a method would be pretty general and not knowledge-intensive in the way that knowledge-based computation is. The ratio of intelligence-out to intelligence-in would be quite high, by contrast with most knowledge-based computation. In a sense the machine is self-programming. If this sort of research program succeeds, it reopens the possibility of a more general problem-solving method. (See Nickles, forthcoming, for further discussion of this idea.) For the purposes of this chapter it is important to note that Koza's approach is inspired by Darwinian evolution. Basically, he breeds populations of computer programs and tests the individuals of each generational cohort for fitness as defined by the problem to be solved. His approach is therefore highly representational, since computer programs are symbolic structures. However, like biological evolution, the artificial evolutionary computation is, in a sense, parallel and distributed. Other investigators are pursuing nonrepresentational, subconceptual sorts of computation using neural nets.

### Some Objections Considered: From Impossible to (Almost) Necessary

The BV + SR thesis has a peculiar status in discussion today. Many investigators still consider it an absurdly impossible mode of innovation, or at the very least hugely inefficient compared to the techniques that scientists, artists, *et alia* actually employ in their creative work. This is the 'monkeys at typewriters' family of objections. At the other extreme, some critics consider the thesis trivial or even tautologous. Here I can respond only briefly to a few of the more frequent

objections. Additional responses can be found in Nickles (forthcoming).

*1. The BV+SR thesis is trivial, even tautologous, a priori true. Hence, it cannot explain anything. For it follows from the very meanings of the key words that any attempt to go beyond present knowledge must proceed blindly. How else could it possibly proceed? By your own account nonnaturalistic modes of inquiry are incoherent insofar as they claim to avoid BV+SR. And you claim that the Meno problem itself virtually requires a BV+SR solution, as do the NFL theorems under conditions of ignorance.*

The thesis has surprisingly far-ranging philosophical, scientific, and policy consequences, as Campbell and Dennett, among others, have shown. So it can hardly be trivial. Nor is it tautologous or a priori true. I do claim that today broadly Darwinian selectionist processes are the only viable account we have, but the future remains open. After all, 'no design without an intelligent designer' seemed virtually tautologous until Darwin came along. It remains to be seen whether present-day and future competitors to the adaptationist program in evolutionary biology—and their analogues for wider selection theory—can seriously complement or (in some cases) replace selectionist models. The argument that, at the frontier of research, trial and error is unavoidable at least provides strong heuristic motivation for the selectionist-adaptationist program.

Tautologies do have the merit of being true, and some have the merit of being useful, even in a creative context. (After all, the Gödel theorems are just logic!) But is the BV+SR claim really tautologous? If it is, then its denial is logically false, and so are alternatives such as divine creation, Lamarckianism, and instructionism. (I do believe that these alternatives are false, but not logically false.) In short, as a thoroughly naturalistic account of design, universal Darwinism can hardly be a priori true. Moreover, not all forms of naturalism embrace universal Darwinism, so the thesis is again at risk. And even within evolutionary biology, the adaptationist thesis (according to which, roughly, all adaptive traits were selected because of their contribution to fitness) is subject to empirical challenge. So here are three levels at which universal BV+SR is at risk.<sup>46</sup>

*2. On the contrary, the universal evolution thesis is absurdly wrong. We can easily provide an alternative model of innovation, namely intelligent design. Scien-*

*tists and other inquirers can often use methods far more powerful than blind trial and error. The human design model is both familiar and conveys intuitive understanding. Paley's explanation of the origin of the watch found on the heath was exactly right. In similar terms we explain the invention and development of the automobile, the airplane, television, and scientific theories. Such explanations are far more plausible and explanatory than appeals to blind chance.*

This is basically the reply that creation theorists and religious intelligent design theorists give to biological evolutionists (e.g. Dembski, 1998, 2001). The reply assumes that we well understand the springs of innovation and that they lie in deliberate, intelligent design. The view I have defended holds, quite to the contrary, that we still possess a very poor understanding of creativity and that the intelligent design model (no design without an intelligent designer possessing at least as much intelligence as that incorporated in the design) is both question-begging and hopelessly unscientific. In this case, familiarity with the God-design story breeds intellectual laziness. I claim that when we look closely at any genuinely innovative design, we discover a design history consisting of step-by-step modifications and recombinations of previously extant designs. It is not for nothing that the first automobiles resembled horse buggies. Moreover, at each stage we typically find a lot of trial and error search for suitable modifications in order to solve some problem or other. That story can certainly be told for the design of Paley's watches. As Campbell suggests, the human design model suppresses its evolutionary past.

*3. But the previous objection is not just a 'religious' objection. Don't scientists and engineers and other innovators often use problem-solving methods far more powerful than trial and error? Don't artists sometimes carefully design their work?*

Of course they do. Once we learn how to solve a class of problems, their solution can often be reduced to routine, a process that is often automated. However, such efforts only provide streamlined ways to solve problems that we can already solve. As such, they can support further research and routinized components of larger design projects, but they themselves do not produce novel design. It is also normally the case that searches for novel solutions are *directed* to some degree. Sometimes they are highly direct or constrained. That is the whole point about the importance of relevant domain knowledge and constrained generation. Nevertheless, constrained search is still search and, to that degree, blind. Campbell (1974a) provides an elaborate discussion under the head of a 'nested hierarchy of vicarious selectors'. No one claims that inquiry in a typical scientific or artistic or

<sup>46</sup> For further discussion of the a priori issue, see Gamble (1983). For the adaptationist controversy, see Sober (2000, ch. 5). A universal Darwinist need not be an extreme adaptationist, I think, and can allow design features that are by-products of other adaptive processes; but the issues become sticky here.

administrative problem situation is so completely lacking in constraints that any and every candidate solution, however crazy, must be considered. No one denies that routine problem-solving is helpful in many design tasks, only that it does not suffice for genuinely novel design. As noted above, the BV + SR model does call attention to the importance of heuristic appraisal of variants—better than chance ways of deciding which candidates are worth pursuing. This is a topic sadly neglected by traditional confirmation theory in philosophy of science (Nickles, 1989).

*4. Changing the representation of a problem can sometimes render a difficult problem easily solvable. There are also other ways of reducing a challenging problem to one that is already familiar. Are not these cases counterexamples to the BV + SR thesis?*

Interesting question, but no; for we must first *search* for an alternative problem representation or a reduction technique. Again, every problem representation has its own evolutionary history. It is hitting upon a representation that makes the problem easily solvable that produces many ‘aha’ experiences, which are themselves Meno recognition events.

*5. Some discoveries are purely deductive and thus do not involve BV + SR.*

There are two points to this reply. First, the discovery of a genuinely innovative proof is not a matter of simple, routine deduction, else much of mathematics would be trivial. On the contrary, some results are totally unexpected: e.g. the (relative) consistency of non-Euclidean geometry, Gödel’s theorems. Dieterich (1986, p. 12) and Cherniak (1986) rightly reject defining the knowledge of an agent in terms of the deductive closure of everything the agent knows. Simon & Lea (1979, p. 26) write:

(F)rom a logical standpoint the processes involved in problem-solving are inductive, not deductive. To be sure, the proof of a theorem in a formal mathematical or logical system (such as Logic Theorist) is a deductive object; that is to say, the theorem stands in a deductive relation to its premises. But the problem-solving task is to discover this deduction, this proof; and the discovery process, which is the problem-solving process, is wholly inductive in nature. It is a search through a large space of logic expressions for the goal expression—the theorem.

Any program that requires genuine search, any program that includes any genuine test operations, such as generate-and-test, has an element of BV + SR

(although not necessarily evolutionary BV + SR in the full-blooded sense). Hence, contrary to appearances, Campbell’s BV + SR thesis is not incompatible with Simon’s work.

Second, we cannot take even deductive reasoning as an innate, God-given human ability that needs no further explanation. At the microcognitive level, various naturalistic theorists treat recognizing deductive structures of even a routine sort as a matter of pattern matching, that is, trial-and-error fitting, much of which occurs at the subconscious level (Johnson-Laird & Byrne, 1991; Margolis, 1987).

*6. Nowadays, Biblical creationists as well as intelligent design theorists often grant that some evolution has occurred but insist that it is microevolution rather than macroevolution, that is, adaptation within a species rather than the emergence of entirely new species. They therefore reject Darwinian claims for the immense creative power of BV + SR processes. How do we know that evolutionary computation can get beyond microevolution, so to speak, to produce genuinely novel epistemic designs?*

This is an important question. We cannot really know until more results are in. However, there are reasons for optimism. How else could we have done it in the past than by implicitly implementing an evolutionary process? I believe that evolutionary biologists have an adequate answer to the biological objection. Moreover, human cultural BV + SR processes can be much more rapid than biological ones. For example, we humans can identify and study the errors of our trial and error processes in order to learn the reasons for failure. We can learn from our mistakes more directly than biological nature can, where mistakes are simply eliminated from the population of the next generation. In nature, roughly speaking, learning or creative problem-solving becomes a matter of sex and death (Sterelny & Griffiths, 1999). In addition, our design failures are not fatal. We can make modifications that are seriously deleterious without totally losing that line of development to extinction. In terms of fitness landscapes, we are therefore able to descend from a local maximum through a valley in order to reach a higher peak. Also, we are not restricted to a branching tree structure of design, corresponding exactly to biological speciation. In effect, we can combine good ideas from different branches into a single new design. With the advent of fast, parallel computational possibilities we are also beginning to catch up with nature’s ability to try out huge populations of variants at once.

Notice that even microevolution refutes the *old* model of design, according to which you cannot get

more design from less.<sup>47</sup> So there can no longer be the same, principled objection to macroevolution.

*7. The Meno problem of inquiry, as you characterize it, is so abstract and artificial that it fails to fit scientific and artistic practice. Specifically, all inquiry begins from a problem, and to have a problem at all is to have some idea of what would count as a solution. So we are never in a position of having to go from zero knowledge to some knowledge, completely blindly.*

Correct, but this point does not threaten the BV + SR thesis. As long as we do not currently know how to solve a problem, we can only proceed blindly. We are at a ‘personal frontier’ (or at a frontier for the whole scientific community) as far as usable knowledge is concerned. A well-formulated problem already incorporates knowledge, or design, and that knowledge itself could have grown out of ignorance only on the basis of prior applications of BV + SR. The history of every well-formulated problem will *also* be an evolutionary history.

There are, of course, larger issues here that I can only mention. One is the origins problem. How did inquiry begin, so to speak? And how could BV + SR methods apply there? (Compare the problem of origins in evolutionary biology, a problem that Darwin himself sidestepped.) This brings us to a second issue. Biological nature is frequently and fruitfully considered, metaphorically, as a problem-solver. But here the variation and selection and transmission mechanisms are not, of course, ‘known’ to the creative agency. Rather, they are implicit in nature itself. Again, learning or creative problem-solving becomes a matter of sex and death. Much more remains to be said about bridging these different ways of considering creative problem-formulating and -solving.

*8. In many cases, for problems at the furthest frontier of research or problems that have been posed but are not yet really on the research agenda, we may have no domain knowledge and hence have to use blind search as a ‘method’. However, many of these problems do in fact have sufficient structure, or belong to a sufficiently structured domain, that a stronger method will be far more efficient.*

Yes, but without our domain knowledge we do not know which methods these are or how to recognize and

<sup>47</sup> A slight qualification is in order. Paley and company did not claim that small chance combinations in nature are absolutely impossible, although they would not have considered these productive of genuine design. But for them it was overwhelmingly improbable that you could get even complex *apparent* designs by chance. In other words, complex apparent designs are almost certainly *genuine* designs and hence (by definition of ‘genuine design’) the work of an intelligent designer.

apply them even should we hit upon them by accident. We can only search for these methods randomly at this point, namely, by learning more about the domain itself. So we are back to square one. It is important not to confuse the mathematical existence of a rule with our knowledge of it. The point of scientific inquiry, after all, is to find the strongest rules we can for a domain. But inquiry means bootstrapping our way to those rules from a condition of relative ignorance.

*9. The NFL theorems imply that if an algorithm works better than average over one domain of problems, then its performance must be worse than average over another. Remarks Wolpert (1996, p. 1362), “There are just as many priors (prior probabilities) for which your favorite algorithm performs worse than pure randomness as for which it performs better”. Doesn’t this mean that there are domains in which no particular BV + SR procedure works well?*

Yes, but this consequence does not undercut the BV + SR thesis. Campbell and other universal Darwinists do not claim that BV + SR will always work. There are possible domains in which *nothing* will work in the sense of finding humanly intelligible scientific results. Nor is it Campbell’s claim that a BV + SR is always, or ever, optimal, objectively speaking. The claim is that, in a condition of ignorance, we have nothing better to go on than some BV + SR process or other.

*10. In a completely ‘cracked’ Humean universe, learning is impossible. There it does seem plausible that no learning rule is better than any other. But we know that our universe is not like that. So why must we take seriously the NFL theorems?*

Knowing that our *universe* is ‘not like that’ provides some empirical knowledge about our universe, but this does not automatically carry over to every domain that we happen to define. Such general knowledge should not be confused with domain-specific knowledge. As Wolpert and Fogel say, in the passages quoted in Section 7, the choice of an efficient learning rule must match the structure of that particular domain. One large-scale example is the familiar lesson that it is not a good idea to model all other sciences on physics. Early investigators assumed not only that the world is lawfully ‘connected’ but also that it is connected everywhere just like simple mechanics. One cannot take for granted the existence of coherent domains of phenomena or problems that call for a unified treatment. They, too, have their evolutionary histories (Shapere, 1974). Think how much effort it took to determine the state variables of physical and chemical systems.

*11. In a condition of minimal domain knowledge, no learning rule is justified. Therefore, no particular version of BV + SR is justified either. So how can*

*Campbell's BV+SR thesis be true? For choosing a non-BV+SR rule is equally justified.*

To be sure, one can choose a non-BV+SR rule, but, in a state of ignorance, one is then choosing blindly at the rules level, the meta-level, so to speak. Thus one is still resorting to trial and error, to some form of BV+SR.

*12. Artificial intelligence experts discuss the weaknesses and the limits of genetic algorithms. How is that possible if the BV+SR thesis is correct?*

These experts are (or should be) discussing the comparative strength of algorithms, their optimality, dominance characteristics, and so on for specific domains. Campbell's thesis claims neither that BV+SR rules are generally stronger than others nor that any particular BV+SR rule is universally useful.

*13. If BV+SR underlies all innovative design, then why so much resistance to the idea, including resistance among scientists and AI experts as well as the general public?*

Ignorance, Madam! This objection had more intuitive punch a decade or two ago, before the present boom in evolutionary computing. Resistance can be largely explained in the usual ways: reluctance to give up comfortable, traditional views; failure to think critically about them; and exaggerating the degree of blindness and chance in evolutionary processes while neglecting their cumulative nature. BV+SR advocates do not say that major innovations come in one big, improbable, chance occurrence. This is the counterpart to the wrongheaded creationist objections to biological evolution—that evolution equates the appearance of organisms with an explosion in a print shop producing the works of Shakespeare, or a hurricane blowing through a junkyard and producing a Boeing 747. On the contrary, BV+SR advocates are gradualists, step-by-step evolutionists, in which later steps build upon earlier ones. Big, greedy jumps are more characteristic of the romantic model of innovation.

### Conclusion

Plato's Meno paradox concludes that genuine learning and (by extension) innovation are *impossible*. Darwin and his successors, however, argue convincingly that, when the relevant conditions are satisfied (blind variation plus selective retention in a stable environment with selection pressures), then evolution is *inevitable*. Campbell and others contend, in effect, that the conditions for evolutionary adaptation *are*, in fact, satisfied in many problem contexts, including all of those in which genuine learning or innovation occurs, and that learning and innovation (the introduction of novel design) can therefore be regarded as adaptation. Conversely, all adaptations can be considered knowledge (often implicit knowledge). As Holland (1995,

p. 31) puts the crucial point, "Perpetual novelty is the hallmark of complex adaptive systems". Short of destroying the system, we cannot prevent novel developments even if we want to (e.g. mutating viruses and bacteria, and attempts to 'fix' permanently a natural language such as French).

So the Meno problem is solved by a quasi-biological process of emergence of novel variants from predecessors in the genealogy. BV+SR is the only way we know to produce more design from less, the only way we know to produce genuine innovation. Although I cannot pretend to have offered a complete defense of that claim here, it does appear that an intelligent design model, whether theological or secular (as in appeals to 'the scientific method' in place of God), cannot, by itself, explain how innovation is possible. Thus we must be very careful how we describe the work of highly creative individuals working at an investigative frontier.

Following Campbell and company, I do *not* claim that unconstrained BV+SR is the source of all innovative design. Hence, I do not claim that adaptations are solely the product of BV+SR. Physical constraints are always operative, and perhaps the physical systems are sometimes self-organizing to some degree. However, insofar as there is cumulative BV+SR at all (and there always is at the frontier of innovation), then it makes sense to speak of adaptation.

My chapter explains and defends this BV+SR thesis with some qualifications. I have tried to meet some leading objections to the thesis without pretending to survey all possible modes of innovation. In particular, I have given little attention to biological processes themselves. To extend the discussion to those areas would require modifying some of my talk about domain knowledge and ignorance, e.g. to speaking instead of variations on a given biological platform. Nor have I investigated the sources of BV+SR other than to make some casual remarks about the noise introduced by linguistic slack, misinterpretation, and historical contingencies. These sources surely include situational and social-contextual as well as individual factors. I have also assumed, without much argument, that learning and innovation amount to bringing novel design into the world.

One point with which Campbell would surely have agreed is that not all BV+SR processes are evolutionary in the full sense (although they are still fully naturalistic). He is less likely to have agreed with my claim that trial and error processes, with their corresponding elements of chance and luck, should be considered *methods* or learning rules rather than signaling the complete absence of method; but such a view is now standard in evolutionary computing. More generally, BV+SR, and full evolutionary BV+SR, when available, can be considered a methodological

shell or family of shells that yield usable methods when the variation, selection, and retention mechanisms are specified in concrete contexts (Nickles, forthcoming). After all, if philosophers count the so-called hypothetico-deductive method as a method, how can they refuse the label to BV + SR?

In addition, I have argued that the NFL theorems support the BV + SR thesis, given that, at the frontier of research, we lack relevant domain knowledge to justify some non-BV + SR rule. BV + SR is the default position in the absence of domain knowledge. Typically, more than one BV + SR process will be available, but it is important to remember that the *warranted* use even of a particular BV + SR rule requires domain knowledge. The NFL theorems may be regarded as formal articulations of Humean intuitions.

And I have shown why the fact that BV + SR rules are not often, or even usually, the most efficient rules for a given domain does not undercut the BV + SR thesis. Campbell's thesis does not assert that BV + SR processes are optimal in some objective sense, and certainly not for routine problem-solving; but rather that they are the *only* procedures available at the frontier of innovation, given our ignorance of what lies beyond. Thus articles such as Baum et al. (2001), while certainly interesting, are not relevant, one way or the other, to the fate of the BV + SR thesis.

Overall, the chapter supports the claim that innovation is better considered a selective-adaptive process than a theorem-proving process or a rational planning or human design process in the traditional sense. Application of this point to human contexts places more emphasis on innovative communities, their traditions and practices, than upon individual creative 'geniuses'. The human design model is not completely wrong, of course, but it turns out to rest on previous applications of BV + SR. Hence the difficult and ironic historical intellectual reversal: when it comes to genuine innovation, BV + SR is the *first* resort rather than the last resort. Not only *can* there be novel, intelligent design without a prescient, intelligent designer, but also we have no other defensible account of it!

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# The Three-Ring Conception of Giftedness: Its Implications for Understanding the Nature of Innovation

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**Abstract:** The Three-Ring Conception of Giftedness focuses on creative/innovative productivity, which differs from schoolhouse or lesson-learning giftedness. Giftedness that leads to innovation emerges from the interaction and overlap of three clusters of traits—well above average ability in a particular domain, task commitment, and creativity—and occurs in certain individuals, at certain times, under certain conditions. A broader conception of giftedness will allow researchers, theorists, and educators to more fully address, answer, and respond to the most pressing questions about where innovation ‘comes from’. Simultaneously, this model, when applied, will assist in the development of individuals most capable of engaging in innovation and improving the quality of life for society.

**Keywords:** Innovation; Gifted; Creativity; Motivation; Task commitment

## Introduction

The age-old issue of ‘what makes giftedness’ and how the contributions of gifted individuals have helped us understand the nature of innovation has been debated by scholars for decades. In the past 20 years, a renewed interest has emerged on this topic. This chapter will attempt to shed some light on this complex and controversial question by describing a broad range of theoretical issues and research studies that have been associated with the study of gifted, talented, and innovative persons. Although the information reported here draws heavily on the theoretical and research literature, it is written from the point of view of an educational practitioner who respects both theory and research, but who also has devoted a major amount of his efforts to translating these types of information into what he believes to be defensible identification and programming practices. Those in the position of offering advice to school systems that are faced with the reality of identifying and serving highly able students must also provide the types of underlying research that lend credibility to their advice. Accordingly, this chapter might be considered a theoretical and research rationale for two separate publications that describe a plan for identifying and programming

for gifted and talented students (Renzulli, 2000; Renzulli & Reis, 1997).

This chapter attempts to show a connection between the development of giftedness in young people and the ways in which gifted behaviors influence the process of innovation. Innovation is defined as original, solution-oriented *actions* that address previously unsolved problems in unique and creative ways. ‘Action’ is emphasized because innovation requires that the innovator will *do something* that leads to development or improvement of a product or process rather than merely thinking about or contemplating that product or process. The chapter is divided into three sections. The first section deals with several major issues that might best be described as the enduring questions and sources of controversy in a search for the meaning of giftedness and related attempts to define this concept. It is hoped that a discussion of these issues will establish common points of understanding between the writer and the reader and, at the same time, point out certain biases that are unavoidable whenever one deals with a complex and value-laden topic.

The second section describes a wide range of research studies that support the writer’s ‘three-ring’ conception of giftedness. The section concludes with

an explicit definition and a brief review of research studies that have been carried out in school programs using an identification system based on the three-ring concept. The final section examines a number of questions raised by scholars and practitioners since the time of the original publication (Renzulli, 1978) of this particular approach to a conception of giftedness.

### Issues in the Study of Conceptions of Giftedness

#### *Purposes and Criteria for a Definition of Giftedness*

One of the first and most important issues that should be dealt with in a search for the meaning of giftedness is that there must be a purpose for defining this concept. The goals of science tell us that a primary purpose is to add new knowledge to our understanding about human conditions, but in an applied field of knowledge there is also a practical purpose for defining concepts. Persons who presume to be the writers of definitions should understand the full ramifications of these purposes and recognize the practical and political uses to which their work might be applied. A definition of giftedness is a formal and explicit statement that might eventually become part of official policies or guidelines. Whether or not it is the writer's intent, such statements will undoubtedly be used to direct identification and programming practices, and therefore we must recognize the consequential nature of this purpose and the pivotal role that definitions play in structuring the entire field. Definitions are open to both scholarly and practical scrutiny, and for these reasons it is important that a definition meet the following criteria:

- (1) It must be based on the best available research about the characteristics of gifted individuals rather than romanticized notions or unsupported opinions.
- (2) It must provide guidance in the selection and/or development of instruments and procedures that can be used to design defensible identification systems.
- (3) It must give direction and be logically related to programming practices such as the selection of materials and instructional methods, the selection and training of teachers; and the determination of procedures whereby programs can be evaluated.
- (4) It must be capable of generating research studies that will verify or fail to verify the validity of the definition.

In view of the practical purposes for which a definition might be used, it is necessary to consider any definition in the larger context of overall programming for the target population we are attempting to serve. In other words, the way in which one views giftedness will be a primary factor in both constructing a plan for identification and in providing services that are relevant to the characteristics that brought certain youngsters to our attention in the first place. If, for example, one

identifies giftedness as extremely high mathematical aptitude, then it would seem nothing short of common sense to use assessment procedures that readily identify potential for superior performance in this particular area of ability. And it would be equally reasonable to assume that a program based on this definition and identification procedure should devote major emphasis to the enhancement of performance in mathematics and related areas. Similarly, a definition that emphasizes artistic abilities should point the way toward relatively specific identification and programming practices. As long as there are differences of opinion among reasonable scholars there will never be a single definition of giftedness, and this is probably the way that it should be. But one requirement for which all writers of definitions should be accountable is the necessity of showing a logical relationship between definition on the one hand and recommended identification and programming practices on the other.

#### *Two Kinds of Giftedness*

A second issue that must be dealt with is that our present efforts to define giftedness are based on a long history of previous studies dealing with human abilities. Most of these studies focused mainly on the concept of intelligence and are briefly discussed here to establish an important point about the process of defining concepts rather than any attempt to equate intelligence with giftedness. Although a detailed review of these studies is beyond the scope of the present chapter, a few of the general conclusions from earlier research are necessary to set the stage for this analysis.<sup>1</sup>

The first conclusion is that intelligence is not a unitary concept, but rather there are many kinds of intelligence and therefore single definitions cannot be used to explain this complicated concept. The confusion and inconclusiveness about present theories of intelligence have led Sternberg (1984) and others to develop new models for explaining this complicated concept. Sternberg's 'triarchic' theory of human intelligence consists of three subtheories: a contextual subtheory, which relates intelligence to the external world of the individual; a two-facet subtheory, which relates intelligence to both the external and internal worlds of the individual; and a componential subtheory, which relates intelligence to the internal world of the individual. The contextual subtheory defines intelligent behavior in terms of purposive adaptation to, selection of, and shaping of real-world environments relevant to one's life. The two-facet subtheory further constrains this definition by regarding as most relevant to the demonstration of intelligence contextually intelligent behavior that involves adaptation to novelty or

<sup>1</sup> Persons interested in a succinct examination of problems associated with defining intelligence are advised to review 'The Concept of Intelligence' (Neisser, 1979).

automatization of information processing, or both. The componential subtheory specifies the mental mechanisms responsible for the learning, planning, execution, and evaluation of intelligent behavior.

In view of this work and numerous earlier cautions about the dangers of trying to describe intelligence through the use of single scores, it seems safe to conclude that this practice has been and always will be questionable. At the very least, attributes of intelligent behavior must be considered within the context of cultural and situational factors. Indeed, some examinations have concluded that “(t)he concept of intelligence *cannot* be explicitly defined, not only because of the nature of intelligence but also because of the nature of concepts” (Neisser, 1979, p. 179).

A second conclusion is that there is no ideal way to measure intelligence, and therefore we must avoid the typical practice of believing that if we know a person’s IQ score, we also know his or her intelligence. Even Terman warned against total reliance on tests: “We must guard against defining intelligence solely in terms of ability to pass the tests of a given intelligence scale” (1921, p. 131). E. L. Thorndike echoed Terman’s concern by stating, “to assume that we have measured some general power which resides in (the person being tested) and determines his ability in every variety of intellectual task in its entirety is to fly directly in the face of all that is known about the organization of the intellect” (Thorndike, 1921, p. 126).

The reason I have cited these concerns about the historical difficulty of defining and measuring intelligence is to highlight the even larger problem of isolating a unitary definition of giftedness. At the very least we will always have several conceptions (and therefore definitions) of giftedness; but it will help in this analysis to begin by examining two broad categories that have been dealt with in the research literature. I will refer to the first category as ‘schoolhouse giftedness’ and to the second as ‘innovative giftedness’. Before going on to describe each type, I want to emphasize that:

- (1) Both types are important.
- (2) There is usually an interaction between the two types.
- (3) Special programs should make appropriate provisions for encouraging both types of giftedness as well as the numerous occasions when the two types interact with each other.

#### *Schoolhouse Giftedness*

Schoolhouse giftedness might also be called test-taking or lesson-learning giftedness. It is the kind most easily measured by IQ or other cognitive ability tests, and for this reason it is also the type most often used for selecting students for entrance into special programs. The abilities people display on IQ and aptitude tests are exactly the kinds of abilities most valued in traditional

school learning situations. In other words, the games people play on ability tests are similar in nature to games that teachers require in most lesson-learning situations. Research tells us that students who score high on IQ tests are also likely to get high grades in school. Research also has shown that these test-taking and lesson-learning abilities generally remain stable over time. The results of this research should lead us to some very obvious conclusions about schoolhouse giftedness: it exists in varying degrees; it can be identified through standardized assessment techniques; and we should therefore do everything in our power to make appropriate modifications for students who have the ability to cover regular curricular material at advanced rates and levels of understanding. Curriculum compacting (Renzulli, Smith & Reis, 1982), a procedure used for modifying curricular content to accommodate advanced learners, and other acceleration techniques should represent an essential part of any school program that strives to respect the individual differences that are clearly evident from scores yielded by cognitive ability tests.

Although there is a generally positive correlation between IQ scores and school grades, we should not conclude that test scores are the only factors that contribute to success in school. Because IQ scores correlate only from 0.40 to 0.60 with school grades, they account for only 16%–36% of the variance in these indicators of potential. Many youngsters who are moderately below the traditional 3–5% test score cutoff levels for entrance into gifted programs clearly have shown that they can do advanced-level work. Indeed, most of the students in the nation’s major universities and 4-year colleges come from the top 20% of the general population (rather than just the top 3–5%) and Jones (1982) reported that a majority of college graduates in every scientific field of study had IQs between 110 and 120. Are we ‘making sense’ when we exclude such students from access to special services? To deny them this opportunity would be analogous to *forbidding* a youngster from trying out for a basketball team because he or she missed a predetermined ‘cutoff height’ by a few inches! Basketball coaches are not foolish enough to establish *inflexible* cutoff heights because they know that such an arbitrary practice would cause them to overlook the talents of youngsters who may overcome slight limitations in inches with other abilities such as drive, speed, teamwork, ball-handling skills, and perhaps even the ability and motivation to outjump taller persons who are trying out for the team. As educators of gifted and talented youth, we can undoubtedly take a few lessons about flexibility from coaches!

#### *Innovative Giftedness*

If scores on IQ tests and other measures of cognitive ability only account for a limited proportion of the common variance with school grades, we can be

equally certain that these measures do not tell the whole story when it comes to making predictions about innovative giftedness. Before defending this assertion with some research findings, let us briefly review what is meant by this second type of giftedness, the important role that it should play in programming, and, therefore, the reasons we should attempt to assess it in our identification procedures—even if such assessment causes us to look below the top 3–5% on the normal curve of IQ scores.

Innovative giftedness describes those aspects of human activity and involvement where a premium is placed on the development of original material and products that are purposefully designed to have an impact on one or more target audiences. Learning situations that are designed to promote innovative giftedness emphasize the use and application of information (content) and thinking processes in an integrated, inductive, and real-problem-oriented manner. The role of the student is transformed from that of a learner of prescribed lessons to one in which she or he uses the modus operandi of a firsthand inquirer. This approach is quite different from the development of lesson-learning giftedness that tends to emphasize deductive learning, structured training in the development of thinking processes, and the acquisition, storage, and retrieval of information. In other words, innovative giftedness is simply putting one's abilities to work on problems and areas of study that have personal relevance to the student and that can be escalated to appropriately challenging levels of investigative activity. The roles that both students and teachers should play in the pursuit of these problems have been described elsewhere (Renzulli, 1982, 1983).

Why is innovative giftedness important enough for us to question the 'tidy' and relatively easy approach that traditionally has been used to select students on the basis of test scores? Why do some people want to rock the boat by challenging a conception of giftedness that can be numerically defined by simply giving a test? The answers to these questions are simple and yet very compelling. The research reviewed in the second section of this chapter tells us that there is much more to the making of a gifted person than the abilities revealed on traditional tests of intelligence, aptitude, and achievement. Furthermore, history tells us it has been the innovative and productive people of the world, the producers rather than consumers of knowledge, the reconstructionists of thought in all areas of human endeavor, who have become recognized as 'truly gifted' individuals. History does not remember persons who merely scored well on IQ tests or those who learned their lessons well.

#### *The Development of Potential Innovations*

Implicit in any efforts to define and identify gifted youth is the assumption that we will 'do something' to provide various types of specialized learning experi-

ences that show promise of promoting the development of characteristics implicit in the definition. In other words, the *why* question supersedes the *who* and *how* questions. Although there are two generally accepted purposes for providing special education for the gifted, I believe that these two purposes in combination give rise to a third purpose that is intimately related to the definition question.

The first purpose of gifted education<sup>2</sup> is to provide young people with maximum opportunities for self-fulfillment through the development and expression of one or a combination of performance areas where superior potential may be present.

The second purpose is to increase society's supply of persons who will help to solve the problems of contemporary civilization by becoming innovators and producers of knowledge and art rather than mere consumers of existing information.

We value innovators, as opposed to replicators, because they are the persons who go beyond our current levels of knowledge and understanding to bring forth new ideas, questions, solutions to problems, and new products and services that did not exist prior to their application of the creative process. It is the innovators that, in effect, create thousands of jobs for replicators. One creative idea such as a book, a symphony, a new device or software program for a computer starts the wheels of production turning, thereby creating thousands of jobs in both manufacturing and a host of other areas such as finance, advertising, marketing, packaging, transportation, and sales. Thomas Edison's invention of the storage battery gave rise to an entire industry that still prospers today, and has the added benefit of providing a vehicle for the many innovative modifications and improvement that have been made on this innovative product over the years.

Although there may be some arguments for and against both of the above purposes, most people would agree that goals related to self-fulfillment and/or societal contributions are generally consistent with democratic philosophies of education. What is even more important is that the two goals are highly interactive and mutually supportive of each other. In other words, the self-satisfying work of scientists, artists, and leaders in all walks of life usually produces results that might be valuable contributions to society. Carrying this point one step farther, we might even conclude that appropriate kinds of learning experiences can and should be engineered to achieve the twofold goals described above. Keeping in mind the interaction of these two goals, and the priority status of the self-fulfillment goal, it is safe to conclude that supplementary investments of public funds and systematic

<sup>2</sup> The term *gifted education* will be used in substitution for the more technically accurate but somewhat awkward term *education of the gifted*.

effort for highly able youth should be expected to produce at least some results geared toward the public good. If, as Gowan (1978) has pointed out, the purpose of gifted programs is to increase the size of society's reservoir of potentially innovative and productive adults, then the argument for gifted education programs that focus on creative productivity (rather than lesson-learning giftedness) is a very simple one. If we agree with the goals of gifted education set forth earlier in the chapter, and if we believe that our programs should produce the next generation of leaders, problem-solvers, and persons who will make important contributions to the arts and sciences, then does it not make good sense to model our training programs after the *modus operandi* of these persons rather than after those of the lesson learner? This is especially true because research (as described later in the chapter) tells us that the most efficient lesson learners are not necessarily those persons who go on to make important contributions in the realm of creative productivity. And in this day and age, when knowledge is expanding at almost geometric proportions, it would seem wise to consider a model that focuses on how our most able students access and make use of information rather than merely on how they accumulate and store it.

In other words, innovation almost always takes place in context—in part because of innovation's close association with creativity, which is integrally related to context (Sternberg, Pretz & Kaufman, in press). A person is not always innovative or never innovative. Innovation occurs in certain people (not all people), at certain times (not all the time), and under certain circumstances. To be certain, there are some people who have long and continuous records of creative productivity, but there are others for whom lightning strikes only once! So while we celebrate the monumental record of more than 2000 patents by Edison, we also recognize the singular contribution of *Gone With the Wind* by Margaret Mitchell. The key issue for educators is creating the context that nurtures innovation. By providing young people with opportunities, resources, and encouragement *within their existing or developing areas of interest*, and by helping them experience the joys and rewards of creative productivity, we create a contextual environment that, for some people, will become a lifestyle. It is these people who usually gravitate toward the innovative rather than replicative roles in their respective professions—the medical research scientist rather than the medical practitioner, the fashion designer rather than the person who produces the garments. Both roles (innovator and replicator) are highly valued and necessary for progress in any field, but the trigger for any and all productivity is the one pulled by the innovator.

#### *The Gifted and the Potentially Gifted*

A further issue relates to the subtle but very important distinction that exists between the 'gifted' and the

'potentially gifted'. Most of the research reviewed later in the chapter deals with student and adult populations whose members have been judged (by one or more criteria) to be gifted. In most cases, researchers have studied those who have been identified as 'being gifted' much more intensively than they have studied persons who were not recognized or selected because of unusual accomplishments. The general approach to the study of gifted persons could easily lead the casual reader to believe that giftedness is a condition that is magically bestowed on a person in much the same way that nature endows us with blue eyes, red hair, or a dark complexion. This position is *not* supported by the research. Rather, what the research clearly and unequivocally tells us is that *giftedness can be developed* in some people if an appropriate interaction takes place between a person, his or her environment, and a particular area of human endeavor.

It should be kept in mind that when I describe, in the paragraphs that follow, a certain trait as being a component of giftedness (for example, creativity), I am in no way assuming that one is 'born with' this trait, even if one happens to possess a high IQ. Almost all human abilities can be developed, and therefore my intent is to call attention to the potentially gifted (that is to say, those who could 'make it' under the right conditions) as well as to those who have been studied because they gained some type of recognition. Implicit in this concept of the potentially gifted, then, is the idea that giftedness emerges or 'comes out' at different times and under different circumstances. Without such an approach there would be no hope whatsoever of identifying bright underachievers, students from disadvantaged backgrounds, or any other special population that is not easily identified through traditional testing procedures.

#### *Are People 'Gifted' or Do They Display Gifted Behaviors?*

A fifth and final issue underlying the search for a definition of giftedness is more nearly a bias and a hope for at least one major change in the ways we view this area of study. Except for certain functional purposes related mainly to professional focal points (i.e. research, training, legislation) and to ease of expression, I believe that a term such as *the gifted* is counterproductive to educational efforts aimed at identification and programming for certain students in the general school population. Rather, it is my hope that in the years ahead we will shift our emphasis from the present concept of 'being gifted' (or not being gifted) to a concern about developing *gifted behaviors* in those youngsters who have the highest potential for benefiting from special education services. This slight shift in terminology might appear to be an exercise in heuristic hairsplitting, but I believe that it has significant implications for the entire way we think about the concept of giftedness and the ways in which we

structure the field for important research endeavors<sup>3</sup> and effective educational programming.

For too many years we have pretended that we can identify gifted children in an absolute and unequivocal fashion. Many people have been led to believe that certain individuals have been endowed with a golden chromosome that makes them 'gifted persons'. This belief has further led to the mistaken idea that all we need to do is find the right combination of factors that prove the existence of this chromosome. The further use of such terms as the 'truly gifted', the 'moderately gifted', and the 'borderline gifted' only serves to confound the issue and might result in further misguided searches for silver and bronze chromosomes. This misuse of the concept of giftedness has given rise to a great deal of confusion and controversy about both identification and programming, and the result has been needless squabbling among professionals in the field. Another result has been that so many mixed messages have been sent to educators and the public at large that both groups now have a justifiable skepticism about the credibility of the gifted education establishment and our ability to offer services that are qualitatively different from general education.

Most of the confusion and controversy surrounding the definition of giftedness can be placed in proper perspective by raising a series of questions that strike right at the heart of key issues related to this area of study. These questions are organized into the following clusters:

- (1) Are giftedness and high IQ one and the same? And if so, how high does one's IQ need to be before one can be considered gifted? If giftedness and high IQ are not the same, what are some of the other characteristics that contribute to the expression of giftedness? Is there any justification for providing selective services for certain students who may fall below a predetermined IQ cutoff score?
- (2) Is giftedness an absolute or a relative concept? That is, is a person either gifted or not gifted (the absolute view) or can varying kinds and degrees of gifted behaviors be displayed in certain people, at certain times, and under certain circumstances (the relative view)? Is gifted a static concept (i.e. you have it or you don't have it) or is it a dynamic concept (i.e. it varies both within persons and within learning-performance situations)?
- (3) What causes only a minuscule number of Thomas Edisons or Langston Hugheses or Isadora Duncans to emerge as innovators, whereas millions of others

with equal 'equipment' and educational advantages (or disadvantages) never rise above mediocrity? Why do some people who have not enjoyed the advantages of special educational opportunities become innovators, whereas others who have gone through the best of educational programming opportunities fail to make an innovative contribution?

In the section that follows, a series of research studies will be reviewed in an effort to answer these questions. Taken collectively, these research studies are the most powerful argument that can be put forth to policymakers who must render important decisions about the regulations and guidelines that will dictate identification practices in their states or local school districts. An examination of this research clearly tells us that gifted behaviors can be developed in those who are not necessarily individuals who earn the highest scores on standardized tests. The two major implications of this research for identification practices are equally clear.

First, an effective identification system must take into consideration other factors in addition to test scores. Research has shown that, in spite of the multiple criterion information gathered in many screening procedures, rigid cutoff scores on IQ or achievement tests are still the main if not the only criterion given *serious* consideration in final selection (Alvino, 1981). When screening information reveals outstanding potential for gifted behaviors, it is almost always 'thrown away' if predetermined cutoff scores are not met. Respect for these other factors means that they must be given equal weight and that we can no longer merely give lip service to non-test criteria; nor can we believe that because tests yield 'numbers' they are inherently more valid and objective than other procedures. As Sternberg (1982a) has pointed out, *quantitative* does not necessarily mean *valid*. When it comes to identification that might lead to the development of innovators, it is far better to include rather than exclude those with the potential for developing innovative ideas and products. In order to create environments that produce innovators, educators could focus on opportunities for students to engage in authentic learning. This brand learning consists of *applying* relevant knowledge, thinking skills, and interpersonal skills to the solution of real problems and what happens in real-world situations. For example, students might focus on their learning activities by addressing these essential questions in any given discipline:

- (1) What do people with an interest in this area do?
- (2) What products do they create and/or what services do they provide?
- (3) What methods do they use to carry out their work?
- (4) What resources and materials are needed to produce high-quality products and services?

<sup>3</sup> For example, most of the research on the 'gifted' that has been carried out to date has used high-IQ populations. If one disagrees (even slightly) with the notion that giftedness and high IQ are synonymous, then these research studies must be reexamined. These studies may tell us a great deal about the characteristics, and so on, of high-IQ individuals, but are they necessarily studies of the gifted?

- (5) How, and with whom, do they communicate the results of their work?
- (6) What steps need to be taken to have an impact on intended audiences?

This type of focus would allow students to build a foundation of knowledge and pursue innovative strategies to solve a real problem. Rather than providing students with answers to these questions, the teacher organizes and guides instruction but does not dominate the exploration process. As the facilitator of situations to foster innovation, the teacher helps students select challenging projects. These activities should be student-driven, with the teacher playing an advisory role. Learning experiences that follow this model will provide for opportunities for students to take creative risks which may lead to the development of innovations.

The second research-based implication will undoubtedly be a major controversy in the field for many years, but it needs to be dealt with if we are ever going to defuse a majority of the criticism that has been justifiably directed at our field. Simply stated, we must reexamine identification procedures that result in a total pre-selection of certain students and the concomitant implication that these young people are and always will be 'gifted'. This absolute approach (i.e. you have it or you don't have it) coupled with the almost total reliance on test scores is not only inconsistent with what the research tells us, but almost arrogant in the assumption that we can use a single one-hour segment of a young person's total being to determine if he or she is 'gifted'.

The alternative to such an absolutist view is that we may have to forgo the 'tidy' and comfortable tradition of 'knowing' on the first day of school who is gifted and who is not gifted. Rather, our orientation must be redirected toward developing 'gifted behaviors' in certain students (not all students), at certain times (not all the time), and under certain circumstances. The tradeoff for tidiness and administrative expediency will result in a much more flexible approach to both identification and programming and a system that not only shows a greater respect for the research on gifted and talented people but is both fairer and more acceptable to other educators and to the general public.

### Research Underlying the Three-Ring Conception of Giftedness

One way of analyzing the research underlying conceptions of giftedness is to review existing definitions along a continuum ranging from conservative to liberal. *Conservative* and *liberal* are used here not in their political connotations but rather according to the degree of restrictiveness that is used in determining who is eligible for special programs and services.

Restrictiveness can be expressed in two ways. First, a definition can limit the number of specific performance areas that are considered in determining eligibility for special programs. A conservative definition, for example, might limit eligibility to academic performance only and exclude other areas such as music, art, drama, leadership, public speaking, social service, and creative writing. Second, a definition can limit the degree or level of excellence that one must attain by establishing extremely high cutoff points.

At the conservative end of the continuum is Terman's (1926) definition of giftedness as 'the top 1% level in general intellectual ability as measured by the Stanford-Binet Intelligence Scale or a comparable instrument' (1926, p. 43).

In this definition, restrictiveness is present in terms of both the type of performance specified (i.e. how well one scores on an intelligence test) and the level of performance one must attain to be considered gifted (top 1%). At the other end of the continuum can be found more liberal definitions, such as the following one by Witty (1958):

There are children whose outstanding potentialities in art, in writing, or in social leadership can be recognized largely by their performance. Hence, we have recommended that the definition of giftedness be expanded and that we consider any child gifted whose performance, in a potentially valuable line of human activity, is consistently remarkable (p. 62).

Although liberal definitions have the obvious advantage of expanding the conception of giftedness, they also open up two 'cans of worms' by introducing a values issue (What are the potentially valuable lines of human activity?) and the age-old problem of subjectivity in measurement.

In recent years the values issue has been largely resolved. There are very few educators who cling tenaciously to a 'straight IQ' or purely academic definition of giftedness. 'Multiple talent' and 'multiple criteria' are almost the bywords of the present-day gifted student movement, and most persons would have little difficulty in accepting a definition that includes almost every area of human activity that manifests itself in a socially useful form of expression.

The problem of subjectivity in measurement is not as easily resolved. As the definition of giftedness is extended beyond those abilities that are clearly reflected in tests of intelligence, achievement, and academic aptitude, it becomes necessary to put less emphasis on precise estimates of performance and potential and more emphasis on the opinions of qualified human judges in making decisions about admission to special programs. The crux of the issue boils down to a simple and yet very important question: How much of a trade-off are we willing to make on the objective-subjective continuum in order to allow recognition of a broader spectrum of human abilities? If

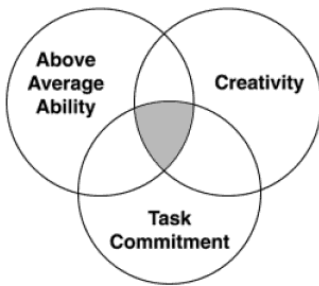


Figure 1. The three-ring conception of giftedness.

some degree of subjectivity cannot be tolerated, then our definition of giftedness and the resulting programs will logically be limited to abilities that can be measured only by objective tests.

### The Three-Ring Conception of Giftedness

Research on innovative people has consistently shown that although no single criterion can be used to determine giftedness, persons who have achieved recognition because of their unique accomplishments and creative contributions possess a relatively well-defined set of three interlocking clusters of traits. These clusters consist of above-average, though not necessarily superior, ability, task commitment, and creativity (see Fig. 1). It is important to point out that no single cluster 'makes giftedness'. Rather, it is the interaction among the three clusters that research has shown to be the necessary ingredient for innovative accomplishment (Renzulli, 1978). This interaction is represented by the shaded portion of Fig. 1. It is also important to point out that each cluster plays an important role in contributing to the display of gifted behaviors. This point is emphasized because one of the major errors that continues to be made in identification procedures is to overemphasize superior abilities at the expense of the other two clusters of traits.

#### Well-Above-Average Ability

Well-above-average ability can be defined in two ways.

*General ability* consists of the capacity to process information, to integrate experiences that result in appropriate and adaptive responses in new situations, and the capacity to engage in abstract thinking. Examples of general ability are verbal and numerical reasoning, spatial relations, memory, and word fluency. These abilities are usually measured by tests of general aptitude or intelligence, and are broadly applicable to a variety of traditional learning situations.

*Specific abilities* consist of the capacity to acquire knowledge, skill, or the ability to perform in one or more activities of a specialized kind and within a restricted range. These abilities are defined in a manner that represents the ways in which human beings express themselves in real-life (i.e. non-test) situations.

Examples of specific abilities are chemistry, ballet, mathematics, musical composition, sculpture, and photography. Each specific ability can be further subdivided into even more specific areas (e.g. portrait photography, astrophotography, photo journalism, etc.). Specific abilities in certain areas such as mathematics and chemistry have a strong relationship with general ability, and, therefore, some indication of potential in these areas can be determined from tests of general aptitude and intelligence. They can also be measured by achievement tests and tests of specific aptitude. Many specific abilities, however, cannot be easily measured by tests, and, therefore, areas such as the arts must be evaluated through one or more performance-based assessment techniques.

Within this model the term *above-average ability* will be used to describe both general and specific abilities. *Above average* should also be interpreted to mean the upper range of potential within any given area. Although it is difficult to assign numerical values to many specific areas of ability, when I refer to 'well above average ability' I clearly have in mind persons who are capable of performance or the potential for performance that is representative of the top 15–20% of any given area of human endeavor.

Although the influence of intelligence, as traditionally measured, quite obviously varies with specific areas of performance, many researchers have found that creative accomplishment is not necessarily a function of measured intelligence. In a review of several research studies dealing with the relationship between academic aptitude tests and professional achievement, Wallach (1976) has concluded that: "Above intermediate score levels, academic skills assessments are found to show so little criterion validity as to be a questionable basis on which to make consequential decisions about students' futures. What the academic tests do predict are the results a person will obtain on other tests of the same kind" (p. 57).

Wallach goes on to point out that academic test scores at the upper ranges—precisely the score levels that are most often used for selecting persons for entrance into special programs—do not necessarily reflect the potential for innovative accomplishment. Wallach suggests that test scores be used to screen out persons who score in the lower ranges and that beyond this point, decisions should be based on other indicators of potential for superior performance.

Numerous research studies support Wallach's findings that there is a limited relationship between test scores and school grades on the one hand, and real-world accomplishments on the other (Bloom, 1963; Harmon, 1963; Helson & Crutchfield, 1979; Hudson, 1960; Mednick, 1963; Parloff et al., 1968; Richards, Holland & Lutz, 1967; Wallach & Wing, 1969). In fact, in a study dealing with the prediction of various dimensions of achievement among college students, Holland & Astin (1962) found that "getting good

grades in college has little connection with more remote and more socially relevant kinds of achievement; indeed, in some colleges, the higher the student's grades, the less likely it is that he is a person with creative potential. So it seems desirable to extend our criteria of talented performance" (pp. 132–133). A study by the American College Testing Program (Munday & Davis, 1974) entitled 'Varieties of Accomplishment After College: Perspectives on the Meaning of Academic Talent', concluded that:

the adult accomplishments were found to be uncorrelated with academic talent, including test scores, high school grades, and college grades. However, the adult accomplishments were related to comparable high school nonacademic (extra curricular) accomplishments. This suggests that there are many kinds of talents related to later success which might be identified and nurtured by educational institutions (p. 2).

The pervasiveness of this general finding is demonstrated by Hoyt (1965), who reviewed 46 studies dealing with the relationship between traditional indications of academic success and postcollege performance in the fields of business, teaching, engineering, medicine, scientific research, and other areas such as the ministry, journalism, government, and miscellaneous professions. From this extensive review, Hoyt concluded that traditional indications of academic success have no more than a very modest correlation with various indicators of success in the adult world and that "There is good reason to believe that academic achievement (knowledge) and other types of educational growth and development are relatively independent of each other" (p. 73).

The experimental studies conducted by Sternberg (1981) and Sternberg & Davidson (1982) added a new dimension to our understanding about the role that intelligence tests should play in making identification decisions. After numerous investigations into the relationship between traditionally measured intelligence and other factors such as problem-solving and insightful solutions to complex problems, Sternberg (1982b) concludes that:

tests only work for some of the people some of the time—not for all of the people all of the time—and that some of the assumptions we make in our use of tests are, at best, correct only for a segment of the tested population, and at worst, correct for none of it. As a result we fail to identify many gifted individuals for whom the assumptions underlying our use of tests are particularly inadequate. The problem, then, is not only that tests are of limited validity for everyone but that their validity varies across individuals. For some people, tests scores may be quite informative, for others such scores may be worse than useless. Use of test score cutoffs and formulas

results in a serious problem of underidentification of gifted children (p. 157).

The studies raise some basic questions about the use of tests as a major criterion for making selection decisions. The research reported above clearly indicates that vast numbers *and* proportions of our most productive persons are *not* those who scored at the 95th percentile or above on standardized tests of intelligence, nor were they necessarily straight A students who discovered early how to play the lesson-learning game. In other words, more innovative persons came from below the 95th percentile than above it, and if such cutoff scores are needed to determine entrance into special programs, we may be guilty of actually discriminating against persons who have the greatest potential for high levels of accomplishment.

The most defensible conclusion about the use of intelligence tests that can be put forward at this time is based on research findings dealing with the 'threshold effect'. Reviews by Chambers (1969) and Stein (1968) and research by Walberg (1969, 1971) indicate that accomplishments in various fields require minimal levels of intelligence, but that beyond these levels, degrees of attainment are weakly associated with intelligence. In studies of creativity it is generally acknowledged that a fairly high though not exceptional level of intelligence is necessary for high degrees of creative achievement (Barron, 1969; Campbell, 1960; Guilford, 1964, 1967; McNemar, 1964; Vernon, 1967).

Research on the threshold effect indicates that different fields and subject matter areas require varying degrees of intelligence for high-level accomplishment. In mathematics and physics the correlation of measured intelligence with originality in problem-solving tends to be positive but quite low. Correlations between intelligence and the rated quality of work by painters, sculptors, and designers is zero or slightly negative (Barron, 1968). Although it is difficult to determine exactly how much measured intelligence is necessary for high levels of innovative accomplishment within any given field, there is a consensus among many researchers (Barron, 1969; Bloom, 1963; Cox, 1926; Harmon, 1963; Helson & Crutchfield, 1970; MacKinnon, 1962, 1965; Oden, 1968; Roe, 1952; Terman, 1954) that once the IQ is 120 or higher other variables become increasingly important. These variables are discussed in the paragraphs that follow.

#### *Task Commitment*

A second cluster of traits that consistently has been found in innovative persons is a refined or focused form of motivation known as task commitment. Whereas motivation is usually defined in terms of a general energizing process that triggers responses in organisms, task commitment represents energy brought to bear on a particular problem (task) or specific

performance area. The terms that are most frequently used to describe task commitment are perseverance, endurance, hard work, dedicated practice, self-confidence, and a belief in one's ability to carry out important work. In addition to perceptiveness (Albert, 1975) and a better sense for identifying significant problems (Zuckerman, 1979), research on persons of unusual accomplishment has consistently shown that a special fascination for and involvement with the subject matter of one's chosen field "are the almost invariable precursors of original and distinctive work" (Barron, 1969, p. 3). Even in young people whom Bloom & Sosniak (1981) identified as extreme cases of talent development, early evidence of task commitment was present. Bloom & Sosniak report that "after age 12 our talented individuals spent as much time on their talent field each week as their average peer spent watching television" (p. 94).

The argument for including this nonintellective cluster of traits in a definition of giftedness is nothing short of overwhelming. From popular maxims and autobiographical accounts to hard-core research findings, one of the key ingredients that has characterized the work of gifted persons is their ability to involve themselves totally in a specific problem or area for an extended period of time.

The legacy of both Sir Francis Galton and Lewis Terman clearly indicates that task commitment is an important part of the making of a gifted person. Although Galton was a strong proponent of the hereditary basis for what he called 'natural ability', he nevertheless subscribed heavily to the belief that hard work was part and parcel of giftedness:

By natural ability, I mean those qualities of intellect and disposition, which urge and qualify a man to perform acts that lead to reputation. I do not mean capacity without zeal, nor zeal without capacity, nor even a combination of both of them, without an adequate power of doing a great deal of very laborious work. But I mean a nature which, when left to itself, will, urged by an inherent stimulus, climb the path that leads to eminence and has strength to reach the summit—on which, if hindered or thwarted, will fret and strive until the hindrance is overcome, and it is again free to follow its laboring instinct (Galton, 1869, p. 33, as quoted in Albert, 1975, p. 142).

The monumental studies of Lewis Terman undoubtedly represent the most widely recognized and frequently quoted research on the characteristics of gifted persons. Terman's studies, however, have unintentionally left a mixed legacy because most persons have dwelt (and continue to dwell) on 'early Terman' rather than the conclusions he reached *after* several decades of intensive research. As such, it is important to consider the following conclusion that he reached as a result of 30 years of follow-up studies on his initial population:

A detailed analysis was made of the 150 most successful and 150 least successful men among the gifted subjects in an attempt to identify some of the non-intellectual factors that affect life success. . . . Since the less successful subjects do not differ to any extent in intelligence as measured by tests, it is clear that notable achievement calls for more than a high order of intelligence.

The results (of the follow-up) indicated that personality factors are extremely important determiners of achievement. . . . The four traits on which (the most and least successful groups) differed most widely were *persistence in the accomplishment of ends, integration toward goals, self-confidence, and freedom from inferiority feelings*. In the total picture the greatest contrast between the two groups was in all-round emotional and social adjustment, and in *drive to achieve* (Terman, 1959, p. 148; italics added).

Although Terman never suggested that task commitment should replace intelligence in our conception of giftedness, he did state that 'intellect and achievement are far from perfectly correlated'.

Several research studies support the findings of Galton and Terman and have shown that innovative persons are far more task-oriented and involved in their work than are people in the general population. Perhaps the best known of these studies is the work of Roe (1952) and MacKinnon (1964, 1965). Roe conducted an intensive study of the characteristics of 64 eminent scientists and found that *all* of her subjects had a high level of commitment to their work. MacKinnon pointed out traits that were important in creative accomplishments: "It is clear that creative architects more often stress their inventiveness, independence and individuality, their *enthusiasm, determination, and industry*" (1964, p. 365; italics added).

Extensive reviews of research carried out by Nicholls (1972) and McCurdy (1960) found patterns of characteristics that were consistently similar to the findings reported by Roe and MacKinnon. Although the studies cited thus far used different research procedures and dealt with a variety of populations, there is a striking similarity in their major conclusions. First, academic ability (as traditionally measured by tests or grade point averages) showed limited relationships to innovative accomplishment. Second, nonintellectual factors, and especially those related to task commitment, consistently played an important part in the cluster of traits that characterized highly productive people. Although this second cluster of traits is not as easily and objectively identifiable as general cognitive abilities are, these traits are nevertheless a major component of giftedness and should, therefore, be reflected in our definition.

### Creativity

The third cluster of traits that characterizes gifted persons consists of factors usually lumped together under the general heading of 'creativity'. As one reviews the literature in this area, it becomes readily apparent that the words *gifted*, *genius*, and *eminent creators* or *highly creative persons* are used synonymously. In many of the research projects discussed above, the persons ultimately selected for intensive study were in fact recognized *because* of their creative accomplishments. In MacKinnon's (1964) study, for example, panels of qualified judges (professors of architecture and editors of major American architectural journals) were asked first to nominate and later to rate an initial pool of nominees, using the following dimensions of creativity:

- (1) Originality of thinking and freshness of approaches to architectural problems.
- (2) Constructive ingenuity.
- (3) Ability to set aside established conventions and procedures when appropriate.
- (4) A flair for devising effective and original fulfillments of the major demands of architecture, namely, technology (firmness), visual form (delight), planning (commodity), and human awareness and social purpose (p. 360).

When discussing creativity, it is important to consider the problems researchers have encountered in establishing relationships between creativity tests and other more substantial accomplishments. A major issue that has been raised by several investigators deals with whether or not tests of divergent thinking actually measure 'true' creativity. Although some validation studies have reported limited relationships between measures of divergent thinking and creative performance criteria (Dellas & Gaier, 1970; Guilford, 1967; Shapiro, 1968; Torrance, 1969) the research evidence for the predictive validity of such tests has been limited. Unfortunately, very few tests have been validated against real-life criteria of creative accomplishment; however, future longitudinal studies using these relatively new instruments might show promise of establishing higher levels of predictive validity. Thus, although divergent thinking is indeed a characteristic of highly creative persons, caution should be exercised in the use and interpretation of tests designed to measure this capacity.

Given the inherent limitations of creativity tests, a number of writers have focused attention on alternative methods for assessing creativity. Among others, Nicholls (1972) suggests that an analysis of creative products is preferable to the trait-based approach in making predictions about creative potential (p. 721), and Wallach (1976) proposes that student self-reports about creative accomplishment are sufficiently accurate to provide a usable source of data. Simonton (in press)

and Weisberg (in press) provide extensive summaries of issues related to the study of creativity and creative potential; much of the literature they review confirms the importance and complexity of the interactions among nature, the environment—including the Zeitgeist—and ability.

Although few persons would argue against the importance of including creativity in a definition of giftedness, the conclusions and recommendations discussed above raise the haunting issue of subjectivity in measurement. In view of what the research suggests about the questionable value of more objective measures of divergent thinking, perhaps the time has come for persons in all areas of endeavor to develop more careful procedures for evaluating the products of candidates for special programs.

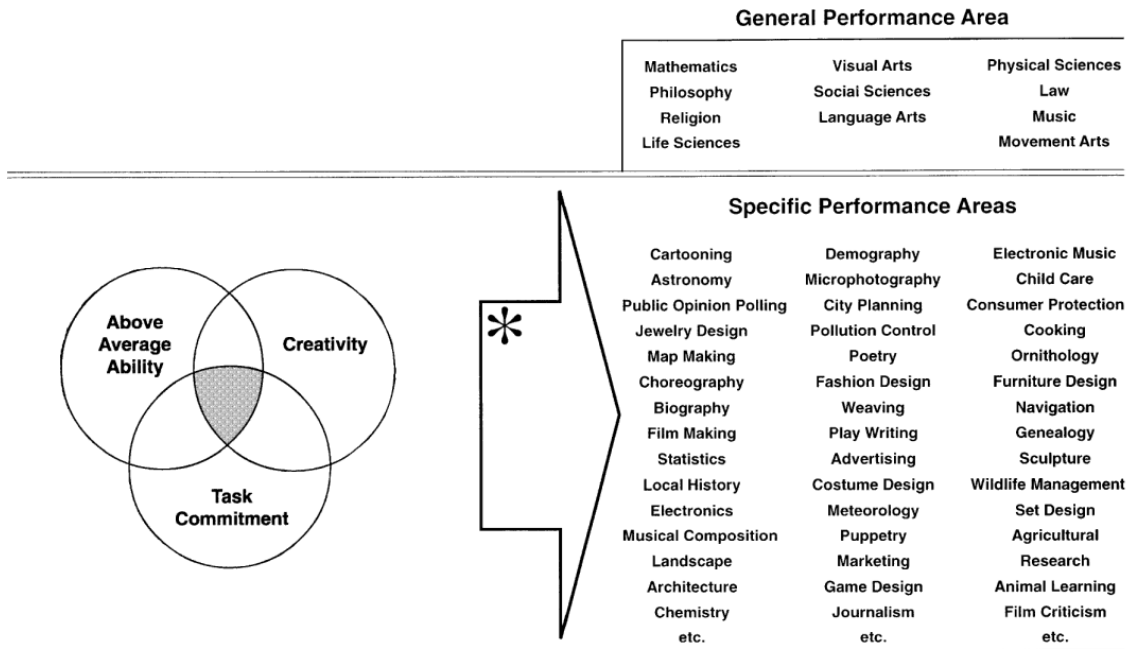
### Discussion and Generalizations

The studies reviewed in the preceding sections lend support to a small number of basic generalizations that can be used to develop an operational definition of giftedness. The first of these generalizations is that giftedness consists of an interaction among three clusters of traits—above-average but not necessarily superior general abilities, task commitment, and creativity. Any definition or set of identification procedures that does not give equal attention to all three clusters is simply ignoring the results of the best available research dealing with this topic.

Related to this generalization is the need to make a distinction between traditional indicators of academic proficiency and innovation. A sad but true fact is that special programs have favored proficient lesson learners and test takers at the expense of persons who may score somewhat lower on tests but who more than compensate for such scores by having high levels of task commitment and creativity. It is these persons whom research has shown to be those who ultimately make the most innovative contributions to their respective fields of endeavor.

A second generalization is that an operational definition should be applicable to all socially useful performance areas. The one thing that the three clusters discussed above have in common is that each can be brought to bear on a multitude of specific performance areas. As was indicated earlier, the interaction or overlap among the clusters 'makes giftedness', but giftedness does not exist in a vacuum. Our definition must, therefore, reflect yet another interaction, but in this case it is the interaction between the overlap of the clusters and any performance area to which the overlap might be applied. This interaction is represented by the large arrow in Fig. 2.

A third and final generalization concerns the types of information that should be used to identify superior performance in specific areas. Although it is a relatively easy task to include specific performance areas in a definition, developing identification procedures



\* This arrow should read as "... brought to bear upon ..."

Figure 2. Relationship between the three-ring conception of giftedness and contexts for innovation.

that will enable us to recognize specific areas of superior performance is a more difficult problem. Test developers have thus far devoted most of their energy to the development of measures of general ability, and this emphasis is undoubtedly why these tests are relied on so heavily in identification. However, an operational definition should give direction to needed research and development, especially in the ways that these activities relate to instruments and procedures for student selection. A defensible definition can thus become a model that will generate vast amounts of appropriate research in the years ahead.

**A Definition of Gifted Behavior**

Although no single statement can effectively integrate the many ramifications of the research studies I have described, the following definition of gifted behavior attempts to summarize the major conclusions and generalizations resulting from this review of research:

Gifted behavior consists of behaviors that reflect an interaction among three basic clusters of human traits—these clusters being above average general and/or specific abilities, high levels of task commitment, and high levels of creativity. Gifted and talented children are those possessing or capable of developing this composite set of traits and applying them to any potentially valuable area of human performance. Children who manifest or are capable of developing an interaction among the three clusters require a wide

variety of educational opportunities and services that are not ordinarily provided through regular instructional programs.

A graphic representation of this definition is presented in Fig. 2, and the following ‘taxonomy’ of behavioral manifestations of each cluster is a summary of the major concepts and conclusions emanating from the work of the theorists and researchers discussed in the preceding paragraphs:

*Well-above-average ability*

General ability:

- (1) High levels of abstract thinking, verbal and numerical reasoning, spatial relations, memory, and word fluency.
- (2) Adaptation to and the shaping of novel situations encountered in the external environment.
- (3) The automatization of information processing; rapid, accurate, and selective retrieval of information.

Specific ability:

- (1) The application of various combinations of the above general abilities to one or more specialized areas of knowledge or areas of human performance (e.g. the arts, leadership, administration).
- (2) The capacity for acquiring and making appropriate use of advanced amounts of formal knowledge, tacit knowledge, technique, logistics, and strategy

- in the pursuit of particular problems or the manifestation of specialized areas of performance.
- (3) The capacity to sort out relevant and irrelevant information associated with a particular problem or area of study or performance.

#### *Task commitment*

- (1) The capacity for high levels of interest, enthusiasm, fascination, and involvement in a particular problem, area of study, or form of human expression.
- (2) The capacity for perseverance, endurance, determination, hard work, and dedicated practice.
- (3) Self-confidence, a strong ego and a belief in one's ability to carry out important work, freedom from inferiority feelings, drive to achieve.
- (4) The ability to identify significant problems within specialized areas; the ability to tune in to major channels of communication and new developments within given fields.
- (5) Setting high standards for one's work; maintaining an openness to self and external criticism; developing an aesthetic sense of taste, quality, and excellence about one's own work and the work of others.

#### *Creativity*

- (1) Fluency, flexibility, and originality of thought.
- (2) Openness to experience; receptive to that which is new and different (even irrational) in the thoughts, actions, and products of oneself and others.
- (3) Curious, speculative, adventurous, and 'mentally playful'; willing to take risks in thought and action, even to the point of being uninhibited.
- (4) Sensitive to detail, aesthetic characteristics of ideas and things; willing to act on and react to external stimulation and one's own ideas and feelings.

As is always the case with lists of traits such as the above, there is an overlap among individual items, and an interaction between and among the general categories and the specific traits. It is also important to point out that not all of the traits need be present in any given individual or situation to produce a display of gifted behaviors. It is for this reason that the three-ring conception of giftedness emphasizes the interaction among the clusters rather than any single cluster. It is also for this reason that I believe gifted behaviors take place in certain people (not all people), at certain times (not all the time), and under certain circumstances (not all circumstances).

### **Discussion About the Three Rings**

Since the original publication of the three-ring conception of giftedness (Renzulli, 1977), a number of questions have been raised about the overall model and the interrelationships between and among the three rings. In this section, I will use the most frequently

asked questions as an outline for a discussion that will, I hope, clarify some of the concerns raised by persons who have expressed interest (both positive and negative) in this particular approach to the conception of giftedness.

#### *Are There Additional Clusters of Abilities that Should be Added to the Three-Ring Conception of Giftedness?*

One of the most frequent reactions to this work has been the suggestion that the three clusters of traits portrayed in the model do not adequately account for the development of gifted behaviors. An extensive examination of the research on human abilities has led me to an interesting conclusion about this question and has resulted in a modification of the original model. This modification is represented figurally by the houndstooth background in which the three rings are now imbedded (see Fig. 1).

The major conclusion is that the interaction among the original three rings is still the most important feature leading to the display of gifted behaviors. There are, however, a host of other factors that must be taken into account in our efforts to explain what causes some persons to display gifted behaviors at certain times and under certain circumstances. I have grouped these factors into the two traditional dimensions of studies about human beings commonly referred to as personality and environment. The research<sup>4</sup> clearly shows that each of the factors listed in Table 1 plays varying roles in the manifestation of gifted behaviors. What is even more important is the interaction between the two categories and among the numerous factors listed in each column (In fact, a houndstooth pattern was selected over an earlier checkerboard design in an effort to convey this interaction.) When we consider the almost limitless number of combinations between and among the factors listed in Table 1, it is easy to realize why so much confusion has existed about the definition of giftedness.

Each of the factors is obviously a complex entity in and of itself and could undoubtedly be subdivided into numerous component parts. The factor of socioeconomic status, for example, accounts for such things as prenatal care and nutrition, educational opportunities, and even things such as 'occupational inheritance'. Werts (1968) found, for example, that there is a clear tendency for college students to gravitate toward the occupation of their fathers. On the personality side of the ledger, MacKinnon (1965) found that in studies of highly effective individuals it was discovered time and time again that persons of the

<sup>4</sup> Literally hundreds of research studies have been carried out on the factors listed. For persons interested in an economical summary of personality and environmental influences on the development of gifted behaviors, I would recommend the following: D. K. Simonton (1978); B. T. Eiduson & L. Beckman (1973).

Table 1. Personality and environmental factors influencing giftedness.

Personality factors	Environmental factors
Perception of self	Socioeconomic status
Courage	Parental personalities
Character	Education of parents
Intuition	Stimulation of childhood interests
Charm or charisma	Family position
Need for achievement	Formal education
Ego strength	Role-model availability
Energy	Physical illness and/or well-being
Sense of destiny	Chance factors (financial inheritance, death, living near an art museum, divorce, etc.)
Personal attractiveness*	Zeitgeist

\* Although personal attractiveness is undoubtedly a physical characteristic, the ways in which others react to one's physical being are quite obviously important determinants in the development of personality.

most extraordinary effectiveness had life histories marked by severe frustrations, deprivations, and traumatic experiences. Findings such as these help to highlight the complexity of the problem. The advantages of high socioeconomic status, a favorable educational background, and early life experiences that do not include hardship, frustration, or disappointment may lead to a productive career for some individuals, but for others it may very well eliminate the kinds of frustration that might become the 'trigger' to a more positive application of one's abilities.<sup>5</sup>

An analysis of the role that personality and environment play in the development of gifted behaviors and potentially innovative behaviors is beyond the scope of this chapter, and in many ways for school persons who are charged with the responsibilities of identifying and developing gifted and potentially innovative behaviors, they are beyond the realm of our *direct* influence. Each of the factors above shares one or a combination of two characteristics. First, most of the personality factors are long-term developmental traits or traits that in some cases are genetically determined. Although the school can play an important role in developing things like courage and need for achievement, it is highly unrealistic to believe that we can shoulder the major responsibility for overall personality formation. Second, many factors such as socioeconomic status, parental personalities, and family position are chance factors that children must take as givens when they are born and that educators must take as givens when young people walk through the schoolhouse door. We cannot tell a child to be the firstborn or to have parents who stress achievement! It is for these reasons that I have concentrated my efforts on the three sets of clusters set forth in the original model. Of course, certain aspects of the original three clusters are also

chance factors, but a large amount of research clearly has shown that creativity and task commitment are in fact modifiable and can be influenced in a highly positive fashion by purposeful kinds of educational experiences (Reis & Renzulli, 1982). And although the jury is still out on the issue of how much of one's ability is influenced by heredity and how much by environment, I think it is safe to conclude that abilities (both general and specific) can be influenced to varying degrees by the best kinds of learning experiences.

#### *Are the Three Rings Constant?*

Most educators and psychologists would agree that the above-average-ability ring represents a generally stable or constant set of characteristics. In other words, if an individual shows high ability in a certain area such as mathematics, it is almost undeniable that mathematical ability was present in the months and years preceding a 'judgment day' (i.e. a day when identification procedures took place) and that these abilities will also tend to remain high in the months and years following any given identification event. In view of the types of assessment procedures most readily available and economically administered, it is easy to see why this type of giftedness has been so popular in making decisions about entrance into special programs. Educators always feel more comfortable and confident with traits that can be reliably and objectively measured, and the 'comfort' engendered by the use of such tests often causes them to ignore or only pay lip service to the other two clusters of traits.

In our identification model (Renzulli et al., 1981), we have used above-average ability as the major criterion for identifying a group of students who are referred to as the Talent Pool. This group generally consists of the top 15–20% of the general school population. Test scores, teacher ratings, and other forms of 'status information' (i.e. information that can be gathered and analyzed at a fixed point in time) are of

<sup>5</sup> I am reminded of the well-known quote by Dylan Thomas: 'There's only one thing that's worse than having an unhappy childhood, and that's having a too-happy childhood'.

practical value in making certain kinds of first-level decisions about accessibility to some of the general services that should be provided by a special program. This procedure guarantees admission to those students who earn the highest scores on cognitive ability tests. Primary among the services provided to Talent Pool students are procedures for making appropriate modifications in the regular curriculum in areas where advanced levels of ability can be clearly documented. It is nothing short of common sense to adjust the curriculum in those areas where high levels of proficiency are shown. Indeed, advanced coverage of traditional material and accelerated courses should be the 'regular curriculum' for youngsters with high ability in one or more school subjects.

The task commitment and creativity clusters are a different story! These traits are not present or absent in the same permanent fashion as pointed out in our mathematics example above. Equally important is the fact that we cannot assess them by the highly objective and quantifiable means that characterize test score assessment of traditional cognitive abilities. We simply cannot put a percentile on the value of an innovative idea, nor can we assign a standard score to the amount of effort and energy that a student might be willing to devote to a highly demanding task. Creativity and task commitment 'come and go' as a function of the various types of situations in which certain individuals become involved.

There are three things that we know for certain about the creativity and task commitment clusters. First, the clusters are variable rather than permanent. Although there may be a tendency for some individuals to 'hatch' more innovative ideas than others and to have greater reservoirs of energy that promote more frequent and intensive involvement in situations, a person is not either creative or not creative in the same way that one has a high ability in mathematics or musical composition. Almost all studies of highly accomplished individuals clearly indicate that their work is characterized by peaks and valleys of both creativity and task commitment. One simply cannot (and probably should not) operate at maximum levels of output in these two areas on a constant basis. Even Thomas Edison, who is still acknowledged to be the world's record holder of original patents, did not have an innovative idea for a new invention every waking moment of his life. And the most productive persons have consistently reported 'fallow' periods and even experiences of 'burnout' following long and sustained encounters with the manifestation of their talents.

The second thing we know about task commitment and creativity is that they can be developed through appropriate stimulation and training. We also know that because of variations in interest and receptivity, some people are more influenced by certain situations than others. The important point, however, is that we cannot predetermine which individuals will respond most

favorably to a particular type of stimulation experience. Through general interest assessment techniques and a wide variety of stimulus variation we can, however, increase the probability of generating a greater number of innovative ideas and increased manifestations of task commitment in Talent Pool students. In our identification model, the ways in which students *react* to planned and unplanned stimulation experiences has been termed 'action information'. This type of information constitutes the second level of identification and is used to make decisions about which students might revolve into more individualized and advanced kinds of learning activities. The important distinction between status and action information is that the latter type cannot be gathered before students have been selected for entrance into a special program. Giftedness, or at least the beginnings of situations in which gifted behaviors might be displayed and developed, is in the *responses* of individuals rather than in the stimulus events. This second-level identification procedure is, therefore, part and parcel of the general enrichment experiences that are provided for Talent Pool students, and is based on the concept of *situational testing* that has been described in the theoretical literature on test and measurements (Freeman, 1962, pp. 538-554).

Finally, the third thing we know about creativity and task commitment is that these two clusters almost always stimulate each other. A person gets an innovative idea; the idea, is encouraged and reinforced by oneself and/or others. The person decides to 'do something' with the idea, and thus his or her commitment to the task begins to emerge. Similarly, a large commitment to solving a particular problem will frequently trigger the process of creative problem-solving. In this latter case we have a situation that has undoubtedly given rise to the old adage 'necessity is the mother of invention.'

This final point is especially important for effective programming. Students participating in a gifted program should be patently aware of opportunities to follow through on innovative ideas and commitments that have been stimulated in areas of particular interest. Similarly, persons responsible for special programming should be knowledgeable about strategies for reinforcing, nurturing, and providing appropriate resources to students at those times when creativity and/or task commitment are displayed.

#### *Are the Rings of Equal Size?*

In the original publication of the three-ring conception of giftedness, I stated that the clusters must be viewed as 'equal partners' in contributing to the display of gifted behaviors. I would like to modify this position slightly, but will first set forth an obvious conclusion about lesson-learning giftedness. I have no doubt that the higher one's level of traditionally measured cognitive ability, the better equipped he or she will be to

perform in most traditional (lesson) learning situations. As was indicated earlier, the abilities that enable persons to perform well on intelligence and achievement tests are the same kinds of thinking processes called for in most traditional learning situations, and therefore the above-average ability cluster is a predominant influence in lesson-learning giftedness.

When it comes to innovative giftedness, however, I believe that an interaction among all three clusters is necessary for high-level performance. This is not to say that all clusters must be of equal size or that the size of the clusters remains constant throughout the pursuit of innovative endeavors. For example, task commitment may be minimal or even absent at the inception of a very large and robust innovative idea; and the energy and enthusiasm for pursuing the idea may never be as large as the idea itself. Similarly, there are undoubtedly cases in which an extremely innovative idea and a large amount of task commitment will overcome somewhat lesser amounts of traditionally measured ability. Such a combination may even cause a person to increase her or his ability by gaining the technical proficiency needed to see an idea through to fruition. Because we cannot assign numerical values to the creativity and task commitment clusters, empirical verification of this interpretation of the three rings is impossible. But case studies based on the experience of innovative individuals and research that has been carried out on programs using this model (Reis, 1981) clearly indicate that larger clusters do in fact compensate for somewhat decreased size on one or both of the other two areas. The important point, however, is that all three rings must be present and interacting to some degree in order for high levels of productivity to emerge.

#### *Summary: What Makes Innovative Giftedness?*

In recent years we have seen a resurgence of interest in all aspects of the study of giftedness and related efforts to provide special educational services for this often neglected segment of our school population. A healthy aspect of this renewed interest has been the emergence of new and innovative theories to explain the concept and a greater variety of research studies that show promise of giving us better insights and more defensible approaches to both identification and programming. Conflicting theoretical explanations abound and various interpretations of research findings add an element of excitement and challenge that can only result in greater understanding of the concept in the years ahead. So long as the concept itself is viewed from the vantage points of different subcultures within the general population and differing societal values, we can be assured that there will always be a wholesome variety of answers to the age-old question: What makes innovative giftedness? These differences in interpretation are indeed a salient and positive characteristic of any field that attempts to further our understanding of the human condition.

This chapter provides a framework that draws upon the best available research about gifted, talented, and innovative individuals. There is a growing body of research offered in support of the validity of the three-ring conception of giftedness. The conception and definition presented in this chapter have been developed from a decidedly educational perspective because I believe that efforts to define this concept must be relevant to the persons who will be most influenced by this type of work. I also believe that conceptual explanations and definitions must point the way toward practices that are economical, realistic, and defensible in terms of an organized body of underlying research and follow-up validation studies. These kinds of information can be brought forward to decision-makers who raise questions about why particular identification and programming models are being suggested by persons who are interested in serving gifted youth.

The task of providing better services to our most promising young people cannot wait until theorists and researchers produce an unassailable ultimate truth, because such truths probably do not exist. Educators need to create learning environments with numerous opportunities to foster the development of innovation and support the potential innovators in our society. We can not ignore this vital potential asset.

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# Innovation and Strategic Reflexivity: An Evolutionary Approach Applied to Services

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**Abstract:** Innovation in firms is discussed by using the notion of strategic reflexivity and applying a strategic innovation theory, which is within the evolutionary tradition. Market conditions and internal resources are the drivers of the innovation process. Firms manage their innovation process and market position through the strategy. Reflexivity is a social process in the firm in which managers and the employees consider the innovation process and the strategy. The social process includes organizational patterns, interaction and role patterns and organizational learning. The theory is applied to case studies of development of service concepts in service firms.

**Keywords:** Innovation; Strategic reflexivity; Evolutionary approach; Services; Social process.

## Introduction

### *Aim of the Chapter*

This chapter will discuss how firms develop by innovating. Innovation will be understood within the framework of the strategic innovation theory, which sees innovation as being determined by the firm's strategy (Sundbo, 1998a, 2001, 2002). Strategic reflexivity (Sundbo & Fuglsang, 2002) is an important concept within this theory. The concept refers to behavior which guides the innovation process. Strategic reflexivity leads to organizational learning. The aim of the chapter is to demonstrate how the concepts of strategic reflexivity and innovation can be used to attain a general understanding of the firm's development.

### *Innovation and Strategic Reflexivity*

The topic of innovation belongs, in part, to economics (see for example Swedberg & Granovetter, 2001), but the approach taken here is primarily sociological. The explanation of innovation provided here takes a middle path between those who argue that innovation is determined by social structure and those who maintain that it is solely dependent on the acts of individuals. The view is that there is an element of truth in both of these approaches, which is to say that whilst social structure heavily influences the behavior of individuals, individuals' actions also determine social structure.

This view is common amongst sociologists (e.g. Bourdieu & Wacquant, 1992; Giddens, 1984).

*Strategic reflexivity* is a concept that can unite economic and sociological explanations of innovation. The contribution from economics is that we can understand the development of the firm in terms of a market game with an arbitrary outcome (a game in which the outcome cannot be predicted, but the outcome can be stated with a certain degree of probability). Since the outcome of market game is arbitrary, firms do not—and cannot—successfully just follow certain trajectories or just rely on being part of institutions (such as a stable network). The market changes continuously, as does the rest of the society, and the firm needs to act in new, path and institutional breaking ways to survive.

Economics has invented some theoretical approaches, such as game theory, to explain the situation with arbitrary outcome (Gintis, 2000; Owen, 1995). Such situations have also been described by cybernetics and systems theory (Beer, 1959; Boulding, 1985). However, this chapter will focus on the sociology behind the firm's understanding of possible outcomes and market strategy. The analysis emphasizes the social process of defining, maintaining and changing the way that the firm tackles a market with arbitrary outcome. The fundamental approach here is that the firm is not a living entity. A firm cannot assess probabilities and decide routes. People within (or

perhaps outside) the firm assess and decide routes. They do so not as anarchistic individuals (such as the classic entrepreneur, cf. Schumpeter, 1934) or as social beings determined by structure (for example by institutions). They do assess probabilities and decide routes within a social system (namely the firm's organization) characterized by interaction, repeating patterns of acting, norms and so on as well as regularly changing patterns of behavior.

The firm formulates a strategy, which defines the goals for its future activities. Innovation is a social process. The social process is *reflexive* in the way that the employees and managers consider how the firm should develop to avoid the external threats from competitors, changes in customers preferences and political regulation, and further, how the firm could utilize the possibilities for new market positioning (e.g. marketing new products or decreasing prices through process innovations). The overall idea of how the firm should develop is encapsulated in the strategy.

This chapter thus discusses how the interaction processes within the firm can be understood as an explanation of the firm's innovation activities. The latter may only, to a certain degree, be done in theoretical terms because the interaction processes follow varied patterns. Empirical studies are necessary to investigate the different empirical forms of the interaction processes.

The strategic reflexive approach is within the tradition of evolutionary theory (e.g. Metcalfe, 1998).

### Core Concepts

The core concepts that will be used in the chapter are the following:

*Innovation* takes place when either a new element or a new combination of old elements (cf. Schumpeter, 1934) is introduced. This is Schumpeter's classic definition of innovation which emphasizes both the act (to introduce something) as well as the result (the new product or the new organization). Schumpeter's definition will be employed here.

However, there are various types of innovation and innovative activity.

*Product innovation* refers to the introduction of a new product to the market.

*Process innovation* refers to the introduction of new production processes such as those enabled by new technology, or new work routines.

*Organizational innovation* designates the introduction of a new organizational form or a new management philosophy.

*Market innovation* denotes a firm's new market behavior such as a new strategy, new marketing, new alliances and so forth.

*Innovative behavior* concerns the firm's organization of the innovative activities: the production of ideas or

inventions and their development into marketed products or practically implemented processes or organizational forms. Innovative behavior can be observed from outside the firm. The internal social process by which an innovation is developed and implemented is called the *innovation process*. The innovation process is an interaction between several actors (managers and employees); the constellation of these actors is called an *interaction system*.

There are many *small changes* in firms—products, processes, etc. Not any change is an innovation. To be classified as an innovation, the change must be substantial, which means that it is reproduced (cf. Gallouj, 1994; Sundbo, 1997, 1998b): if the innovation is a product (or a service), it is an innovation when it is produced in many copies. A process or an organizational innovation is one that is implemented throughout, or at least a large part of, the organization. However, even small changes which are not substantial enough to be called innovations may develop the firm. These will also be dealt with in this chapter.

*Learning* is the collection of experiences of what is good and what is bad. In relation to innovation and strategic reflexivity, it means the experience of which strategies and innovations were successful. It also refers to evaluating how the process of formulating strategies and organizing innovation activities can be successful. Learning can be both *individual* (each employee and manager learns) and *organizational* (the individual learning is dealt with others in the organization) (cf. Argyris & Schon, 1978).

*Firm development* concerns a firm developing either when it grows (in turnover, number of employees or profit) because of innovation or small changes or when it gains a competitive advantage by innovating (even though it does not grow immediately). Development can be achieved through innovation, small changes, learning, and by strategic reflexivity.

### Structure of the Chapter

I will begin the chapter by discussing how the development of the firm can be understood theoretically. First, I will explain how strategic innovation theory, including the notion of strategic reflexivity, is based on evolutionary theory. Next, I will state the axioms of the strategic reflexivity explanation of innovation, which will then be outlined in the following section.

The theoretical discussion is applied to empirical cases, namely the development of service concepts in service firms.

A *service concept* is the total system of a service product (Desrumaux et al., 1998). A service concept includes the way the service product is produced and delivered (including the involvement of the customer and how the service solves the problem), the market position that the service enterprise and its products obtain, and the internal life of the firm (such as

corporate culture, HRM and so on). The development of a new service concept combines product, process, organization and market innovations, as well as technological and social innovations.

The cases presented here have been selected because innovation in services normally includes many factors: new products, new processes, organizational and delivery systems, new market behavior, etc. Thus the cases can illustrate the various aspects of innovation.

The final section will sum up the theory and findings.

### **The Basic Position: A 'Soft' (or Non-functionalistic) Evolutionary Approach**

The use of the concept of strategic reflexivity is not based on a universal interpretation of the development of the firm. The development of the firm is historical, which means that firms act in different ways in different situations. Further, the theory of innovation employed here is not a general theory of the firm. This theory only concerns how firms develop, which means how they change and innovate.

The theory of innovation presented here may be characterized as an evolutionary theory. However, it is not a 'hard' evolutionary theory such as functionalistic versions of Darwin's biological theory of 'the survival of the fittest' (cf. Smith, 1977). Such theories are based on the belief that a limited number of factors guide the selection process and the individuals or species which meet those requirements will survive. The task for the firm, according to the hard version of a social evolutionary theory, is to find out what these factors are, and then the future development of the firm can be predicted. The hard versions are based on linear determination chains.

The hard versions of evolutionary theory can also be found within economics and sociology. Hannan & Freeman (1989) have postulated a theory of organizational ecology concerning which firms will survive competition. An example of a hard version is also Nelson & Winter's (1982) attempt to find the ultimate mechanism of the development of the firm, a mechanism they called a 'routines'. Another example is the use of the concepts of knowledge and competence as explanation of the development of the firm, cf. Hodgson (1998), and Hamel & Prahalad (1994). The theories of social change in the 1950s and 1960s (Barnett, 1953; LaPierre, 1965; Moore, 1963; Ogburn, 1950; Rogers, 1995—most of which were based on Tarde, 1895) are examples of sociological theories, which used the diffusion of technology as a core concept to explain social change. A 'hard' evolutionary theory is fundamentally functionalistic: those organisms (e.g. in economics—firms) that develop the best functions in relation to the environment will survive.

Modern biology has, based on studies of ecological systems, launched a 'soft' version of evolutionary theory (Eldredge, 1999; Jørgensen, 1992; Krebs, 1988;

Prigogine & Stengers, 1986). The development of species is created by many factors and by relations between these factors. There are many determinants, and even relations may be determinants (cf. the discussion within physics between Bohr, Einstein and others about relativity, e.g. that measuring instruments distort the results). Such interdependencies mean that imbalances in the system often happen, but there are also periods of balance. The development mechanisms are extremely difficult to grasp because there are so many, and they differ from situation to situation. Future development cannot, or only with extreme difficulty, be predicted and general laws may only be stated in terms of probability. In such a system, the individual or species has better possibilities to influence the system to its benefit if this person or species can act consciously. However, the individual or species may be prepared of other individuals and species will also attempt to influence the system to own their benefit. The entrance of other actors means that not only will there be a competition between these two actors, but the competitive behavior of the actors may also affect the system, and thus change the rules of survival. This 'soft' evolutionary model can be applied to social and economic systems such as a firm, and this is what is attempted here. The 'soft' variant is not functionalistic: it claims that the firms which survive and grow are not necessarily the 'fittest'. The firms which are most successful at the moment can be the least successful in the very near future. The firm can not rely on routines (cf. Nelson & Winter, 1982) and existing capacities: it must continuously reflect and frequently develop new strategies to influence the market system and to grow. It may even change the rules of survival.

The 'soft' evolutionary system can be characterized as a 'chaotic system' as in the modern version of the mathematical chaos theory (Devaney, 1992). This theory says that the system is complex, and there are no straight lines and no simple cause-effect relationships, so one cannot predict the outcome of a certain causal factor. The system may seem to be without any order, but, some patterns are repeated throughout the system. For example, cascading running water seems to flow coincidentally, but some types of whirl can be found at several places in the whirlpool. Thus there is a certain probability of finding a particular whirl type in a certain part of the whirlpool. Chaos theory has been applied to social systems as well (Kiel & Elliott, 1996; Quinn, 1985; Stacey, 1993). An example of how it has been applied is project-organized firms such as those which are research- and development-intensive. Their organization may be without much formal structure, having no formal leaders, and every person has several roles in different projects. The organization seems to be anarchistic to a certain degree. However, one may find some patterns that are repeated. For example, in most project teams, certain roles are developed such as those

of the conflict-solving person, the critical person who asks questions, and the person who presents creative, new ideas, etc.

The 'soft' evolutionary system could also be characterized by a metaphor drawing on the modern version of health, a series of physical, psychological and social factors, all of which influence our health. A complete explanation of the total system cannot be provided, but explanations of parts of the system can, however, even sub-systems can be influenced by changes in other sub-systems. If, for example, social conventions among the managers in the managerial system are changed, they may influence the informal social conventions that exist among the employees making them less creative and less interested in participating in innovative activities.

The insecurity of the evolutionary system is the reason why strategic reflexivity is so important. Strategic reflexivity is the firm's attempt to manage its competitive behavior. The firm should beat its competitors and set the rules under which the market system functions so that they are advantageous to that particular firm.

### **Axioms of the Innovation Theory**

I will now discuss how innovation and change can be theoretically understood by using the notion of strategic reflexivity. This is a new approach and demands that some axioms be stated. I will therefore start with three statements that define the framework for the coming detailed discussion.

#### *First Statement: Innovation Concerns Human Beings Within the Firm*

In recent decades, in both economics and business administration, there has been an increasing interest in innovation, knowledge management, technological development, organizational learning and so forth. Innovation may be seen as the core notion within this group. Innovation is something that is going on in firms and in systems of firms (cf. Edquist, 1997; Nelson, 1993).

Fundamentally, the reason for the increasing interest in these topics is a desire to understand the development of the firm as an explanation for economic growth. If we are really to develop such an understanding, we need to go back to Schumpeter's work (1934) and his views concerning economic development. To Schumpeter, economic development means new solutions to society's problems and needs. One could see the process of developing new solutions in terms of social change, which a sociological discipline was called (e.g. LaPiere, 1965; Moore, 1963). However, one does not need to formulate the notion of social change in a functionalist manner within a 'hard' evolutionary approach. The process of diffusing the innovation does not need to be rational in the sense that a problem can be defined, and the new element solves

that problem. The diffusion of a new element can be caused by people just choosing another way of living, which the new elements make possible (Barnett, 1953).

Introducing the concept of strategic reflexivity re-introduces the idea of social change but in a 'soft' evolutionary way. However, here the idea is restricted to social change within firm organizations, and it is also limited to economic actions. The latter means actions which—directly or indirectly—lead to initiatives taken in the market.

The objective of the strategic reflexivity approach thus is broader than new, physical products of technology. The approach emphasizes the behavior that leads to the development of the firm, economic growth, and social change. Innovation is traditionally identified as the result of that behavior—a new product, a new production process, etc. (Coombs et al., 1987; Freeman & Soete, 1997). The results (the innovations) are of course important since they change the world. However, if we want to understand and explain the development process so that we are in a position to guide it, we need to study it. The process is therefore more important than the results. That is why innovation in this chapter has been defined as the process as well as the result (however, compared to the traditional innovation theory, the emphasis is on the process).

Innovation could be interpreted as a process of social change. New elements are invented and diffused throughout society changing it, our lives or particular sub-structures of the society (such as how we transport ourselves, how we spend our free time, how we work, etc.).

Actions, including innovation, are undertaken by persons in a social system. The approach here is to understand innovation and change as sociological processes which take place within the firm organization and between the persons within the firm and outsiders.

#### *Second Statement: The Changes Are Neither Institutional Nor Unpredictable Anarchical*

The process of change that innovation (and the small changes) brings about do not follow a constant trajectory and are not totally anarchical and unpredictable. Innovation and change is a trial-and-error process, but one which can be managed to some degree. However, the management must be ready to introduce new principles of management in each phase of the trial-and-error process, since the conditions for the innovative activity may change for each phase.

Understanding innovation in terms of the notion of strategic reflexivity differs from the institutional approach that has become popular in social sciences during the last decade (Hodgson, 1993; Nielsen & Johnson, 1998). Innovation patterns and change are not institutionalized processes and cannot be. Some institutional theories try to respond to this fact and maintain the institutional approach by saying that change itself

can be institutionalized (Johnson, 1992; Nelson & Winter, 1982). A social system such as a firm can be oriented towards change, and change becomes a value and a norm. However, the point is that the conditions of change are constantly changing, and so new goals, values, norms and types of actions are regularly needed. Thus it makes no sense to call such a change system an institution. Institutions are systems where norms, action patterns and goals are relatively permanent (e.g. the family, the church). To call the firm's innovation and change system an institution within the framework outlined here would be a complete watering down of the concept 'institution', which would then just mean a social system or structure. The interpretation of the development of the firm presented in this chapter thus implies a critical approach to institutional theory's explanation of change.

The interpretation also implies that a firm's development cannot be explained by any deterministic, trajectorial approach. Theories of path dependency have been presented (e.g. Dosi, 1982; Freeman & Perez, 1988; Teece, 1986), stating that people's behavior become institutionalized. People follow well-known paths, even when they participate in a change process. The fact that they participate in a social system also leads them to follow existing paths because the change process is a social process, and people are conservative when they operate within a social system. Innovations are seen as a result of logical trajectories which exist within the system of innovation (cf. Dosi, 1982; Freeman & Soete, 1997). This is only partly true. People and even social systems are able to break the inertia and trajectory and create new paths. They can innovate rules and new ways in which the innovation process is managed and executed.

The path dependency theories come from within the technology-economic paradigm (e.g. Dosi et al., 1988; Mensch, 1979; Piatier, 1984; Rosenberg, 1972—cf. Sundbo, 1998a), which emphasizes the technology and science push. The technology and science push precondition is valid in some industries and firms (e.g. high-tech) where the scientific discoveries and technological inventions are so useful and marketable that they guarantee market success. However, this only happens in the minority of situations. In most firms, it is difficult to market an innovation and difficult to know which innovations will be successful. Therefore, the firms will act carefully and follow the way of strategic reflexivity. The rise and fall of the ICT-software-Internet industry in 1999–2000 illustrates how, in such a short time, even a high-tech industry can rely on technology push as its driving force.

Recently, there has been a tendency to treat knowledge as the key factor in explaining the development of the firm and economy (Eliasson, 1989; OECD, 1996). However, this is also insufficient. Some theories explain firms' behavior as if knowledge in itself

presents the solutions and way forward. According to these theories, knowledge is the determinant and therefore the most important factor in explaining economic growth (e.g. Boden & Miles, 2001; OECD, 1996). Within the framework adopted here, knowledge is not such a determinant. Knowledge is an important raw material, but it is people who, in the social change process, create changes by using knowledge. The people decide which knowledge to select. Firms may often follow a technological or other trajectory (e.g. a service professional trajectory; cf. Sundbo & Gallouj, 2000). However, they may often have greater success by not adapting to the most advanced steps in a trajectory, but by using low technology or technology from another trajectory, adding services to the product, or just changing the trajectory. Innovation through strategic reflection is not just knowledge but action, as the entrepreneur theory states (Binks & Vale, 1990; Schumpeter, 1934). The human will to act—even if it does not make sense in terms of existing knowledge—is the most important. This assumption also makes innovation into a social process where self-interest, firm policy and so forth play a role.

Certain patterns can be established for firms' innovative behavior. Such patterns could, for example, be that some firms follow a technological trajectory where the technological inventions determine the innovations that the firms develop. Another pattern could be that the firm establishes a strategy, picks up different technological elements and mixes them with new organizational and marketing elements (cf. the chapter by Veryzer in this book).

An individual-anarchical approach has characterized the early innovation and social change literature (e.g. Johannisson, 1987; McClelland, 1961; Menger, 1950; see also Sexton & Kasarda, 1992), inspired by the individual approach of the two classic authors, Schumpeter (1934) and Tarde (1895). The entrepreneur has been seen as the change agent and the one who creates innovation, and the entrepreneur is an individual. Since entrepreneurs are creative, the change process is anarchical and unpredictable; there is no pattern. However, single individuals alone do not create innovation within modern firms. They may play an important role (cf. Drucker, 1985; Kanter, 1984; Pinchot, 1985), but the innovation is developed within a social system in which several individuals take part in the process. The implication of these assumptions is that the innovation process in the firms follows certain—but not universal—patterns and is not completely anarchical.

### *Third Statement: Managers are Seeking Interpretation and Social Interaction*

Managers are seeking the efficient solution for the firm's development. To find that demands interpretation of the environment and of their own possibilities (statement of the internal resources; cf. the resource

based theory of the firm, e.g. Penrose, 1959; Grant, 1991). A seeking interpretation becomes the result of the attempt to efficiently develop the firm. The managers within the firm look for the best interpretation of the future way to go and the best kind of innovations. However, they are uncertain of which interpretation and which solution is the best. Therefore, they turn to other people—particularly the employees—to discuss and develop the best solution. They engage in reflexive strategic behavior, which is an interactive social process that creates innovation (as already stated; cf. also Gallouj, 2002).

### **The Development of the Firm: Innovation and Change by Reflexive Learning**

In this section I will outline the theory of strategic reflexivity. I will first discuss the relationship between innovation and small changes, and how both these phenomena can be included in the theory. Next, the discussion of the theory starts by emphasizing its point of departure, the market and strategy, which are connected to firms' market relations. After that, I will discuss the concept of reflexivity, which emphasizes the internal processes that take place in the firm. I will sum up by discussing how the innovation and change processes result in reflexive organizational learning.

#### *Innovation and Change*

The border between innovations and what are called here small changes is fluid (cf. Sundbo, 1997). The small changes are improvements in given situations and are not reproduced, and individually they do not, therefore, lead to a significant development of the firm. How can the management benefit from the many small changes? By making them as reproducible as possible, which is achieved by creating a general learning system in the organization. The other employees in the firm ought to imitate these changes, and the organization should collect knowledge about the experiences.

Firms develop through a mixture of two types of activities. First, more formalized innovation activities, which may be both top-down and bottom-up. Second, many small changes which are made general through organizational learning, which means the imitation of best practices within the firm.

The firm develops by learning from the innovation activities and the launching of new products and other innovations, as will be explained later. This form of development can be characterized as reflexive learning based. In the reflexive organizational learning the firm unites the innovation and small change efforts into a common one, which is to develop a better awareness throughout the company of possibilities for the future development of the firm.

#### *Innovation is a Market-Oriented Development Process*

The point of departure, and the end goal, for any innovation process is the market because that is where

the firm makes its profit, which is the ultimate goal. Marketing as an explanation of the development of innovation processes can also be found in the chapters by Veryzer and Trott in this book (see also Kotler, 1983).

The firm has to interact with the market. It must 'read' market trends and must innovate either to keep up with the trends or to alter them and be in a position to create the market trend. The firm also has to follow the effects of its own market behavior to see whether it is successful or not.

This market-oriented approach emphasizes the pull side of the development process—how the market possibilities determine the development process. However, as mentioned earlier, the firm is also characterized by following some trajectories (the push side).

#### *Strategy*

I will now go on to the core discussion of the firms' development process. The notion of strategic reflexivity is the core of the development theory discussed here. Therefore, I will start by defining what I mean by strategy in this section, and by reflexivity in the next one.

Important for the firm's development is not the actual market situation, but the future one. The firm has to make an interpretation of where the future market, including the wants of the customers and the competitors, is moving. For example, whether customers' preferences in the future become more ethically determined, they want extra services attached to the products or new, innovative competitors may occur in the future. Then the firm has to choose its direction and make a strategy which defines its goals in terms of its market position and its development. Furthermore, the strategy defines (at least generally) how the firm should reach these goals. The strategy is the means that the firm uses to navigate through the uncertain waters of the market.

The strategy is based not only on market possibilities, but also on the internal resources (competencies, financial strength, customer relations, innovation capabilities, etc.) that the firm possesses (Sundbo, 2001). Further, the strategy is based on the organization and the employees (including the managers) that the firm has and their competencies. The future development of the firm must be created by that organization and the employees and managers, or by some other employees or managers that the firm hires externally. The firm may also change the organization and its way of functioning, for example by creating a new corporate culture, a new organizational structure, or by employing new people with new competencies.

When I say *the firm* interprets the future market possibilities, and decides the strategy, I mean some person(s) within the firm, namely the top management. It may very well be that the other employees are also involved in this process, or it may be that the

interpretation and strategy are formulated by only some persons within the top management, or by managers outside the top management. However, the top management has the final responsibility.

The strategy is the framework for making decisions about the development of the firm, including innovation, and is also a source of inspiration for innovative ideas (since the strategy tells people where the firm wants to go). Innovation and change activities should follow the strategy and be within its limits. The top management has the task of ensuring that the firm's development is in tune with the strategy, but the firm's development is not a totally rational process where the management can guarantee the outcome. The management will attempt to carry out the process rationally and will succeed in many situations but also fail in many others. The management could fail, for example, because the interpretation of the market and competitors' moves turns out to be mistaken, or the people in the organization act in unforeseen ways, or the necessary resources cannot be procured.

The strategy is therefore continuously under consideration. If it seems to be wrong, it should be corrected. Again this is not always a smooth rational process. It is a difficult decision when and how to change the strategy, and it cannot be rationally based, although some rules of sense may be used.

Strategy has been understood in different ways (cf. Chaffee, 1985; Mintzberg, 1994; Sundbo, 1998b): rational, processual, intentional, and political. Here I present an interpretation of strategy as interpretative and processual, which means that the strategy is a result of reflections about the business environment. Further, strategy is also a result of reflections over internal resources, and an interpretation of where the business environment will move in the future.

### *Reflexivity*

Until now I have discussed strategy. Strategy marks *that* the firm has to find its way through an uncertain but arbitrary predictable future market. The other part of the central concept employed here is reflexivity, which concerns *how* the firm finds its way, and when it should change its ways or perhaps even strategy. The concept of reflexivity belongs to theories of organization, and emphasizes the process aspect of those theories (which is another aspect of the organization apart from the structural one).

### Reflexivity as a Form of Human Behavior

Reflection is based on the assumption that people seek to act rationally. They try to set up a strategy for themselves, or the social system in which they participate. However, they cannot in situations which are changing rapidly just rely on existing routines and trajectories, and consequently individuals' behavior becomes reflexive.

Reflection occurs at the level of the individual member of the organization whether he or she is a manager or an employee. Reflection means that the individual considers an unknown future with arbitrary outcomes. One must mobilize all the formal, trajectoryal knowledge that one has, and use it creatively to produce new solutions. One has to break norms and patterns to develop new solutions, and get them accepted and implemented. At the same time, one has to ensure that the social system (in our case the organization) is not completely dismantled, because learning from the past, which is useful, may then end, leading to the demise of the firm. Otherwise, one has to choose to follow existing routines and patterns.

Is reflection an automatic reaction, a biological, behavioristic response to a stimulus (as Pavlov's behavioristic theory expresses? (Pavlov, 1966)) Or is reflection an intentional behavior, manifestation of which demands an act of will, and here even an act of creativity (which means that the individual or a social system has to remember to analyze the situation, and that it may be possible to do something new in a situation)? The assumption here is definitely the latter. Studies of innovation tell us that there are no systems, based on nature, which simply respond to economic stimuli.

Reflections are considerations that individuals make about innovation possibilities, and the development of the firm based on three premises:

- (1) The goal for the development of the firm (which is expressed in the strategy, which is mostly, but not always, taken as the framework for reflections);
- (2) The knowledge that the individuals possess;
- (3) Ideas of what could be concretely done.

The concept of reflexivity has become popular within contemporary sociology (e.g. Bourdieu & Wacquant, 1994) and is one of the core concepts of Ulrik Beck's work (1992). He discusses reflexivity in relation to what he describes as the risk society—a complex and dangerous world, which is primarily due to environmental pollution, in which we now live. The citizen becomes occupied by the possibility of considering what pollution means for his or her life and what can be done about it. The citizen becomes dependent on experts for making these considerations. Another approach within sociology emphasizes that people themselves become reflexive or employ strategies towards the world in their everyday life. This latter approach is based on the assumption that contemporary citizens have become more individualistic, better educated, more career-oriented, etc. This approach has been argued for by Anthony Giddens (1984), for example. However, such ideas are not new; similar thoughts can be found in Durkheim (1933), where he expressed his worries concerning the early industrial society.

### Reflexivity as an Organizational Factor

Reflection implies interaction. The individual makes his personal reflections in interaction with other people, and the firm's reflections are also based on interaction: the result of a collective, social process as mentioned before. Generally, the group will be the unit which reflects, and may often be good at doing so, but individuals may do better. Despite being potentially better, individuals often talk to others to reduce their responsibility for unsuccessful innovations.

I view that part of the organization which carries out the innovation activities as being a dual organization (cf. Daft, 1978; Sundbo, 1998b). On one level it consists of the top management, who primarily have the task of managing the firm's development, and lower line management which is responsible for day-to-day production. The top management may consist of one or more managers. Generally, one may talk about a management structure (which may differ depending on the number of managers). The top management concentrates on the firm's general lines of the firm's development, which primarily means the strategy, but also ensures that the innovation and the reflection processes are running smoothly. On the other level, the dual organization consists of the employees and the middle managers. They are all placed within a formal structure, but they establish a network structure, which is informal, loosely coupled and interactive. This loosely coupled network structure is not a part of the formal structure of the organization; it cannot be found in the official schemes depicting the organization. Nevertheless, this structure exists and is created by the organization's members. It is part of their social nature, and it creates a common organizational culture. The network structure is a 'greenhouse' for innovative ideas and informal reflections because it constitutes a collective, a creative milieu. The network structure operates in relation to specific tasks such as innovations, analyses, the storing and use of knowledge and experiences, etc.

The development process (innovation and reflection) may be a top-down process where the top management takes the initiative and involves the employees. It may also be a bottom-up process where ideas, knowledge and entrepreneurship come from individual employees or from a collective process within the network structure, or managers start a process of development of innovation and reflection. Often it will be a mixture of both. Whatever, the top management will guide the process and finally decide upon the usefulness of the innovations and what consequences can be drawn from the reflections that have been made by the employees and managers in the network structure. The top management structure and network structure interact. Their mutual life is often harmonious and complementary. The top management needs the network

structure to generate innovative ideas. The top managers can rarely get the ideas they need themselves and they cannot just rely on scientific or expert trajectories. They also need the network structure for reflections on whether the strategy, the innovative ideas, and the way the innovation process is organized are the right ones in a given market situation. However, if the management were not there, the firm would be broken down by individual, anarchic entrepreneur behavior. The top management keeps the firm together, the network structure cannot contribute to the firm's development without the effort of the top management. However, the relation between the two parts might also be conflictual and destructive.

Special expert departments such as an R&D department or a strategy department, which have development (innovation, strategy, analyses or reflexivity) as their formal task, are in a third position in the organization. Mostly expert departments are related to the top management because they are placed in a hierarchical structure, but they may also play their own game, which will be organized more formally than the aforementioned bottom-up process.

Does reflexivity here mean leaving the formulation and fulfillment of the business strategy to experts or to 'ordinary people', which here would be the employees and middle managers in the firms (cf. the discussion in 'Reflexivity as a Form of Human Behavior')? Traditional innovation theory (e.g. Coombs et al., 1987; Freeman & Soete, 1997) emphasizes experts as those who innovate (researchers in R&D departments, marketing experts, etc.). The assumption here is that the effort of the 'ordinary people'—the employees and middle managers—is the most important, but that they and experts work together in the innovation process. The 'ordinary people' often ensure that innovation takes place, since experts outside the R&D department may hinder innovation (cf. Trott's analysis in his chapter of this book on how marketing experts hinder innovation).

Sometimes, the expert department (for example an R&D department) undertakes the whole innovation process, but this is very rare. Since the market and the customers' needs and reactions to innovations are the crucial factors, the firm needs information and reflections concerning these factors. The employees interact with the customers and are therefore play a necessary part in the process. Besides, many firms (service firms and small firms in particular) have no R&D department or any other expert department.

The involvement of the employees in the innovation process and the reflection process may be formally organized. This organizing will often take the form of creating project teams. The empirical part of this chapter investigates the forms the reflexivity process may take under different conditions.

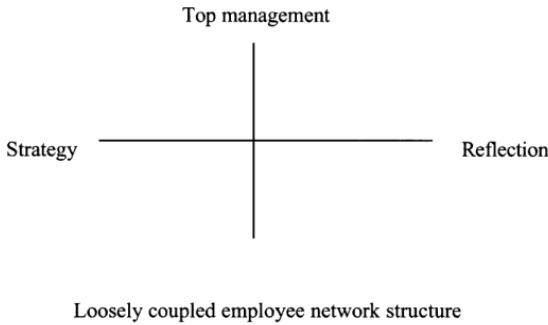


Figure 1. Model of the firm's core development factors.

The firm interacts also with several external actors and participates in formal and informal external networks to develop innovations. However, the external network is not a crucial notion in understanding the development of the firm from within the strategic reflexivity framework (as it is in the 'Uppsala school'; cf. Håkansson, 1987).

*The Functional Core of Strategic Reflexivity—Organizational Learning as the Overall Process*

To sum up the theoretical discussion, we can state the core of the interpretation of the firm's development function presented here and express it in Fig. 1.

The development of the firm is a dialectic process between action and analysis. The strategic part of the core notion compares to the action aspect of the model, and the reflexive part to the analytical aspect. By dialectic, I mean a situation where there are two factors, which are in opposition to each other but nevertheless only function if they interact with each other. Reflection is in conflicts with strategy because when actors reflect, they question strategy. Nevertheless, a workable strategy only exists if there are continuous reflections about its appropriateness.

The success of the firm depends on the mixture of strategy and reflection, and the management of the daily production because innovation and development are not always the primary goals. Firms develop cyclically. They will have steady periods in which they are driven by some non-innovative logic of production. If the firm is going well, there is no need to make radical changes that could destroy it. Innovation and change is risky. Successful firms may be assumed to take steps towards development only when they are aggravated by situations in the market situation (or a little before).

The other dimension in Fig. 1 is the dialectic between the top management and the informal network structure.

The whole dialectic process can be characterized as one of organizational learning, which is the overall attempt of the firm to guide the development. Organizational learning is the experience of how the four

elements of this model (cf. Fig. 1) should be combined in concrete situations. Even organizational learning can help the firm only some of the way. There are often several new factors in new situations, with the consequence that former experiences cannot be used. The learning must be combined with an entrepreneurial daring to try something new—an action perspective. I will come back to how organizational learning is carried out in 'Reflexive Feedback and Organizational Learning'.

**A Case Study: The Creation of New Service Concepts and the Development of the Firm**

As I have stated, the concrete way in which strategic reflexivity is developed varies according to the situation. It is assumed that certain patterns can be found, and the conditions for these patterns specified. These patterns are discovered by concrete empirical analyses, one of which we will now turn to.

Innovations in services can take many forms (cf. Gallouj, 1994). Earlier empirical analyses (Sundbo, 1998b) have demonstrated that the strategy defines the framework for the innovative activity. Here I will investigate whether strategy is developed reflexively and whether the process of developing innovations is reflexive. If the process is reflexive, it will combine considerations and corporate entrepreneurship, creativity, knowledge and learning.

I will begin this section by presenting the cases. Next I will describe how the service firms have formulated their strategies, and then move on to describe how the innovation process was carried out in the firms. Finally I will discuss learning.

The notion of strategic reflexivity and the theoretical statements established above will be the general framework for understanding the development processes. The concrete patterns that the development process follows will be investigated inductively. In the final part of the section, I will attempt to conclude whether several more general (although not universal) patterns can be identified. As far as general patterns can be identified, some models will be presented.

*Empirical Data and Method*

The empirical data are interviews and documentary material from case studies in different service firms. The aim is to investigate the formulation and importance of strategy, how the innovation process is undertaken, and how organizational learning is carried out. This investigation is done by studying how the service firms develop new service concepts.

Eight case studies will be used. The cases are the following: Two insurance companies, ((a) Hafnia and (b) Family Insurance), a bank ((c) Lån & Spar), a payment and credit card company ((d) The Payment Company), a chain of lawyers ((e) Ret & Råd), an engineering consultancy company ((f) COWI), a com-

pany providing cleaning and other manual services ((g) ISS) and (h) a municipal home help in one district of Copenhagen. The data have been collected throughout the 1990s in a project concerning the organization of innovation in service firms (Sundbo, 1998b) and a project on service development, internationalization and competence development (SIC, 1999).

The cases are analyzed in greater detail elsewhere (case (a), (b), (d): Sundbo, 1998b, case (c): Sundbo, 2000, case (e): Henten, 2000, case (f): Larsen et al., 2001, case (g): Sundbo, 1999; Illeris & Sundbo, 2000, case (h): Fuglsang, 2000, 2001).

### *The Formulation of Strategies*

The firms had different ways of formulating the strategies and made different strategies. The interesting questions are: Why did they take different paths, and what made them choose different strategies?

#### Different Patterns of Strategy Formulation in Service Firms

I will describe briefly what the firms did—which means what the top management and other employees did. This can be placed on a scale, which is not exact, relating to the degree of control by the top management. I will start with the firm where top management's control was the greatest and work my way down to where it was least.

The insurance company Hafnia, was dominated by a top entrepreneur (who was employed as a general manager but acted like an entrepreneur. cf. Sundbo, 1998b). He decided on the strategy on the basis of his own personal purposes: insurance companies have large capital because people pay the premium before the company has to pay for damages. He wanted to use the company's fortune for investment to create industrial activities. He wanted to be a new type of capitalist. Therefore, the strategy was to create as large a premium as possible, even if the company might have high damages. The company thus selected a market segmentation strategy: they chose the private upper income market. There was a clear entrepreneurial strategy, but no reflection about whether this strategy was wise. The role of the employees was only to restrict the 'wildness' of the top entrepreneur and that was only pure reaction, not prospectively reflexive. This case demonstrates that the absence of reflexivity can be a disaster, because the company went bankrupt as the entrepreneur and some of his closest managers—who were not reflexive either—were 'too creative' in the firm's investment and accountancy policy. The company went into deficit and then went bankrupt. The social system within the firm had become a back up and follow system for this one entrepreneur and was not a reflexive one.

The home help's strategy was also decided from above, i.e. by the political system. There had been

criticisms of how the public home-help system functions for the users, absenteeism among the employees had been large, and there had been several organizational problems. A new strategy was introduced to improve client quality and job satisfaction by making the system more flexible. There had been much reflection during the political process about the purpose of the home-help organization. Further, the detailed goals and means had been discussed nationwide by professional groups within the system. However, the reflections seem to have limited effects nationwide since the same problems continued. In this particular district the strategy of the home help was adapted in a way that made it work because of the professional tradition and a particular team system that was developed (see 'Examples of Service Concepts').

The Payment Company also had a top-down strategy process. The top management formulated the strategy. However, the firm was owned by a number of banks, and it had to be very careful in its strategy not to provoke the owners, who could very easily become competitors as well. This forced the top management to take a grip of the strategy process. In return, The Payment Company had established an innovation department. Its task was to initiate the development of new service concepts among the employees and to develop a detailed strategy based on innovative ideas and the strategic arguments behind them. They should then be responsible for its implementation. The reflection thus was professionalized and the responsibility for reflection allocated to a formal department. The result was a cautious strategy of product development.

Family Insurance had a top-down strategy process as well. The choice of this form of process was due to experience. The company had had a top entrepreneur as managing director a few years before I carried out the interviews. He had got the employees and managers so occupied with innovation and change that it took up time from daily production and sale, and the company nearly went bankrupt. However, the employees and managers were still involved in innovation activities, which led to ideas concerning strategic changes, and the process was more controlled by the top management. In this case, reflections concerning the strategy were based on experience. The outcome of the process was a market segmentation strategy—the company chose the lower-income private market.

ISS is in an in-between position. The strategy process was run by an office in the headquarters, but the strategy was discussed by the managers throughout the company. The particular structure of the organization—many employees worldwide (about 250,000) and a large labor turnover—made it impossible for the firm to involve the employees and even lower managers. It was the upper managers, who were involved in the strategy process. The involvement of the upper managers was achieved by having them discuss the strategy in

local groups combined with general meetings in which all involved managers were assembled. The process resulted in a strategy which emphasized productivity increase and the development of new, specialized, manual services.

In COWI the top management had the responsibility for the strategy. The market for engineering consultancies was undergoing constant change so the firm had adopted a fluent strategy. The ideas for new strategy elements mostly came from the daily product, which is solving engineering problems for customers, organized as teamwork. The company combines technical solutions with administrative, sociological and economic approaches such as the creation of a democratic administration in a developing country. Reflection was continuous, based on the experiences from projects that should solve the customers' problems. The top management combined these with speculations about what competitors—who potentially can come from other industries—will do in the future. The strategy formulation process resulted in a careful product development strategy. Old products were renewed and some new products (among those management consultancy) were introduced.

Lån & Spar has had a very broad strategy process in which all employees and managers have been involved. The bank is a small bank in an industry with tough competition, so the strategy is a matter of survival. The top management organized training courses where the employees learned what a strategy is, were obliged to discuss the bank's strategy and were requested to present proposals for a new strategy. The final strategy was a result of very comprehensive interactive reflection processes. The top management guided the process to a certain degree since the general manager decided on the final strategy with help from his nearest managers. The bank had chosen a market segmentation strategy which went for the middle and upper income private customers.

Ret & Råd had the most extreme bottom-up process. The chain was established by a group of lawyers, who could see that the market for lawyers would be dominated by large firms. They believed that if small, independent lawyers were to survive, they needed to unite in some way. The strategy thus was one of economics of scale. The strategy of Ret & Råd was also very reflexive. Since Ret & Råd was a chain of independent lawyers, all partners had to agree to any change in the strategy. This condition ensures that everybody is equally involved in the reflection and decision process (perhaps except the employees of the single lawyer), which means that they in fact do not need to be reflexive, but only need to say 'no' to hinder the formulation of a strategy. A common secretariat has been established. The leader of the secretary wanted to develop the chain and strategy further, but it had been extremely difficult to do this. Such a chain of independent professionals seems to be conservative,

and inertia and actual self-interest seem to be impediments to the long-term development of the strategy.

#### General Lessons from the Service Firms

The lessons from the cases are:

The service firms have generally become more strategy- and reflection-oriented during the period under study (the 1990s). In the beginning, they were mostly focused on competitors and only moved when the competitors did. The reflexive basis was limited to competitor watch. Later, they all employed a strategy and were broadly oriented towards many actors, trajectories and internal resources and competencies. Their reflection basis was broader.

The different patterns of strategy formulation can be summed up as the following:

Some of the firms (such as Hafnia) had a top-down process of strategy formulation. Others (such as Ret & Råd) had a bottom-up process. However, most of the firms had a process that was both top-down and bottom-up. These firms had a dual interaction form of strategy formulation. This means that the top management had the final responsibility and control of the strategy process, but the employees and managers were involved in the process. The employees made the reflections in interaction with other employees and actors. The top management also discussed the strategy with their closest managers and sometimes other employees. The two systems, the top-down management system and the bottom-up loosely coupled network system among the employees, interacted with each other. The interaction implies that the initiatives and ideas came sometimes from above and sometimes from below, and these two sets of initiatives and ideas met each other and sometimes melted together. They acted in accordance with the theoretical model established in 'Reflexivity as an Organizational Factor'.

The question to address here is: Which pattern is the most efficient if the firm is to develop successfully? This is difficult to determine. In the cases presented here the two most extreme (top-down and bottom-up) ones were not efficient. The pure top-down system of top entrepreneurship in Hafnia led to bankruptcy because of insufficient reflection, and at the other extreme anarchical entrepreneurship formerly executed in Family Insurance nearly did the same. The extreme egalitarian system of Ret & Råd led to action paralysis. The home help is part of a public, political system with many actors involved in the formulation of the strategy. This did not lead to an efficient strategy, since the clients and employees saw many problems which the system had difficulties in solving. This result also suggests that a decision and reflection system that is too broad but has a weak top management is not the most efficient development system. The system in the home help is not sufficiently dual.

The majority of service firms, who had a dual form of strategy process followed a pattern in which there

was a more equal balance between entrepreneurship, top-down control and employee involvement. Such a pattern was the case with ISS, COWI, Lån & Spar and Family Insurance (during the period studied). These firms were all characterized by a defensive market situation with stagnant markets and hard competition. Therefore, they needed all the inputs they could get without losing control. The Payment Company had professionalized a reflexive strategy process. This company was in a growing market with a good, almost monopolized, situation, but with very hard owners. These firms were more successful in formulating a sustainable strategy.

One may, on the basis of the results, state another hypothesis that the more pressed the firm is on the market, the more they involve employees and managers in the development process. In a very pressed market situation, the firm needs a more radical development with a new strategy and many innovations, which is difficult in that situation. The less pressed they are on the market, the more the development process will be professionalized. In a less pressed situation, innovations within the existing strategic framework will be useful to the firm. However, in that situation, experimenting too much with new strategies should not disturb the favorable market situation. Risky experimentation could be the case if the formulation of the strategy is left to the employees. The above considerations also underlines a hypothesis of a cyclical movement (between pressed and non-pressed market situations) in the development and thus in strategic reflexivity.

### *The Innovation Process*

I shall now turn to discuss the innovation process within the firms. The discussion and conclusions relating to the theory emphasize several elements of the organizational system such as interaction and roles. These organizational elements are important factors in explaining the innovation producing system in the service firms.

The analysis will deal only with innovation. Non-reproduced small changes exist in service firms. Since they are not reproduced, there is no process to describe, and no organizational system to analyze. These changes are important, but they are created by single employees. To study them would demand a comprehensive method of observation or diary writing. There have been insufficient resources in the research projects to use such methods. The process of creating small changes must therefore, unfortunately, be left out of this analysis.

### *Examples of Service Concepts*

To begin with I briefly describe a few selected service concepts and how they were developed in the case firms, just to give an impression of what a service concept can be.

In Family Insurance a new insurance concept for bicycles was invented. The insurance policy could include or exclude validity at different places where the theft of bicycles has a high probability and the premium was correspondingly differentiated. The concept was developed as a collective process in one department.

An insurance agent (which is close to its customers) invented a particular questionnaire to investigate the customers' insurance needs in Hafnia. Somebody else in the company heard about the questionnaire, some of the managers discussed it with the insurance agent, and the questionnaire was developed and made general for use throughout company. The questionnaire was a product as well as a marketing tool, and functioned also as a process innovation (a tool in creating individually modularized insurance by combining standard elements).

ISS developed a new cleaning concept for small and medium-sized business customers. Instead of the normal cleaning assistants following a detailed routine managed by inspectors, the management of the cleaning division had developed a new concept. Flexible teams were established, and they agreed with the customers and planned their work themselves. The team leaders gained a special role. Not only did they manage the day-to-day work, but they did it in a way that involved the team members, and they created attractive social conditions in the teams. This behavior resulted in increased quality, productivity, customer satisfaction, and decreased absenteeism. The behavior was developed by a particular type of team leaders, typically 30 to 40-year-old women.

In the home help a similar type of team leader was developed. The process was managed by a group of managers in the district but again was the particular team leader type developed through the process.

The Payment Company developed a chip-based cash payment card. The card can be used in payment instead of cash. The card was more like a traditional manufacturing product and was developed in an R&D like department.

Lån & Spar had organized a large organization development project where the employees were involved in strategy development and innovation activities in teams. A couple of the results were two service concepts. One was a new credit card characterized by a low interest rate, and it only took very short time (about 15 minutes) to get the card due to a new IT-based credit assessment system. The credit card concept was developed by one team, which had been set up as a result of a training course. One employee became particularly engaged in the process and later became the leader of the group that produced and marketed the credit card. Another new concept was a customer database with information about the customers. The database was useful for marketing and advising. It was

developed as a collective project within the IT department.

Ret & Råd was based on an organizational innovation, namely to unite independent lawyers in a chain and to utilize their different competencies. A division of labor was established, and the lawyers remained independent. The idea was created by a few lawyers and was diffused to, and further developed by, other lawyers, who entered the chain.

The service concepts thus are of a very different kind and are developed in different ways, but in most of these cases they were developed by involving a large part of the organization.

#### The Innovation Process and Strategic Framework

Earlier analyses of some of these cases have demonstrated that the strategy was the framework for the innovation activities (Sundbo, 1998b). The strategy thus generally functions as a limitation of, but also inspiration for, innovative activities. This is as more the true the more top management emphasizes the strategy, and invites the employees to develop new ideas. The middle managers have a particular role here. They are generally the most innovative people, they implement the strategy and top management's effort in the day to day work, and they often become leaders in the interaction process.

One might assume that the employees and managers would have a greater self-interest that makes them fight for their own ideas. They do, but their ideas were within the strategy. They had to be that to be accepted in the firm and this acceptance is the basis for personal success and career. New ideas were, in rare cases, implemented just by entrepreneurship and were then results not of reflections but of pure action orientation. Sometimes the entrepreneurs succeeded, which resulted in a change of the real strategy, but mostly they were squeezed out and may have established their own firm.

Thus, the process of strategic reflexivity is continuing in the innovation process. Corporate culture, which has been seen as a fundamental factor for creating innovation (e.g. Sjölander, 1985), might not be the most important factor as my empirical studies demonstrated. Culture is a long-lasting, fundamental factor and therefore not reflexive and not strategically based. Culture cannot change as fast as strategy. Corporate culture might be reflexive in the way that it is created by the management as Schein (1984) says. However, the corporate culture is then part of the strategy, and the strategy is the core key to understanding the social processes within the firm.

The case studies have demonstrated that people within the organization can be oriented towards being innovative. Such an innovation orientation demands a comprehensive effort from the management, but that may be done, as the Lån & Spar case demonstrates (Sundbo, 2000) even though there are problems in

doing this. The problems are also demonstrated in the Lån & Spar case. The employees in the bank have been more occupied by the general motivation factor—how they relate to other people and how they can personally learn from change processes—than by innovating.

#### Patterns of Interaction

The ideas for innovation are often developed in a certain pattern within the interaction system. These ideas may be the result of the employees' daily interaction, for example with colleagues and customers. Even when the customers are the source of ideas, the innovative idea in most cases is a result of the interaction between the employee and the customer. The customer has a problem or a want, which the employee cannot guess unless he meets the customer. The customer does not express his or her wants or problem as an idea for a new service concept. The employee translates the interaction into an idea for a service concept. That was how the insurance agent in Hafnia developed the Hafnia questionnaire. The development of the idea and the implementation of the service concept are also interaction processes in which several employees and managers from different departments participate.

In the case firms I found different interaction patterns, which can be generalized. The interaction patterns reflect the way in which ideas for innovations come to the surface and the innovations are developed. These are generalizations, and the interactions had more details, which followed different ways in the single case. Now I will outline the main patterns (a development of innovative organizational models that have been studied previously; Sundbo, 1998b). The interaction patterns also show the power system within the firm and how the organization in general is built and functions.

Four different interaction patterns can be identified. The first one is the most top-down pattern found in Family Insurance and Hafnia. The top management guided the process by signaling which type of service concept was wanted and often picked out which persons should work with an idea. The interaction was of course between these persons, but the top management was deeply involved in almost all interactions. This pattern could be called *the management pattern*. A particular variant was Hafnia where the managing director was the entrepreneur himself. The interaction system was largely centered around commenting and developing his ideas.

The pattern in Ret & Råd and The Payment Company could be called *the professionalized pattern*. A particular department had the task of initiating new service concepts and of initiating interactions in the organization to develop the concepts. In Ret & Råd, the professional secretariat of the network had to convince the independent lawyers of the new ideas, which made the task extremely difficult. The leader of the secretar-

iat quitted his job during the period of investigation because of the difficulties in getting changes accepted in the network.

The third pattern is *the team pattern*. Service concepts are developed through an intense interaction process within a team. The team members also interact with external individuals and the top management, but the main part of the interaction is within the team. Only in the final implementation period is the interaction pattern diffused to a larger part of the organization. This pattern was found in COWI, ISS and the home help.

Lån & Spar had the most extended interaction pattern for development of new service concepts. A very large part of the organization was involved. The top management participated in the daily interactions—although the managing director had the power to decide on all service concepts, and did that after having consulted other managers. This fourth pattern could be called *the total pattern*.

#### Role Patterns

In the development of new service concepts people had different roles in the interaction process. These roles have different functions in getting the innovation process running. Role is a core concept within social psychology and sociology (Maccoby et al., 1966; Parsons, 1951) and is a useful concept in this analysis. Formerly some roles in Family Insurance and The Payment Company have been described (Sundbo, 1998b). These roles were: the entrepreneur role, which is creation of ideas and struggle for implementing them (the entrepreneur is a type exposing him—or herself very much); the analyst role, which has the reflection function and analyses the possibilities and outcomes—this is a purely reflexive role; and the producer role. The first two had a function in the innovation process while the third concerns the effort of having the daily production system running. A role is something that the organization members play when he or she is at work. An individual does not need to play the role the whole time and can play several roles simultaneously.

From the other case studies referred to here, I can identify three roles which fulfil three functions in the innovation process of developing service concepts. These are the *entrepreneur* and the *analyst*, as were formerly found, plus a new role, the *interactor* (Sundbo, 2001), which has the function of having the interaction process running. Theoretically, one may state that a balance with all three roles equally represented is the optimal for innovation (here we can forget the producer role because we only are dealing with innovation). This can be expressed in the model of Fig. 2.

Interaction is what makes this system of role mixture reflexive in relation to the pure entrepreneurship system. The process where more than one individual is involved leads to more reflection due to a certain

opposition (cf. Tarde, 1897). Opposition means that there is always a certain skepticism towards new ideas.

#### *Reflexive Feedback and Organizational Learning*

Theoretically one must state that if the social system is reflexive, the innovation processes should result in learning: the experiences about how the process went and how the innovations worked in practice should be collected, analyzed and result in strategic changes. The reflexive practice should result in a feedback to the overall goal, the strategy.

The feedback mechanism concerns how suitable the actual strategy and the way in which the innovation process is carried out are. Firstly, the feedback mechanism includes how the learning of the innovation processes could result in a change of the strategy. An experience might for example be that the firm has difficulties in implementing certain innovations, which could result in a change of the strategy. Secondly, the feedback mechanism includes how learning about the innovation process could result in a change in the way in which the service concept development process is organized and carried out. It might, for example, be that some project teams function badly or there are difficulties in engaging the employees in developing new ideas.

The total feedback and learning development process can theoretically be expressed in the model shown in Fig. 3.

The process starts with reflections concerning the market and the internal resources. The reflections are interpreted by the management, which leads to a strategy. The strategy leads to innovation processes that—in this case—resulted in new service concepts. Experiences from the innovation process may lead to a change in the strategy or in the way of carrying out the innovation activities, which is another reflection. When the final outcome of the innovation process (here, the service concept) has worked for some time, further considerations may lead to the conclusion that a new market position or new internal resources are needed, which are further processes of reflection.

All these processes are experience-based learning, which leads to feedbacks to earlier factors in the model. The reflections may involve theoretical elements (found in management books or procured from consultants), but these will be considered within the framework of the concrete experiences.

The model above is of course very formalized. The model might give associations to cybernetics (e.g. Beer, 1964). The real processes are not fully rational and may have all variants of extra loops, inefficiencies, and mistakes as the empirical cases demonstrate. Therefore, the postulate here is not that the process is a smooth-running efficient process that can be described by a cybernetic model. The model is an abstract heuristic model that presents the elements in

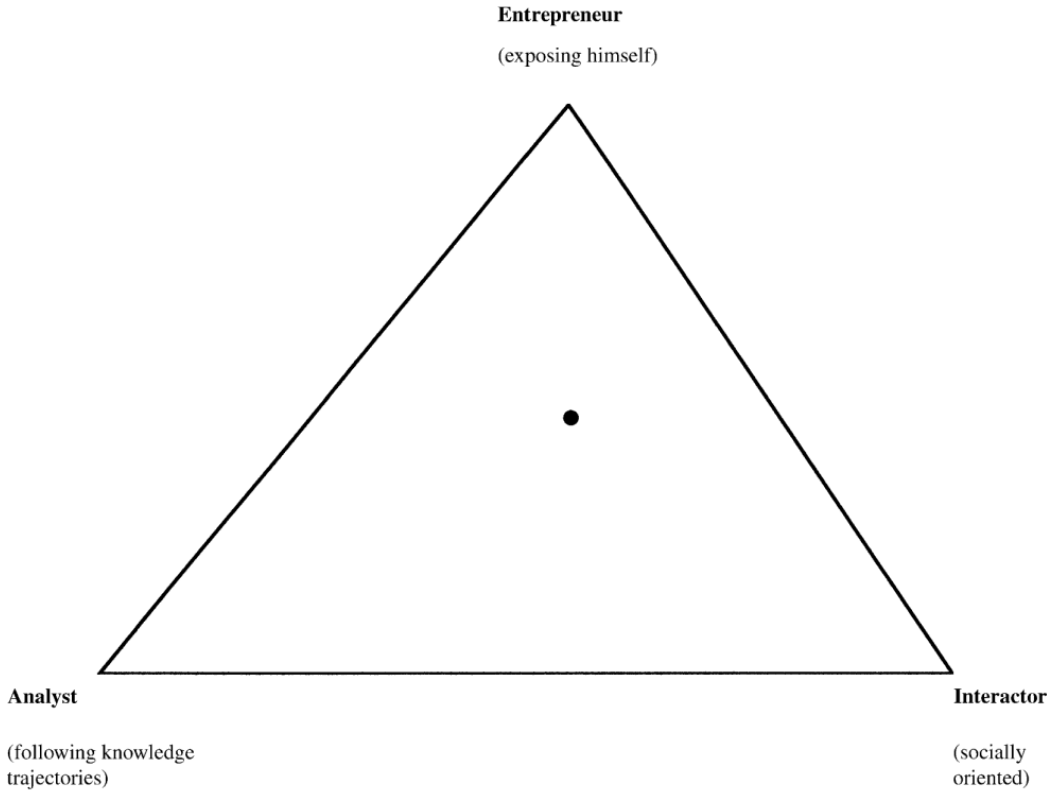


Figure 2. Model of the roles in the innovation process.

the process. The real pattern is chaotic as stated, so the real model should be extremely complex, which would be impossible to draw.

Examples of some chaotic elements of the model in real life can be found in the case studies. Organizational learning functioned generally poorly in the service firms studied. The firms wanted to collect the experiences from innovation processes but had difficulties. For example Lån & Spar had difficulties, even though the management actively attempted to create a feedback system, and the title of the total organiza-

tional development project was ‘the learning organization’ (Sundbo, 2000). The difficulties were caused by at least two factors. One was that the employees and managers were not interested in formally registering the general experiences. Such registering was considered an activity that counts not as a valuable competence but as a bureaucratic duty. Further, the bank had difficulties in storing the experiences. They tried to use note sheets in the IT system, but that did not work as a general learning data bank and the experiences were not systematized.

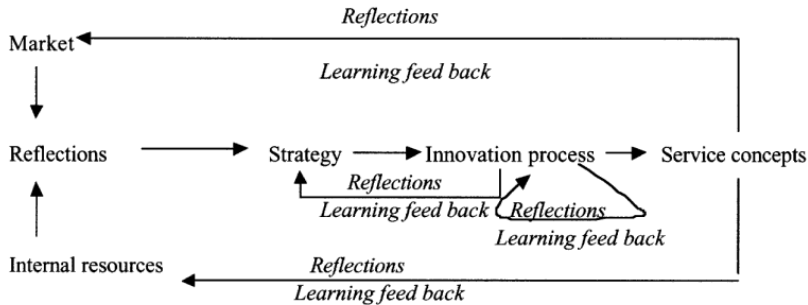


Figure 3. Model of the organizational learning process and feedback mechanisms.

COWI had difficulties in collecting experiences from the work and development in the project teams. The team members were already engaged in new projects before the first ones were completed and never did have time to systematize the experiences and communicate them to other parts of the organization.

The strategy was changed as a consequence of innovation experiences in some of the service firms. Family Insurance changed their strategy from being innovative and going for an advanced market segment to going more conservatively for the medium- and lower-income private market due to its experiences with problems of managing the internal personnel resources (whether they should be innovative or productive). The Payment Company has recently changed its strategy away from launching technical tools such as the chip-based cash payment card back to basics, credit cards, because of a failing market.

### Summing Up

This chapter has presented a theoretical approach to the development of the firm, namely a strategic innovation theory (cf. Sundbo, 1998a, 2001, 2002). The theory focuses on the activities that lead to innovations. This theoretical approach is a 'soft' evolutionary one. Primarily, the firm relates to the market developments and this is decisive for its innovation activities. However, the firm also relates itself to the internal resources and their ability to contribute to the development. External trajectories, which include new knowledge and technology, also play a role, but only by presenting possibilities; they do not determine the development of the firm. The firm's relation to these factors is expressed in the strategy, which is not just a written plan, but a management policy.

The strategy defines the goal(s) for the development of the firm in broad terms and is the overall means for attempting to guide the firm's development. This statement expresses a quasi-rational approach: the top management attempts to steer the process, but that is only possible to a certain degree. The top management becomes dependent on involving the employees and middle managers in all steps of the process—from formulating the strategy over innovation activities to organizational learning.

Innovation and change can be characterized as a process of strategic reflexivity. The strategic reflexive process is a process of innovation and of small changes made by individuals or small groups. There is a certain organizational structure within which these activities are carried out, but the structure varies in different situations.

Therefore, innovation cannot be described by one causal or descriptive model, but certain patterns, which vary and are repeated in different combinations, may be observed (as is expressed in chaos theory; cf. Kiel & Elliott, 1996; Quinn, 1985; Stacey, 1993). In the chapter, such patterns were investigated in one type of

firm, namely different service firms. The results of this investigation were:

The processes are taking place in a reflexive, interactive organization system as was demonstrated by an empirical case: the development of service concepts. Four interaction patterns within the innovation process could be observed. The interaction process depends on three core roles as entrepreneur, analyst and interactor.

A theoretical organizational learning system in the form of a feedback mechanism was outlined. This learning system is learning by experience and reflexive. The feedback loops may lead to a change in strategy (and thus the way the firm should go in its innovation activities) and of how the innovation activities should be carried out and organized.

Empirically, it was observed that the service firms had difficulties in establishing efficient feedback mechanisms and learning because employees and managers were not motivated to do this and because of a lack of tools for storing the experiences.

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# The Nature and Dynamics of Discontinuous and Disruptive Innovations from a Learning and Knowledge Management Perspective

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**Abstract:** In this chapter we will discuss and profile the evolutionary and revolutionary dimensions of the nature and dynamics of innovation as a socio-technical phenomenon. We will focus in particular on the *process, content, context, and impact* of both *discontinuous* and *disruptive* innovations. We postulate that at the heart of the competence to generate and perhaps more significantly *to leverage discontinuous and in particular disruptive innovations, lies the individual and organizational capacity for higher-order learning* and for managing the stock and flow of specialized and domain-specific knowledge. We will provide both concepts and cases to illustrate our ideas and supply thematic anchors for academic and practitioner contexts.

**Keywords:** Disruptive innovation; Discontinuous innovation; Higher-order technological learning; Knowledge management.

## Introduction

A little revolution now and then, is a good thing

Thomas Jefferson

'Innovation' is a word derived from the Latin meaning 'to introduce something new to the existing realm and order of things'. In this sense, innovation is endowed with a faculty of discontinuity and possibly disruptiveness in the form of a continuum of discontinuities reflected by a simple analogy to the way we walk. From a business perspective, an innovation is perceived as the happy ending of the commercialization journey of an invention, when that journey is indeed successful and leads to the creation of a sustainable and flourishing market niche or new market. Not all innovations are discontinuous, and not all discontinuous innovations prove to be disruptive. This is determined by the scope, timing, and impact of the innovation under consideration.

The literature on innovation, particularly regarding technological innovation, is populated by a number of taxonomies which attempt to categorize innovations by

significance, similarity (and dissimilarity), technical domain, and other characteristics. As the vocabulary used to describe innovation has grown and evolved, scholars naturally generate multiple taxonomies which are at times overlapping, redundant, or divergent. A recent review of the literature on new product development found that in just 21 empirical studies, researchers have developed 15 different constructs for describing various aspects of innovation (Garcia & Calantone, 2002). Some of the distinctions produced by previous authors include *process vs. product* innovation (Utterback & Abernathy, 1975), *incremental vs. radical* innovation (Henderson & Clark, 1990), and *evolutionary vs. revolutionary* innovation (Utterback, 1996):

*Technological innovation* is defined here as a situationally new development through which people extend their control over the environment. Essentially, technology is a tool of some kind that allows an individual to do something new. A technological innovation is basically information organized in a new way. So technology transfer amounts to the

communication of information, usually from one organization to another.

This chapter focuses on the recent discussion by Christensen (1997) of *disruptive* (as opposed to sustaining) technologies, and the related concept of *discontinuous* (as opposed to continuous) innovation (Anderson & Tushman, 1990). This particular type of innovation is significant, as there have been many attempts to determine the extent to which discontinuous innovations can be ‘managed’, and how companies can try to predict and leverage the emergence of disruptive technologies. In this chapter we will discuss and profile the evolutionary and revolutionary dimensions of the nature and dynamics of innovation as a socio-technical phenomenon and focus in particular on the process, content, context, and impact of both discontinuous as well as disruptive innovations.

*We postulate that at the heart of the competence to generate and perhaps more significantly to leverage discontinuous and in particular disruptive innovations, lies the individual and organizational capacity for higher-order learning and for managing the stock and flow of specialized and domain-specific knowledge. We will provide both concepts and cases to illustrate our ideas and supply thematic anchors for academic and practitioner contexts.*

### The Nature and Dynamics of Innovation

Basic research is what I am doing when I do not know what I am doing.

Dr Wehrner von Braun

Before a definition of innovation can be discussed, the related term ‘invention’ must be understood. Florida considers invention as a breakthrough and innovation as an actualization (Florida, 1990). Hindle further clarifies invention by labeling it as the creative origin of new process and the enabler of innovation (Hindle, 1986), which has impacts on social, economic, and financial processes. Thus the emerging definition of invention may be stated as the creative process of progress while innovation is defined by the impact on societies and markets (actualization). “Innovation generally lowers the cost of responding to a change in the commercial environment” (Wallace, 1995). Thus, innovation has the connotation of market influence.

Identifying the source of innovation may assist in the definition. The pace of improvements brought about by innovation, the rate of innovation, may be determined by the technology pull or market push factors. The question of a specific source of innovation is brought about by a process of ‘*learning by doing*’ (Rosenberg, 1976). In this is meant that innovation, through the continuous incremental effects of knowledge acquisition, has the effect of cumulatively impacting on future innovations.

Other related terms, like science and technology, should be defined in the context of innovation. Traditional epistemology defines science and scientific knowledge as the world of objective theories, objective problems and objective arguments. Further clarification is found in Kuhn (1962) defining *science* as research firmly based on one or more past achievements.

*Technology* is defined as that “which allows one to engage in a certain activity. . . with consistent quality of output”, the “*art of science and the science of art*” (Carayannis, 2001) or ‘*the science of crafts*’ (von Braun, 1997). Diwan adds that technological foundations are market size, standards, innovation, high motivation, and supply of capital (Diwan, 1991) The impact of innovation may be directed to multiple sectors. For example, Jonash lists product/service, process, and business innovation as the key impact areas. Product/service is the development and commercialization of hard goods, process is new ways of producing and delivering cost-time-quality advantages, and business innovation is new models of conducting business for competitive advantage (Jonash & Sommerlatte, 1999).

A fundamental challenge to the present analysis is the distinction between what is and what is not an innovation. When related to technologies, one common definition of an innovation is “an idea, practice, or object that is perceived as new by an individual or other unit of adoption” (Rogers, 1983, p. 11). Thus, a technological innovation is a new idea, practice, or object with a significant technology component.

A technical discovery or invention (the creation of something new) is not significant to a company unless that new technology can be utilized to add value to the company, through increased revenues, reduced cost, and similar improvements in financial results. This has two important consequences for the analysis of any innovation in the context of a business organization.

First, an innovation must be integrated into the operations and strategy of the organization, so that it has a distinct impact on how the organization creates value or on the type of value the organization provides in the market.

Second, an innovation is a social process, since it is only through the intervention and management of people that an organization can realize the benefits of an innovation.

The discussion of innovation clearly leads to the development of a model, to understand the evolving nature of innovation. Innovation management is concerned with the activities of the firm undertaken to yield solutions to problems of product, process, and administration. Innovation involves uncertainty and dis-equilibrium. Nelson & Winter (1982) propose that almost any change, even trivial, represents innovation. They also suggest, given the uncertainty, that innovation results in the generation of new technologies and changes in relative weighting of existing technologies

(ibid). This results in the *disruptive process* of dis-equilibrium. As an innovation is adopted and diffused, existing technologies may become less useful (reduction in weight factors) or even useless (weighing equivalent to '0') and abandoned altogether. The adoption phase is where uncertainty is introduced. New technologies are not adopted automatically but rather, markets influence the adoption rate (Carayannis, 1997, 1998). Innovative technologies must propose to solve a market need such as reduced costs or increased utility or increased productivity. The markets, however, are social constructs and subject to non-innovation related criteria. For example, an invention may be promising, offering a substantial reduction on the cost of a product which normally would influence the market to accept the given innovation; but due to issues like information asymmetry (the lack of knowledge in the market concerning the invention's properties), the invention may not be readily accepted by the markets. Thus the innovation may remain an invention. If, however, the innovation is market-accepted, the results will bring about change to the existing technologies being replaced, leading to a change in the relative weighting of the existing technology. This is in effect dis-equilibrium.

Given the uncertainty and change inherent in the innovation process, management must develop skills and understanding of the process a method for managing the disruption. The problems of managing the resulting disruption are strategic in nature. The problems may be classified into three groups, *engineering, entrepreneurial, and administrative* (Drejer, 2002). This grouping correlates to the related types of innovation namely, *product, process, and administrative innovation*:

- The engineering problem is one of selecting the appropriate technologies for proper operational performance.
- The entrepreneurial problem refers to defining the product/service domain and target markets.
- Administrative problems are concerned with reducing the uncertainty and risk during the previous phases.

In much of the foregoing discussion, a recurring theme about innovation is that of *uncertainty*, leading to the conclusion that an effective model of innovation must include a multi-dimensional approach (uncertainty is defined as unknown unknowns whereas risk is defined as known knowns). One model posited as an aide to understanding is the Multidimensional Model of Innovation (MMI) (Cooper, 1998). This model attempts to define the understanding of innovation by establishing three-dimensional boundaries. The planes are defined as product-process, incremental-radical, and administrative-technical. The product-process boundary concerns itself with the end product and its relationship to the methods employed by firms to produce and

distribute the product. Incremental-radical defines the degree of relative strategic change that accompanies the diffusion of an innovation. This is a measure of the disturbance or dis-equilibrium in the market. Technological-administrative boundaries refer to the relationship of innovation change to the firm's operational core. The use of technological refers to the influences on basic firm output while the administrative boundary would include innovations affecting associated factors of policy, resources, and social aspects of the firm.

#### *A Historical and Socio-Technical Perspective on Innovation*

But in capitalist reality, . . . it is not price competition which counts but the competition from the new commodity, the new technology, the source of supply, the new type of organization, . . . competition which . . . strikes not at the margins of the existing firms but at their foundations and their very lives.

Joseph A. Schumpeter

Capitalism, Socialism and Democracy, 1942

To review the history of innovation, one must look toward the classic works of Schumpeter. Schumpeter, an economist, wrote 'The Theory of Economic Development' in 1934 as an inquiry into profit, capital, credit, interest, and the business cycles. His main contributions were: (a) the expansion of Adam Smith's economic principles of land-labor-capital into land-labor-capital-technology-entrepreneurship; and (b) the introduction of the concept of dis-equilibrium into economic discourse.

It is interesting to note that Schumpeter was a socialist and believed that the capitalist system would eventually collapse from within and be replaced by a socialist system. On this point he agreed with Marx, but his version of socialism was in many respects very different. Marx felt very strongly that the economic model employed would determine the construct of society. The cornerstone of his theoretical structure was the 'Theory of Value' (*Das Kapital*) where the value of a commodity, given perfect equilibrium and perfect competition, is proportional to the input of labor. Schumpeter disagreed with Marx on this issue offering the conclusion that both perfect equilibrium and perfect competition were problematic at best. Additional disagreements centered on the inclusion of the value of land in the equation. Another point on which Schumpeter disagreed, is Marx's contention that the capitalist system would implode (*Zusammenbruchstheorie*) as a result of its intrinsic inequities. In Schumpeter's view, the natural evolution of capitalism would destroy the foundations of capitalism from within. In fact, he believed that the economic depression of the 1930s was an indication of a paradigm shift, reinforcing his beliefs. Schumpeter viewed capitalism in much the same way as he viewed the process of innovation. Both

were generally considered stable processes (under perfect conditions) from a theoretical model perspective but Schumpeter introduced the conceptual theory of dis-equilibrium as the key influential factor and this could be further expanded into the concept of continuum of punctuated dis-equilibria (Carayannis, 1994b) to capture and articulate the concept of successive Fisher–Pry curves (S-curves) with discontinuous and/or disruptive innovations causing a change of curve and/or change of ‘the rules of the game’ as we will see later:

Michael Tushman and Charles O’Reilly suggest that discontinuous innovation involves breaking with the past to create new technologies, processes, and organizational ‘S-curves’ that result in significant leaps in the value delivered to customers. Similarly, Clay Christensen, Gary Hamel and C. K. Prahalad, and James Utterback describe discontinuous innovation as involving ‘disruptive technologies’, ‘discontinuities’, or ‘radical innovations’ that permit entire industries and markets to emerge, transform, or disappear (Kaplan, 1999).

Early capitalism is often referred to as ‘laissez-faire’ but post-WWII capitalism is much more bounded by social, political and legal norms. In following Schumpeter’s principle of evolutionary capitalism, it may be that the bounded capitalism of the modern era is a logical extension of Schumpeter’s theory.

The concept of innovation as a ‘socio-technical’ system is well established. Rogers (1995), for example, defined innovation in terms of the perceptions of the individuals or groups which adopt an innovation. Attempts to classify innovations in purely technical terms fall into the trap of portraying the result of a social process as something entirely divorced from human influence.

We propose an approach to classifying and subdividing the concepts of innovation along four fundamental dimensions:

- (1) The *process* of innovation (the way in which the innovation is developed, diffused, and adopted)
- (2) The *content* of innovation (the specific technical or social nature of the innovation itself)
- (3) The *context* of innovation (the environment in which the innovation emerges, and the effect of that environment on the innovation)
- (4) The *impact* of innovation (the social and technological change which results from the completion of the innovation process) (Carayannis, 2002).

Using these four dimensions of innovation, we can delve more deeply into the social implications of disruptive and discontinuous innovation, which in turn facilitates the integration of innovation management concepts with those of organizational learning and knowledge management. In putting these elements in

perspective, one needs to bear in mind the following key creativity and innovation drivers and qualifiers:

- (1) Context: In what context do all of the above occur?
- (2) Process: What is the process by which the above are realized?
- (3) Content: What is the content of the above in terms of reaction on the others?
- (4) Impact: What is the impact of each of the above on the others?
  - All of these attributes must be considered at all levels including the firm, industry, national and global levels;
  - What you invent determines the content of the innovation;
  - Commercialization is a necessary but not sufficient condition for innovation;
  - Creativity and competition may be exogenous factors to competitiveness;
  - Competition facilitates or suppresses competitiveness (see Fig. 1);
  - Consolidation may breed complacency;
  - Disruptive technologies can renew competitiveness.

However, excessive rivalry may sap competitiveness leading to the *Acceleration Trap* (von Braun, 1997) and the *Differentiation Trap* (Christensen, 1997) (see Fig. 1). These are situations of increasingly shorter and unsustainable product cycles and spiraling R&D costs with shrinking profit margins and market shares—the result of excessive competition and declining competitiveness (what we term *hyper-rivalry* in the private sector). In these situations, change takes place so fast that firms often fail to benefit fully from it (their learning curves are not steep enough) and they also end up using resources inefficiently and undermining their market position by engaging in price wars or frivolous innovation races. Then firms can find themselves ‘trapped’ in a vicious spiral of increasing competition and declining competitiveness and end up rendering their market niches increasingly hard to sustain.

#### *Common Frameworks and Typologies for Characterizing Innovation*

Comforted by idols, we can lose the urge to question and thus we can willingly arrest our growth as persons: ‘One must invoke tremendous counterforces in order to cross this natural, *all too natural progressus in simile, the continual development of man toward the similar, average, herdlike common!*’

Nietzsche, Thus Spake Zarathustra, 58

Innovation may be generally categorized as product, process, or administrative (Tidd, 2001). Others classify innovation by regional influences (Evangelista et al., 2001), or decision criteria (Rogers, 1995). Still others view innovation as product-process-radical-techno-

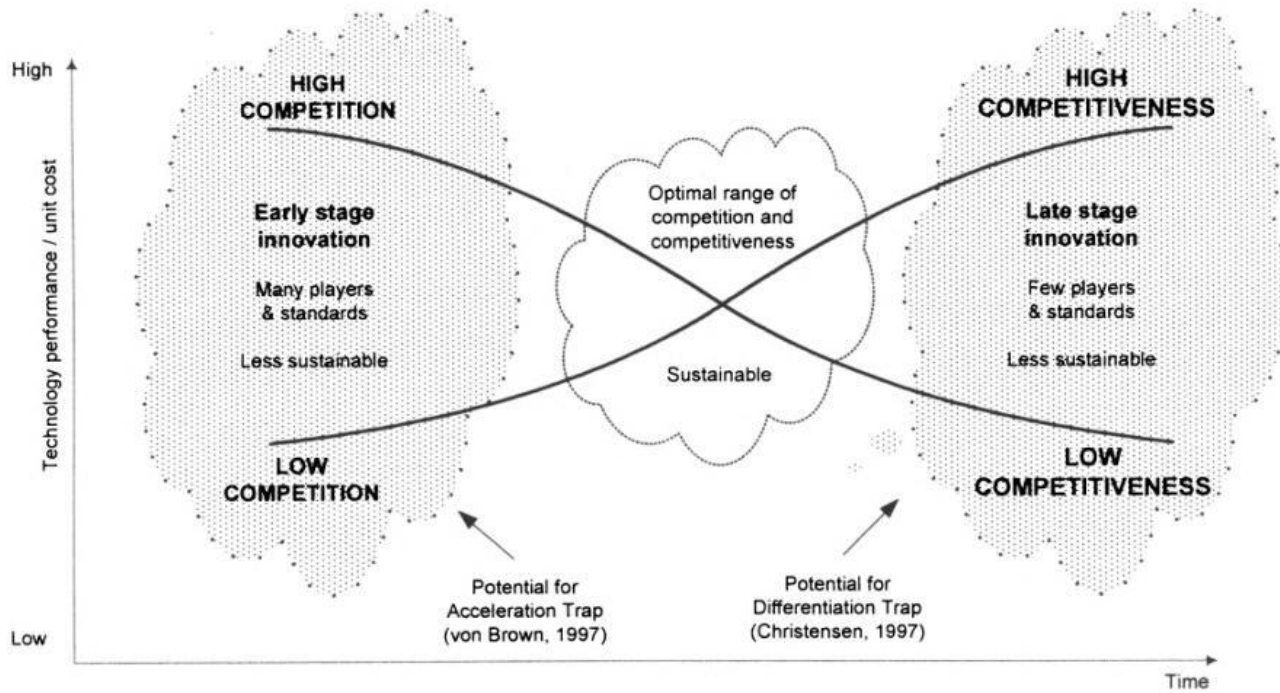


Figure 1. Competitiveness vs. competition trade-offs.

logical (Cooper, 1998). Another view of classifying types characterizes innovation by decision systems (Rogers, 1995). This method relies on the principle that adoption of innovation may be influenced by both individuals and entire social systems. There is also a distinction between sustaining and disruptive innovations (Christensen, 1997) and continuous and discontinuous innovations (Tushman, 1990):

Discontinuities are often described as technological breakthroughs that help companies rewrite industry rules or create entirely new industries. Rarely have distinctions been made within the concept of ‘discontinuity’, not to mention how to identify these radical innovations. For the corporate strategist, a big question remains: how to actually structure opportunity identification so it becomes a rational process—one that yields breakthroughs reliably (vs. waiting for opportunities to arise serendipitously) (Kaplan, 1999).

*Process innovation* refers to change in the methods employed by a firm in delivering products or services. An example is the use of Internet technologies for supply-chain management, where the process of ordering, tracking, and billing would be Internet-based. *Product innovation* reflects change in the end product or service of the firm. An example of product innovation is the addition of a new feature such as adding a remote to a television to improve the user interaction. *Administrative innovation* refers to change in the characteristics of organizational or institutional elements. Changes in policy, organization structure, or resource allocation are examples of administrative innovations.

Using regional differences to classify innovation is a very narrow view, usually reserved to a specific technology innovation comparison. One of the drawbacks with this method is assessment of the regional nature of an innovation. For example, in the case of R&D measured by the number of patents, the region of patent invention may differ from the locale of registration—especially in the case of multinational corporations (MNC). A patent for an invention of Asian origin may be initiated in a U.S. patent filing if the headquarters is a U.S. MNC—thus the patent would be considered U.S. if measured regionally.

Integrating numerous past studies on technological innovation (especially those by Abernathy, Anderson, Clark, Henderson, Tushman & Utterback) produces a common framework distinguishing four generic types of technological innovation: *incremental, generational, radical* and *architectural*.

*Incremental* innovations exploit the potential of established designs, and often reinforce the dominance of established firms. They improve the existing functional capabilities of a technology by means of small scale improvements in the technology’s value-adding

attributes such as performance, safety, quality, and cost.

*Generational* or next-generation technology innovations are incremental innovations that lead to the creation of a new but not radically different system.

*Radical* innovations introduce new concepts that depart significantly from past practices and help create products or processes based on a different set of engineering or scientific principles and often open up entirely new markets and potential applications. They provide ‘a brand-new functional capability which is a discontinuity in the then-current technological capabilities’.

*Architectural* innovations serve to extend the radical-incremental classification of innovation and introduce the notion of changes in the way in which the components of a product or system are linked together.

Another common distinction is the difference between *evolutionary* innovation, where technological change appears to follow a process of ‘natural selection’ (with technical improvements resulting from the ‘survival of the fittest’) and *revolutionary* innovation, where the change appears as a break or non-contiguous change in the course of the technology. These two approaches to envisioning innovation are not mutually exclusive, however.

Using the four perspectives given above, we can show how these concepts relate to one another in a more complete framework for the analysis of innovation.

Process	Content
Evolutionary innovation	Incremental innovation or Generational innovation
Revolutionary innovation	Radical innovation or Architectural innovation

The complete framework with all four dimensions provides us with a way to relate *discontinuous* and *disruptive* technologies to these other concepts.

Process	Content	Context	Impact
Evolutionary innovation	Incremental innovation	Continuous innovation	Non-disruptive or
	Generational innovation	Continuous innovation	Disruptive innovation
Revolutionary innovation	Radical innovation	Discontinuous innovation	Non-disruptive or
	Architectural innovation	Discontinuous innovation	Disruptive innovation

Not all innovations are discontinuous, not all discontinuous innovations prove to be disruptive and not all disruptive innovations are discontinuous. This is determined by the scope, timing, and impact of the innovation under consideration and there are different strategies to deal with the challenges and opportunities arising from planned or serendipitous technological discontinuities and disruptions. Christensen (1997, p. 179) recommends three strategies for leveraging such contingencies and specifically in the case of 'technological performance over-supply' that creates the potential for an acceleration and/or a differentiation trap (von Braun, 1997) (see Figs 2 and 3):

- Strategy 1 is to ascend the trajectory of sustaining technologies into ever-higher tiers of the market;
- Strategy 2 is to march in lock step with the needs of customers in a given tier of the market;
- Strategy 3 is to use marketing initiatives to steepen the slopes of the market trajectories so that customers demand the performance improvements that the technologists provide.

Kaplan (1999) discusses four strategies for leveraging such contingencies:

Substantial growth over the long horizon requires discontinuous innovation—disruptive technologies, radical innovations and discontinuities that permit entire industries and markets to emerge. Soren Kaplan's experiences as process technology manager with Hewlett-Packard's Strategic Change Services in Palo Alto serves as a framework for all businesses dealing with the new innovation paradigms. He proposes four strategies: radical cannibalism, competitive displacement, market innovation and industry genesis. A strategy involving industry creation has a big advantage in that direct competition does not usually exist. It results in a new form of customer value with a new-to-the-world value proposition.

### The Process of Innovation

The lowest form of thinking is the bare recognition of the object.

The highest, the comprehensive intuition of the man who sees all things as part of a system.

Plato

An adequate definition of the process of innovation is inherently problematic. The field is nascent and there seems to be as many different definitions as there are researchers. However, there is sufficient information available to evoke a common understanding on many points.

The innovative process is defined by the correlation of its elements of study (Nelson, 1977). Inventions may be measured and the R&D process may be studied and defined. Science and invention may be linked, sources

of innovation elaborated upon, organization factors investigated, the evolution of technology studied, diffusion of innovation measured, and the learning phenomena exposed. Invention is viewed as complementary, cumulative, and leap-frogging (Rosenberg, 1982). *Complementary invention* is the invention of a new process/product that is related to an existing technology; the invention of the mouse to support computer-human interaction is an example. *Cumulative inventions* are those that build upon, or 'tweak' an existing invention, such as a product improvement like the pouring spout on juice containers. Leap-frog invention infers a radical change away from existing technologies and echoes discontinuity in markets.

In understanding the process, one must understand the concept of innovation 'imperative' (Cooper, 1998) as a key driver. In a competitive environment, managers are driven to success, both individually and organizationally. In order to achieve organization success, the manager must do more than develop, implement, and approve innovation. They are compelled to constantly innovate in order to attain success, driving the organization to higher levels of innovation diffusion.

Most models of innovation are based on three basic ideas (Drejer, 2002). First, organization can act to create or choose their environment. Second, management's strategic choices shape the organization's structure and processes. Third, once chosen, the structure and processes constrain strategy. This is a very interesting insight into innovation models. If an organization can choose its environment, and if the choice is rational, it should be able to choose the best environment for success of its strategy. There are numerous examples of firm strategies that did not perform as expected. Is this principle negated by non-performance of strategy? It may be that exogenous factors influence the choice of environment. This is an interesting question for further study but it is not in the scope of this paper.

In the U.S., economic policy has an influence on innovation. In general, U.S. policy may be categorized as selective targeting (Nelson, 1982). Historically, U.S. policy could not necessarily be labeled as supportive of innovation. Advances have been uneven (disruptive) and slow to influence productivity and relative costs. This is evidenced by a review of Total Factor Productivity (TFP) comparisons:

*TFP was developed by Solow in 1957 as the Growth Theory and has become the dominant approach to measuring productivity. Solow's theorem is that the Productivity Residual is uncorrelated with any variable that is uncorrelated with the rate of growth or in other words the Productivity Residual is a measure of the shift of the production function (increase in efficiency). TFP considers the traditional inputs to productivity of labor and output and adds*

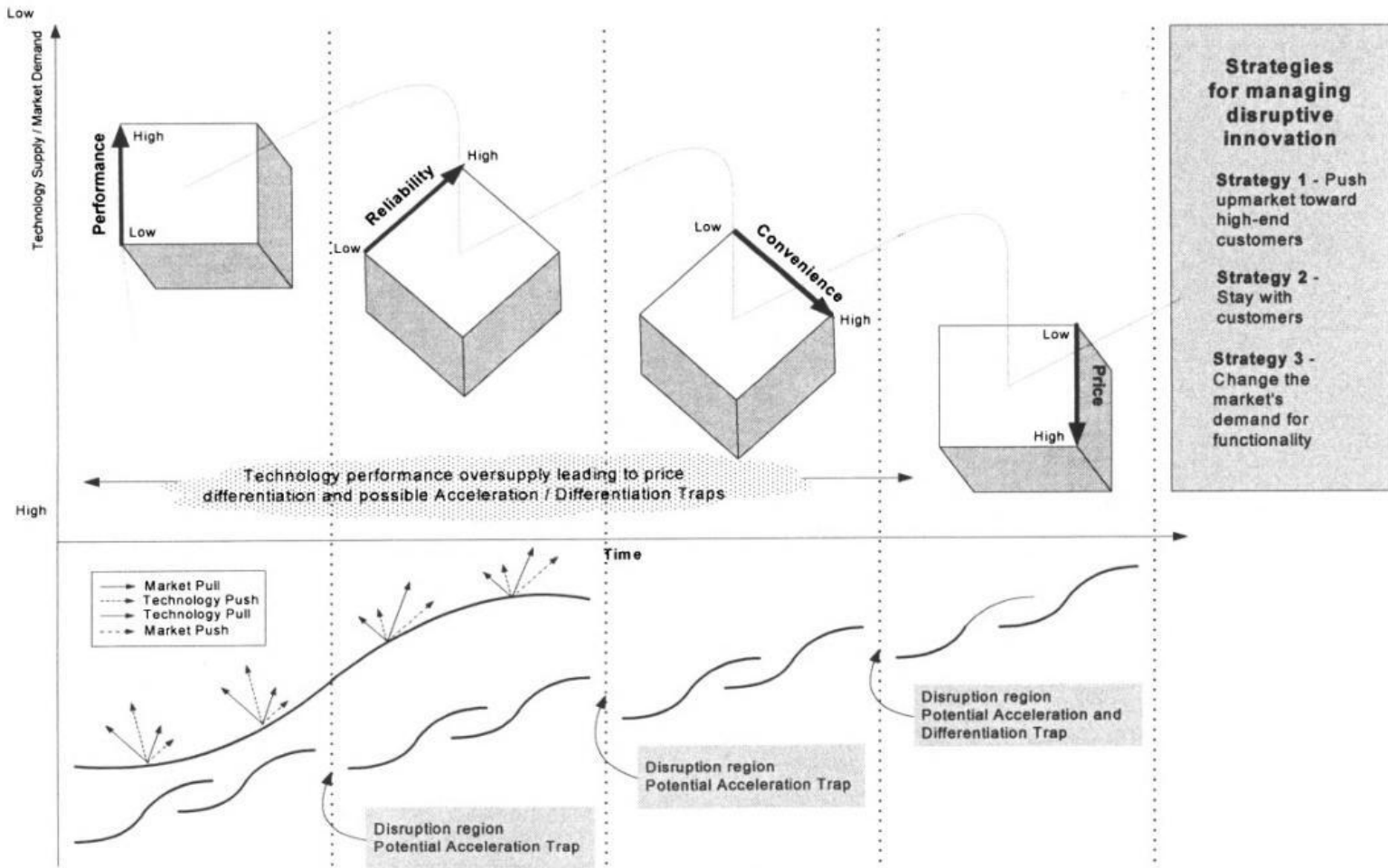


Figure 2. Competitiveness vs. competition trade-offs.

the dimension of the influence of capital. TFP is often referred to as Solow's residual. Prior to TFP, measurement of productivity was subject to factors that may incorrectly influence the outcome, like a rise in demand or a rise in price would cloud the real measurement. It is interesting to note that the TFP calculation is neutral to a rise in demand or a rise in price.

The TFP residual is considered to be an indicator of R&D performance and, as such, can be a measure of the effectiveness of innovation—at the industry or national level. Many researchers (Nelson, 1982) have concluded that TFP residual, as a measure of industry wide R&D effort, is more influential than measuring a single firm.

There are several key recurring principles of innovation. They are an integrated organizational approach, incentives for innovators, a systematic process to convert invention into innovation, team skills, communications, learning, and project management (Rolfe, 1999). These principles are instrumental in developing an innovation process. It is interesting to note the interdependencies of learning and team skills to innovation. Generally, in a team environment, individual members of a team do not possess sufficient knowledge in themselves but if collectively the team 'knowledge sum' is greater than non-team knowledge, the team will be a successful implementor of innovation. Since the common construct of teams is subject to change, the ability of the team to retain knowledge through effective learning is an important criterion for long-term success.

Identifying innovation as a process as opposed to a discrete event or outcome is generally credited to Peter Drucker (Cooper, 1998; Drejer, 2002). The control of the process of innovation is referred to as innovation management. In this context, innovation management is defined by five key activities; technological integration, the process of innovation, strategic planning, organizational change, and business development (Drejer, 2002). Technological integration refers to the relationship between technologies and the product of the firm. The process of innovation is the set of cross-functional activities that create and sustain innovation. Strategic planning involves the planning of technologies related to the innovation. Organizational change comprehends the disruptive nature of innovations on knowledge/skill requirements, new markets, new employees, etc. Business development refers to the creation of new markets for the products of innovation. It is interesting to note that innovation may be a driver of business development and also may be driven by it. This dichotomy may be explained by the fact that, in the early stages, innovation causes a disruptive change in the organization by its very nature, creating new markets for example. As the business evolves, 'technology pull' becomes evident. As competition catches up

or competitive innovations become evident, the requirement for more and more innovation to maintain market position will surface, thus causing the firm to drive innovation.

The organization is influenced by innovation in several ways. Creativity is driven by competition, change, externalities, learning, climate, communications, processes, and social interaction of individuals (Rolfe, 1999). While innovation is a purposeful act, the prime characteristic is uncertainty (Nelson, 1977). This characteristic tends to influence the set of drivers affecting the organization. In this way, as characteristics such as creativity drive innovation, the creativity itself is impacted. The impact may be positive or negative, and so the creativity may be changed and strategic plans may be ineffectual. Soren Kaplan (1999) discusses the four types of discontinuities identified at Hewlett Packard and outlines a framework that could serve as a guideline for technology managers and policy makers alike:

We have discovered four types of discontinuities through our work at HP. As a result, we have developed a framework to help leaders with discontinuous innovation opportunity identification—the process of exploring new revenue streams and identifying compelling propositions for providing heightened forms of customer value. This is the strategic intent that defines compelling new business possibilities capable of driving substantial growth. The framework takes the perspective of an organization that wishes to explore opportunities for discontinuous innovation and is founded upon three assumptions. First, we believe discontinuous innovation involves creating new forms of customer value within existing or new markets. Second, by pursuing discontinuous innovations, organizations create new competitive space or displace existing methods of delivering value to customers. Our final assumption involves the structure of the model itself. We define four discrete innovation strategies but suggest that these classifications not be regarded as mutually exclusive. Instead, these categories should focus efforts on opportunity identification by providing an understanding of 'gray areas' that all too often cloud the definition of 'discontinuity' (Kaplan, 1999).

#### *Measures of Innovation*

Truth emerges more readily from error than from confusion.

Sir Francis Bacon

How should innovation be measured, if indeed it can be measured? Research and Development (R&D) is generally the initial measurement tool utilized (Evangalista et al., 2001) but R&D itself may be measured based on different attributes. For example, as an R&D/Intellectual Property rights (IPR) measurement, the

number of patents is generally the measurement axiom. However, other attributes are frequently measured also, such as research funding budgets, number of researchers, number of significant inventions, number of new products, amount of published research, etc. (Tidd, 2001). Still, other attributes are linked in a more subtle way, such as increased productivity and growth or lower costs (Nelson & Winter, 1982). Another classification of measurable characteristics is the social impact of innovation. Examples would include the ability to measure the user benefits, lower consumer prices, user time savings, and other social enablers (Mansfield et al., 1977). A typology of measurable characteristics may help to bring together the disparate measurables (Table 1).

The main categorization is between ‘hard’ and ‘soft’ measurables. Hard measurables are those characteristics that may be directly linked to the innovation process. For example, the number of patents issued is direct outcome of the process of research and generally is not influenced by outside factors. Productivity improvements, however, may be the direct result of an innovation but the link is less clear due to other influential characteristics—productivity increases could be influenced by the mere fact of managerial increased interest surrounding the implementation of a productivity innovation. This is not to assume that the innovation was not the primary influence of productivity gains but rather the measurement process may not be sufficiently rigorous to differentiate the various influences.

R&D has a direct effect on output. In studies conducted in the manufacturing field, it was noted that *applied* research and development funding was a more powerful explanation of differences in productivity growth across manufacturing industries than total R&D funding by the entire industry (Nelson, 1977). This would indicate that R&D expenditures are a direct measure of firm productivity. Firm productivity is

greater than the norm, as expressed by industry norms.

The adoption of measures of innovation may be influenced by a firm’s business and technology strategy. A firm with a high profit objective, may choose to measure innovation characteristics that have a proclivity to specific goals (Nelson & Winter, 2000). This type of weighting may be more beneficial when characteristics are more directly linked, namely, hard measurables.

*Managing Innovation Through Knowledge Management and Learning*

Until philosophers are kings, or the kings and princes of this world have the spirit and power of philosophy, . . . cities will never have rest from their evils—no, nor the human race as I believe . . .

Plato, *The Republic*, Vol. 5, p. 492

The proposition that innovation can be ‘managed’ has been explored by numerous authors. For example, Burns & Stalker (1961) wrote their book *The Management of Innovation* based in part on an earlier study of the research and development laboratory at a local company. Whereas industrial innovation previously seemed to occur in a haphazard and disorganized manner, the post-war era brought strong interest in the idea that innovation could occur systematically, and could even be ‘planned’. The merging of the field of organization studies (e.g. Cyert & March, 1963) and the study of the function of management (e.g. Barnard, 1938; Drucker, 1999a, 1999b) provided a new foundation for understanding the innovation process. Further studies on innovation form the basis for a new field of expertise and knowledge on the nature of technological and organizational innovation. Knowledge management is not always fully or properly understood by managers. Instead, in many cases, practitioners and often academics mean information and technology

Table 1. Innovation measures—hard vs. soft.

Hard Measurables		Soft Measurables	
Characteristic	Measure	Characteristic	Measure
R&D	<ul style="list-style-type: none"> <li>• Patents</li> <li>• R&amp;D Budget</li> <li>• New Products</li> <li>• R&amp;D Staff</li> <li>• Publications</li> <li>• R&amp;D Incentives</li> <li>• New Features</li> <li>• Inventions</li> <li>• New Markets</li> <li>• Product Extensions</li> <li>• Conferences</li> <li>• CRADAs</li> <li>• Partnerships</li> </ul>	Impact	<ul style="list-style-type: none"> <li>• Productivity</li> <li>• Growth</li> <li>• Lower Costs</li> <li>• Flexibility</li> <li>• Supply/Demand</li> <li>• Firm Size</li> <li>• Market Influence</li> </ul>
		Social	<ul style="list-style-type: none"> <li>• User Benefits</li> <li>• Lower Prices</li> <li>• Social Enablers</li> <li>• Time Savers</li> </ul>

management when they talk about knowledge management. Knowledge management is more about the art of truly understanding organizational culture dynamics and accessing, leveraging and sharing tacit know-how:

A McKinsey survey of 40 companies in Europe, Japan, and the United States showed that many executives think that knowledge management begins and ends with building sophisticated information technology systems.

Some companies go much further: they take the trouble to link all their information together and to build models that increase their profitability by improving processes, products, and customer relations. Such companies understand that true knowledge management requires them to develop ways of making workers aware of those links and goes beyond infrastructure to touch almost every aspect of a business (Hauschild et al., 2001).

### *The Role of Knowledge in Innovation*

Since innovation is not a purely technical undertaking, the knowledge required for the successful management of innovation goes beyond science and engineering. Innovation can be subdivided into two domains: technical knowledge and knowledge transfer (Bohn, 1994), and learning about the administrative processes appropriate for managing technology (Jelinek, 1979). To facilitate the systematic development of innovations, an organization needs to have access to both types of knowledge: technical and administrative:

To be *organizational, rather than individual, learning*, knowledge must be accessible to others rather than the discoverer, subject to both their application or use, and to their change and adaptation . . . . Organizational learning, to be learning rather than 'mere adaptation' must be generalized. It must go beyond simple replication to application, change, refinement. It must include 'rules for learning' and their change and adaptation, rather than the rote iteration of past successful actions . . . . Finally, if learning is to include innovation, it must encompass a system for governing the future as well as the present (Jelinek, 1979, pp. 162–163).

The most challenging aspect of studying the application of knowledge to innovation is to distinguish what information is most relevant and significant to the management of innovation and what is not. The features of the knowledge embedded in the innovation process can vary greatly. Some of that knowledge will be explicit, in the form of technical papers, drawings, and other documents which are codified and easily defined, and some will be tacit, integrated into organizational routines which are transferred only through socialization and collaboration. Therefore, the successful management of innovation can clearly

benefit from a systematic approach to knowledge management.

Knowledge, learning and cognition are classical terms that have been re-discovered in the context of the information technology and knowledge management revolutions. Knowledge management can be viewed as a socio-technical system of tacit and explicit business policies and practices. These are enabled by the strategic integration of information technology tools, business processes, and intellectual, human, and social capital (Conference Board, 1996). Managerial and organizational cognition can be perceived as the human and organizational capability for individual and collective reasoning, learning, emoting and envisioning. Organizational memory, intelligence, and culture are important determinants of cognition processes at both the individual and the organizational levels. We perceive managerial and organizational cognition and knowledge management as transitions across progressively higher levels of knowledge and meta-knowledge.

### *The Relationship Between Knowledge and Learning Knowledge/Meta-knowledge*

The main Greek achievement was to remove explanation of the workings of the world from the realms of religion and magic, and to create a new kind of explanation—*rational explanation*—which was the subject of a new kind of enquiry.

Peter Chechkland  
Systems Thinking, Systems Practice, 1981, p. 32

Beckman (1998) compiled a number of useful and relevant definitions of knowledge and organizational knowledge:

- Knowledge is organized information applicable to problem-solving (Dictionary (1));
- Knowledge is information that has been organized and analyzed to make it understandable and applicable to problem-solving or decision-making (Turban (2));
- Knowledge encompasses the implicit and explicit restrictions placed upon objects (entities), operations, and relationships along with general and specific heuristics and inference procedures involved in the situation being modeled (Sowa (3));
- Knowledge consists of truths and beliefs, perspectives and concepts, judgments and expectations, methodologies and know-how (Wiig (4));
- Knowledge is the whole set of insights, experiences, and procedures which are considered correct and true and which therefore guide the thoughts, behaviors, and communication of people (van der Spek & Spijkervet (5));
- Knowledge is reasoning about information to actively guide task execution, problem-solving, and

- decision-making in order to perform, learn, and teach (Beckman (6));
- Organizational knowledge is the collective sum of human-centered assets, intellectual property assets, infrastructure assets, and market assets (Brookings (26));
  - Organizational knowledge is processed information embedded in routines and processes which enable action. It is also knowledge captured by the organization's systems, processes, products, rules, and culture (Myers (27)).

Beckman (1998) proposes a five-level *Knowledge Hierarchy* in which knowledge can often be transferred from a lower level to a more valuable higher level.

A number of other authors have also proposed knowledge typologies. Nonaka & Takeuchi (7) have divided knowledge accessibility into two categories: tacit and explicit. Beckman (1998) identifies three stages of accessibility: tacit, implicit, and explicit:

- (1) Tacit (human mind, organization)—accessible indirectly only with difficulty through knowledge elicitation and observation of behavior;
- (2) Implicit (human mind, organization)—accessible through querying and discussion, but informal knowledge must first be located and then communicated;
- (3) Explicit (document, computer)—readily accessible, as well as documented into formal knowledge sources that are often well organized.

#### *Relationship Between Knowledge and Learning*

But even though the first step along the road to a momentous invention may be the outcome of a conscious decision, here, as everywhere, the spontaneous idea—the hunch or intuition—plays an important part. In other words, the unconscious collaborates too and often makes decisive contributions. So it is not the conscious effort alone that is responsible for the result; somewhere or other the unconscious with its barely discernible goals and intentions, has its finger in the pie. . . . *Reason alone does not suffice.*

Carl Jung

The Undiscovered Self, 1958, pp. 99–100

Early research on organizational learning in the context of organization theory focused most substantially on attempting to describe learning processes in organizational settings, without necessarily assigning a normative value to learning (cf. Cyert & March, 1963; Levitt & March, 1988; March & Simon, 1958; Nelson & Winter, 1982). Learning as an organizational activity is perceived as an integration of individual efforts and group interactions. Thus, organizational learning becomes a process embedded in relationships among

individuals, through such mechanisms as information sharing, communication, and organizational culture. Some authors use the action-oriented concept of the 'learning organization' to identify paths to maximize organizational learning through a systems approach (Ciborra & Schneider, 1992; Senge, 1990). This perspective presumes that firms which are better at organizational learning will perform better than others in the market.

Other authors point out that learning can decrease organizational performance. Huber (1991) notes, "Entities can incorrectly learn, and they can correctly learn that which is incorrect". Ineffective or inappropriate learning processes can erode firm competitive advantage if they reinforce incorrect linkages between managerial activities and firm performance (Levitt & March, 1988). Even effective learning processes can be undermined by changes in market and environmental conditions which render them irrelevant, or worse, damaging to firm performance. Thus, learning activities can change from core competencies to core rigidities (Leonard-Barton, 1992). It is also possible that competence-destroying technological learning can limit firm performance in the short run but lead to superior performance in the long-term when market conditions adapt to new technologies (Christensen, 1997). Therefore, there is no linear relationship between learning and organizational performance; rather, performance improvement depends on the quality, not quantity, of organizational learning.

- (1) Individual learning;
- (2) Organizational learning;
- (3) Inter-organizational learning.

#### *Types of Learning*

Computo, ergo sum. Particeps sum, ergo sum.  
Cogito, ergo sum.

Rene Descartes

We identify three levels of learning, based on previous theory-building about the impact of learning on building firm capabilities and on modifying operating modes (Carayannis, 1994a, 1994b, 1994c; Carayannis & Kassicieh, 1996). In this hierarchy, we posit three layers of technological learning:

- (1) operational learning or learning and unlearning from experience;
- (2) tactical learning or learning how-to-learn and unlearn from experience; and
- (3) strategic learning or learning to learn-how-to-learn and unlearn from experience.

On the operational learning level, we have accumulated experience and learning by doing: we learn new things (Carayannis, 1994b). This is the short- to medium-term perspective on learning, focusing on new or improved capabilities built through the content learned by an

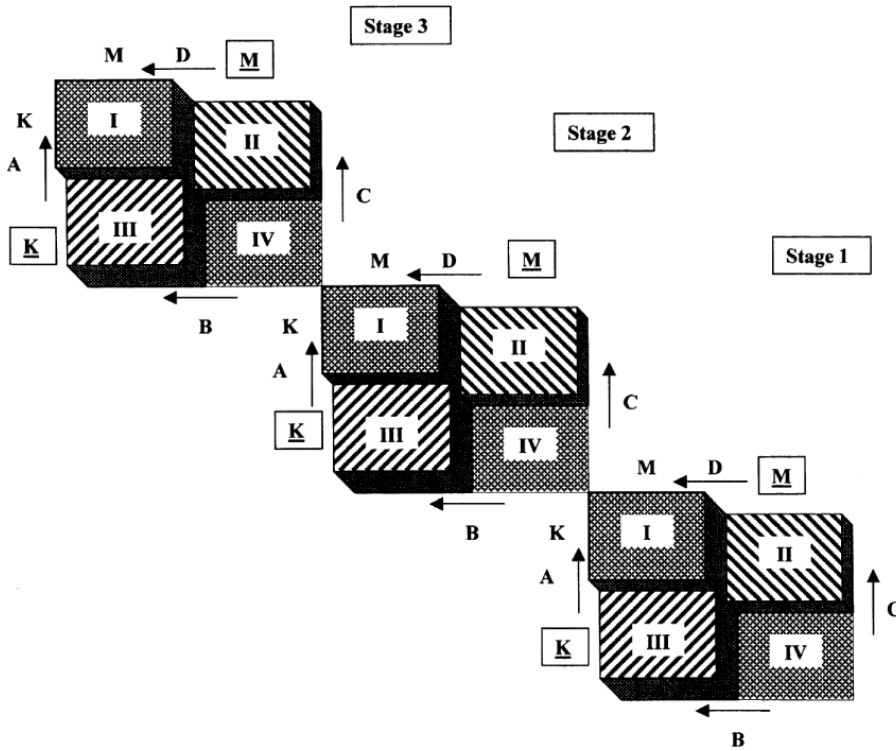


Figure 3. The Organizational Cognition Spiral (OCS).

State I: Awareness of Awareness (MK, K)—State II: Ignorance of Awareness (MK, K)—State III: Awareness of Ignorance (MK, K)—State IV: Ignorance of Ignorance (MK, K). (Possible Pathways: a. IV to II to I or b. IV to III to I). The successive stages (I, II, III) denote cumulatively higher levels of knowledge (K) and meta-knowledge (MK).

networked offices are all around us, thanks to the successful innovation of Xerox. Not only has Xerox been successful on the hardware side of the office; the service (maintenance) of copiers and supplies (toner, paper, etc.) businesses is extremely successful—as well as supporting consulting services and document processing services (solutions).

The innovations of Xerox proliferate, as evidenced by over 7000 active patents in their intellectual property portfolio. However, despite the innovation successes, there have been failures along the way.

The invention of the personal computer with a GUI, desktop, mouse, Ethernet, and the first WYSIWYG word processor never led to a Xerox innovation. The same is true of the first laser printer. In both cases Xerox invented but did not innovate. It took other firms to capture and market the inventions to reach the stage of innovation.

- (1) What criteria led to the success?
- (2) What criteria led to failure?

These are important questions to be asked. The answers may help to categorize the hegemony of ideas and

define success criteria, allowing the development of methodologies for creating and sustaining innovation best practices. In studying innovation it is best to look at both successes and failures as a root-cause analysis. The following is a case study of innovation at Xerox Corporation.

On October 22, 1938 in Astoria, Queens, Chester Carlson invented what later would be referred to as Xerography. In Carlson’s thinking, he was revolutionizing the office process, but he would find that the world did not see his invention in the same frame of reference as he did. Carlson, born in 1906, worked as a printer’s helper during his early career, including publishing a small newsletter on his own.

This early experience impressed him with the physical difficulty of putting words on paper and sharing knowledge. Later he received a degree in physics from the California Institute of Technology and began to work as a research engineer at Bell Labs. A depression-era job loss, followed by a degree in Law, led him to a second career as a patent attorney. As a patent attorney he faced the continuous problem of never having enough carbon copies.

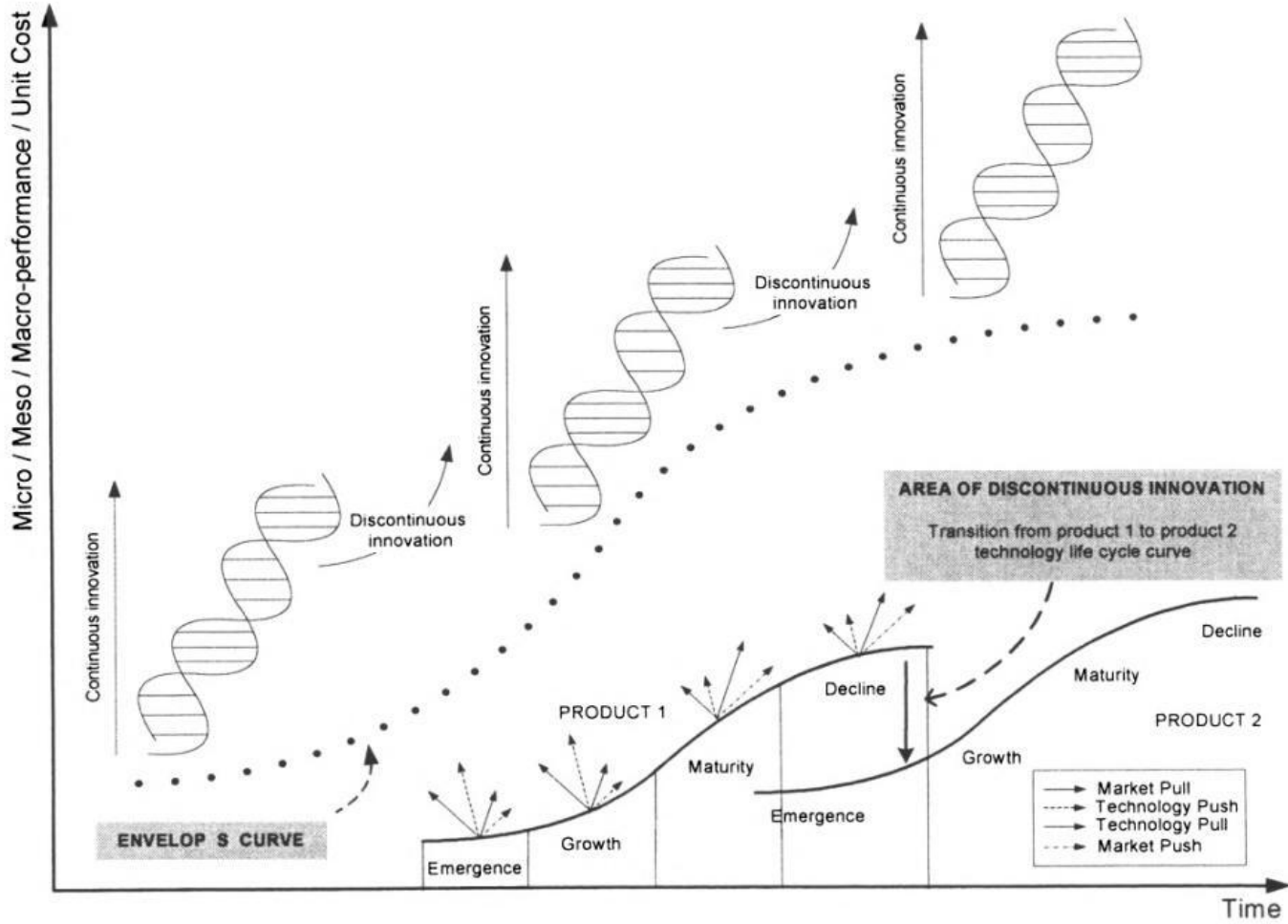


Figure 4. Continuous and discontinuous innovation: Technology performance road map.

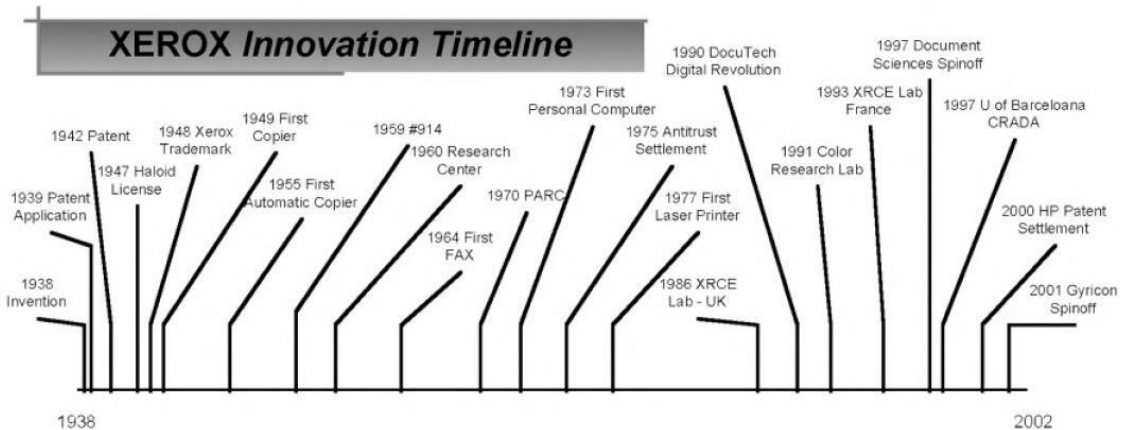


Figure 5. No caption copy supplied.

The only alternatives were to use an expensive photographic process or retyping (and reproofing) lengthy patent applications. In his spare time he researched alternative technologies, eventually finding the work of Hungarian physicist Paul Selenyi on photoconductivity. He performed experiments in his kitchen, eventually replicating the image of '10-22-38 ASTORIA' on a sulfur-coated zinc plate. Innovation is not an easy process, as Carlson was to find out. He searched for a company that would be interested in financing further research in his invention. For 10 years he had no success.

The market was not ready for alternative solutions—the common thinking was that carbon copies, the current technology, were sufficient and another technology was not needed. In 1944, Battelle Memorial Institute, a non-profit research institute, became interested in assisting Carlson in further developing his invention. During the Battelle era, selenium was introduced as an improved photoconductor, and dry ink toner was developed. Finally, in 1947, the Haloid Company, a manufacturer of photo-paper, acquired a license to manufacture a machine to produce xerography. Within one year, the first Xerox copier was shipped, beginning the age of Xerography.

The early copy machine was complex to operate, but it found a niche in producing working masters for offset duplicators—one should remember that the printing technology of the period was 'letterpress', printing from individually cast metal images; a very expensive process. 'Offset' printing was in its infancy and was utilized in low-end, inexpensive printing environments.

By 1959, Haloid improved the equipment and released the no. 914 copier—the first true office copier. The no. 914 was an innovative breakthrough.

The competition of the time, the AB Dick mimeograph, 3M Thermo-Fax, and the Kodak Verifax, were eclipsed within a short period of time. The no. 914 was

so successful that it continued to be the leading technology until 1972.

Xerox continued to innovate throughout its history, albeit not always successfully. In 1973 the first desktop personal computer was developed, leading to the PC revolution. Xerox, due to marketing strategies to be discussed later, did not benefit from this development. Again, in 1977 Xerox developed laser printing but did not move quickly to capture the early market for laser printers like its competitor Hewlett-Packard.

Xerox corrected its innovation strategy when it introduced the DocuTech high-volume black & white print system in 1990, thus creating the digital revolution in putting words on paper. Xerox plans to introduce the iGen3, a color version of the DocuTech technology. It is expected that this will mark the beginning of another revolution, digital color, and bring Xerox the financial rewards of innovation.

In order to fully understand Xerox, one must view the mix of products and services and the market space that is occupied. Currently Xerox products and services may be divided into two major categories—products and services. These can be further divided from products into office, production, equipment maintenance, and the necessary supporting supplies. The services can be further divided into outsourcing, process re-engineering, Solutions (integration services), and software applications.

It is interesting to note that research into the history of products uncovered some interesting products that were once core to the Xerox portfolio—electronic typewriters, workstations, and computer systems. These are no longer in the current portfolio.

Xerox sells its products through a variety of channels including direct sales, telebusiness, resellers, agents, concessionaires, and via the Internet. These channels are managed by various organizations—see table below. The sales organization is global and divided into regional territories. The largest territory is

Table 2. Xerox innovation group research &amp; technology centers.

Group	Location	Est.	Core Expertise	Additional Functions
Digital Imaging Technology Center	Palo Alto, CA	1994	Digital imaging 1:1 communications On-demand printing	Core competence in digital imaging
Solutions and Services Technology Center	Webster, NY	2001	Color science Image sciences and processing Systems architecture Work process studies Software development	Create, assess, acquire, apply technologies Coherence and architected set of solutions and services
Wilson Center for Research and Technology	Webster, NY	1960	Image evaluation Image processing Marking processes Media handling Microsystems Embedded controls Device controls	Color technology Image quality Cost of ownership Xerography patent basis
Xerox Research Centre of Canada	Ontario, Canada	1974	Materials research Imaging materials Inks and Toners Photoreceptors Specialty media Organic materials	Research concepts Supplies and consumables Environmental issues Materials design, Synthesis and evaluation
Xerox Research Centre Europe	Grenoble France	1993	Content analysis contextual computing Mobile computing Ubiquitous computing image processing Work practices knowledge portals E-leering, Publishing, Emerging office	License technology Document access Knowledge sharing  Coordinates research, engineering, and business development activities
Palo Alto Research Center Incorporated (PARC)	Palo Alto, CA	1970	Electronic materials Micro-electro-mechanical systems (MEMS) Semiconductor devices software Engineering, Image analysis Human-computer interaction Wireless computing Knowledge representation	Ubiquitous computing Licensing, collaborative research and spin-off creation Developed first personal computer with WYSIWYG word processor, mouse, Ethernet, and GUI Developed first laser printer

the U.S. covered by the North American Solutions Group (NASG).

It was noted that almost 50% of total Xerox employees work for Xerox Services, most of which are located physically within a customer site. One area of understanding that many researchers of Xerox find difficult, is that of the Solutions business. Xerox defines Solutions as “an integrated offering that includes hardware, software and people-based services, which solves a problem, improves a work process, or creates a market or competitive advantage”. Xerox has divided its Solutions delivery into four main business operations and focuses on production market (graphic arts firms), the office market, and services. The four groups are Documents Systems and Solutions Group (DSSG), Office Systems Group (OSG), Office Printing Business Group (OPBG), and Xerox Global Services (XGS).

Xerography was invented in 1938 but it was not until 1959 that the initial invention was actualized and became an innovation. The 19-year travel from invention to innovation was consumed with both finding a financial partner to further develop the idea (1938–1947) and later by an attempt to define the market (1948–1959). In the 1930s to 1950s the technology of the office was defined by carbon paper and the emerging offset printing process.

Carbon paper allowed for a real-time duplicate of a document, possibly up to eight copies, and early offset duplication was available for 8+ copies, but the cost of the 8–500 copies was somewhat prohibitive. What Chester Carlson and Haloid first found in the search for a market was that the perceived need for the innovation was non-existent. The challenge to Haloid was to develop a market.

The first machine to reproduce copies via Xerography was released in 1949. The market it captured was within the nascent offset printing technology. Specifically, the first Xerox copier was targeted toward making masters for offset duplication. The masters would then in turn be used in the duplicating process, thus making ‘copies’. The Xerox master copy process for offset duplication was expensive and complex to operate, and would soon be overtaken by other, photo-based less expensive technologies. As Haloid refocused its attention back toward replacing carbon paper technology, it found a winner in the 1959 introduction of the no. 914 copier. This combination of market pull and technology push would drive revenue and profits well into the 1970s. From the early Haloid days of unstructured innovation, Xerox has developed a culture of organizing for innovation. Currently, the Xerox organization chart reflects the Innovation Group as directly reporting to the CEO. This underscores the relative importance affixed to innovation within the organization.

#### *Innovation—Faux Pas*

In 1970 Xerox formed the Palo Alto Research Center (PARC), famed as the epicenter of the computer revolution. Researchers at PARC were given freedom to conduct basic research from the beginning. This led to, among other inventions, the first personal computer in 1973 and the first laser printer in 1977.

The personal computer was advanced for its time and consisted of an operating system, a WYSIWYG word processor, and a graphical user interface with a desktop, a mouse, and Ethernet connectivity. With this advanced invention in its portfolio, Xerox should have led the computer revolution—but as history shows us, Xerox did not capitalize on its inventive resources and let others drive the birth of a new market. The question to the student of innovation is why did Xerox let this happen and what can be done to avoid this type of costly mistake in the future! In other words, what is the lesson to be learned from this?

In order to understand Xerox strategies, the authors have taken the approach of investigating the history of Xerox innovation and interviewing key players of the era. In one such interview with Mr. RT, a 30-year veteran of Xerox and an executive involved in West Coast operations for much of his career, the following information was developed.

In the 1970s, in addition to PARC, Xerox had substantial operations centered on the West Coast. One must remember that Xerox is Rochester, NY-based, where the single largest geographical concentration of employees (about 16,000) is located. The visionary of the ‘office of the future’ was Joe Wilson II, then Chairman of Xerox. At that time, in addition to PARC, Xerox-West consisted of Versatec (plotters), XSoft (software application development), Xerox Network Services (Ethernet, networks), Shugart (disk manufacturing), Total Recall (scan and retrieval applications), plus a substantial copier hardware manufacturing facility. This was a very advanced portfolio of technical capabilities and capacity for the time.

PARC itself was a central clearinghouse of computer information in the early 1970s. PARC developed a professional forum as a tool for motivating researchers. Each week, PARC would host a public event to allow its researchers to present their research findings. This forum was well attended by non-Xerox professionals from universities, engineers from the nascent computer industry, and others interested in the research. This early knowledge sharing aided the birth of the computer industry in the Silicon Valley area.

When the personal computer was originally developed, Xerox strategy was to market the PC as a proprietary business-to-business tool. It was more of a ‘portable’ computer than a ‘personal’ computer. The computer consisted of a 32” wide portable unit, a hard drive basically, that could be ported or moved from location to location as required. The computer was to

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# Profitable Product Innovation: The Critical Success Factors

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**Abstract:** This chapter focuses on the critical success factors that underlie new product performance. It is based on the author's and other's research into hundreds of new product launches, probing the question: What distinguishes the best from the rest? Ten common denominators or factors appear to drive new product success, profitability and time-to-market; this chapter outlines these ten critical success factors, and notes the management implications of each. The chapter concludes with a discussion of portfolio management techniques, issues and challenges.

**Keywords:** Product innovation; New product development; Management; Portfolio management; Success factors.

## Introduction

Product innovation—the development of new and improved products—is crucial to the survival and prosperity of the modern corporation. According to a PDMA survey, new products currently account for 33% of company sales, on average (Griffin, 1997). And product life cycles are getting shorter: a 400% reduction over the last 50 years, the result of an accelerating pace of product innovation (Von Braun, 1997).

New products fail at an alarming rate, however. Approximately one in ten product concepts succeeds commercially, according to several studies (Page, 1991; Griffin, 1997), while only one in four development projects is a commercial success (Cooper, 2001). Even by the launch phase—after all the product tests and market testing are done—one-third of product launches still fail commercially. In the high-tech field, the odds are even worse: only 20% of software projects are commercial winners, according to a survey by Kleinschmidt (1999); companies scrap almost one-third of new projects for a loss of \$80 billion annually (King, 1997); and “only one-quarter of IT projects are completed on time, on budget and with all the functions originally specified” (*Risk Magazine*, 1999).

The huge amounts at stake coupled with the high odds of failure make product innovation one of the riskiest endeavors of the modern corporation. Thus many managers, researchers and pundits have sought answers to the age-old question: What makes a new

product a winner? And why are some businesses so much more successful at product development than the rest?

This chapter looks first at the critical success factors that underlie success in product innovation.<sup>1</sup> Next, these many success factors are crafted into a methodology, game plan or process for managing new product projects—a systematic new product process or Stage-Gate system. The chapter concludes with a look at portfolio management—methods for selecting the right new product projects.

## The Critical Success Factors

Much research over the years has uncovered those factors that separate winning new products from less successful ones, and businesses that succeed at product innovation (Cooper, 1999b, 1999c; Cooper & Kleinschmidt, 1986, 1993, 1995a, 1996; Di Benedetto, 1999; Maidique et al., 1984; Mishra et al., 1996; Montoya-Weiss et al., 1994; Rothwell et al., 1974; Sanchez et al., 1991; Song & Parry, 1996). Here are the more important success factors based on these studies:

## A Unique Superior Product

A superior and differentiated product is the number one driver of success and profitability, with success rates reported to be three to five times higher than for ‘me

<sup>1</sup> This chapter is taken from a number of articles and books by the author. See Cooper (1996, 1999a, 2000, 2001).

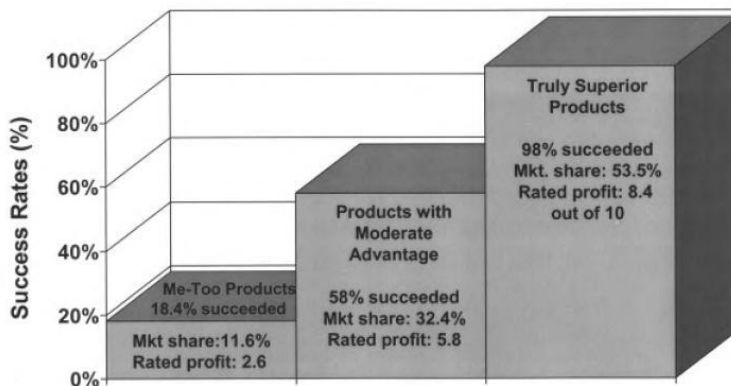


Figure 1. Impact of product superiority on success.

Source: Cooper (2001).

too', reactive products (Cooper, 1999b, 1999c; Cooper & Kleinschmidt, 1993, 1995a, 1996; Mishra et al., 1996; Song & Parry, 1996; Souder & Song, 1997). The NewProd studies<sup>2</sup> show the dramatic impact of product superiority: here the sample of firms was divided into the top 20% and bottom 20% in terms of product superiority: note the differences in performance in Figure 1—much higher success rates, market shares and profitabilities for unique, superior products (Cooper, 2001; Cooper & Kleinschmidt, 1986, 1996). For example, such products (the top 20% in Figure 1) when compared to those with the least degree of differentiation (the bottom 20%):

- have an exceptional commercial success rate of 98.0%, vs. only 18.4% for undifferentiated ones;
- have a market share of 53.5% of the defined target market, vs. only 11.6% for 'me too' new products;
- have a rated profitability of 8.4 out of 10 (vs. only 2.6 out of 10 for undifferentiated products—here 10 = exceptional profits, far exceeding the company's minimum hurdle); and
- meet company sales and profit objectives to a greater degree than do undifferentiated products.

The same studies show, however, that *reactive products*, *undifferentiated products* and *technically driven products that lack customer benefits* are the rule rather than the exception, however; and the majority fail!

What are the ingredients of these unique, superior products with significant competitive advantage?

<sup>2</sup> The *NewProd studies*: a series of investigations by the author and co-workers between 1975 and 2000 that identified the success factors in new product development—the factors that differentiated between winners and losers. The typical methodology was a paired comparison of successful vs. unsuccessful new product projects. NewProd™ is a legally registered trademark of R. G. Cooper & Associates Consultants Inc.

According to research cited above, they are superior to competing products in terms of meeting users' needs, offer unique features not available on competitive products, or solve a problem the customer has with a competitive product. They provide excellent product quality, relative to competitors' products, and in terms of how the user measures quality; they feature good value for money for the customer, reduce the customer's total costs (high value-in-use), and boast excellent price/performance characteristics. And such winning products offer benefits or attributes easily perceived as useful by the customer, and benefits that are highly visible. A point of distinction: *benefits* are what customers or users value and pay money for; by contrast, *attributes* are product features, functionality and performance—the things that engineers and scientists build into products. And note that the product must be superior in the eyes of the customer, not just the eyes of the engineer, scientist or designer: often developers heavily overestimate the customer benefits and desirability of their products (Friar, 1995).

#### A Strong Market Orientation—Market-Driven, Customer-Focused

A thorough understanding of customers' needs and wants, the competitive situation, and the nature of the market is an essential component of new product success. This finding is supported in virtually every study of product success factors (Cooper, 2001; Di Benedetto, 1999; Mishra et al., 1996; Montoya-Weiss, 1994; Song & Montoya-Weiss, 1998; Song & Parry, 1996). Recurring success themes include:

- need recognition;
- understanding user needs;
- market need satisfaction;
- constant customer contact;
- strong market knowledge and market research;
- quality of execution of marketing activities; and

- (2) The development of the market launch plan *must begin early* in the new product project. It should not be left as an afterthought to be undertaken as the product nears commercialization;
  - (3) A market launch plan is only as good as the *market intelligence* upon which it is based. Market studies designed to yield information crucial to marketing planning must be built into the new product game plan;
  - (4) These who will execute the launch—the sales force, technical support people, other front line personnel—must be engaged in the development of the market launch plan. This ensures valuable input and insight into the design of the launch effort, availability of resources when needed, and buy-in by those who must execute to the product and its launch—elements so critical to a successful launch (Hultink, E. J. & Atuahene-Gima, 2000).
- organized as a *cross-functional team* with members from R&D, Engineering, Marketing & Sales, Operations and so on (as opposed to each function doing its own part independently);
  - where the team is dedicated and focused (i.e. devotes a large percentage of their time to this project, as opposed to spread over many projects or other work);
  - where the team members are in constant contact with each other, via frequent but short meetings, interactions, project updates and even co-location;
  - where the team is accountable for the entire project from beginning to end (as opposed to accountability for only one stage of the project); and
  - where there is a strong project leader or champion who leads and drives the project (Barczak, 1995; Markham & Griffin, 1998).

## 7. The Right Organizational Structure, Design and Climate

Product innovation is not a one-department show. It is very much a multidisciplinary, cross-functional effort. Investigations into new product success consistently cite interfaces between R&D and marketing, coordination among key internal groups, multidisciplinary inputs to the new product project, and the role of project teams and the team leader or champion (Cooper, 2001; Markham & Griffin, 1998; Song et al., 1997; Song & Parry, 1996). Successful new product projects feature a balanced process consisting of critical activities that fall into many different functional areas within the firm: marketing and marketing research, engineering, R&D, production, purchasing, and finance (Cooper, 1998; Cooper & Kleinschmidt, 1995b, 1995c, 1996). The Stanford Innovation Project study of new product launches in high-technology firms reveals that a critical distinguishing factor between success and failure is the “simultaneous involvement of the create, make, and market functions” (Maidique et al., 1984). The NewProd studies show that projects undertaken by empowered multifunctional teams are more successful (Cooper, 1999a, 1999c; Cooper & Kleinschmidt, 1993, 1995b, 1996). Similarly, analyses of Japanese successes emphasize their attention to manufacturability from the start of development efforts, the location in one place of engineers, designers, and manufacturers, and the conception of management unconstrained by traditional American functionalism (Peters, 1986, p. 261). Finally Griffin’s review of multiple benchmarking studies, along with her own PDMA best practices study, reveals that effective cross-functional teams are fundamental to success (Griffin, 1997).

Product development must be run as a multi-disciplinary, cross-functional effort. Good organizational design means projects that are:

While the ingredients of good organizational design should be familiar, surprisingly many firms have yet to get the message (Cooper & Kleinschmidt, 1996).

Peters argues strongly in favor of project teams: “the single most important reason for delays in development activities is the absence of multifunction (and outsider) representation on development projects from the start” (Peters, 1986). Peters continues: “The answer is to co-mingle members of all key functions, co-opt each function’s traditional feudal authority, and use teams”.

A second organizational success ingredient is climate and culture. A positive climate is one which supports and encourages intrapreneurs and risk-taking behavior; where new product successes are rewarded and recognized (and failures not punished); and where team efforts are recognized, rather than individuals. For example, the Best companies in the PDMA best practices study emphasize employee recognition for new product performance (Griffin, 1997). A positive climate also means senior managers refraining from ‘micro-managing’ projects and second-guessing the team members; and resources and time being made available for creative people to work on their own ‘unofficial projects’. Idea-submission schemes (where employees are encouraged to submit new product ideas), and open project review meetings (where the entire project team participates), are other facets of a positive climate.

### Top Management Support

Top management support is a necessary ingredient for product innovation. But it must be the right kind of support. The Stanford project, a Hewlett-Packard study, and other investigations have found top management support to be directly linked to new product success (Cooper, 2001; Maidique & Zirger, 1984; Song & Parry, 1996; Wilson, 1991).

Top management’s role in product development is as a facilitator—to set the stage—and not be an actor front and center. One important role of senior management is

to articulate a new product strategy for the business, something that is often missing. An effective new product strategy means defined new product goals (e.g. percentage of the business's sales to be derived from new products); delineated arenas of focus (e.g. product-types, markets, technologies and technology platforms where the business unit intends to concentrate its development efforts); and strategies that have a longer-term orientation and are visible to everyone in the business. Management must also deploy the necessary product development resources, and keep the commitment. And it must commit to a disciplined process to drive products to market. These three factors—an articulated new product strategy, adequate resources, and a disciplined new product process—are the strongest drivers of new product performance at the business unit level, according to a major benchmarking study (Cooper, 1998; Cooper & Kleinschmidt, 1995b, 1995c, 1996). Finally, senior management must empower project teams and support committed champions by acting as mentors, facilitators, 'godfathers', or executive sponsors to project leaders and teams—acting as 'executive champions', as Peters calls them (Peters, 1986, p. 302).

### Leveraging Core Competencies

Leverage and synergy is the common thread that binds the new business to the old. When translated into product innovation, the ability to leverage existing and in-house strengths, competencies, resources, and capabilities increases the odds of success of the new product project. By contrast, 'step-out' projects take the firm into territory that lies beyond the experience and resource base of the company, and increase the odds of failure (Cooper, 1999a, 1999c; Cooper & Kleinschmidt, 1995a, 1995b, 1995c, 1996; Mishra et al., 1996; Song & Parry, 1996).

The reasons for the impact of leverage are clear:

- (1) Resources are available and at marginal cost;
- (2) Operating within one's field of expertise—either familiar markets or familiar technologies—provides considerable 'domain knowledge', which is available to the project team;
- (3) The more often one does something, the better one becomes at doing it—the experience factor. If new product projects are closely related to (leveraged from) current businesses, the chances are that there has been considerable experience with such projects in the past, hence lower costs of execution and fewer misfires.

Two types of leverage are important to product innovation:

- (1) *Technological leverage*: the project's ability to build on in-house development technology, utilize inside engineering skills, and use existing manu-

facturing or operations resources and competencies.

- (2) *Marketing leverage*: the project/company fit in terms of customer base, sales force, distribution channels, customer service resources, advertising and promotion, and market-intelligence skills, knowledge and resources.

These two dimensions of leverage—technological and marketing, and their ingredients—become obvious checklist items in a scoring or rating model to help prioritize new product projects. And if leverage is low, yet the project is attractive for other reasons, then steps must be taken to bolster the internal resources and competencies. Low leverage scores signal the need for outside resources—partnering or out-sourcing (Bonaccorsi & Hayashi, 1994). But neither solution is a panacea—there are risks and costs to both routes to securing the needed resources and competencies (Campbell & Cooper, 1999).

### Market Attractiveness

Market attractiveness is an important strategic variable. Porter's 'five forces' model considers various elements of market attractiveness as a determinant of industry profitability (Porter, 1985). Similarly, various strategic planning models—for example, models used to allocate resources among various existing business units—employ market attractiveness as a key dimension in the two-dimensional map or portfolio grid (Day, 1986).

In the case of new products, market attractiveness is also important: products targeted at more attractive markets are more successful (Cooper, 1999a, 1999c; Cooper & Kleinschmidt, 1995a, 1995b, 1995c, 1996; Maidique et al., 1985; Mishra et al., 1996; Song & Parry, 1996). There are two dimensions of market attractiveness:

- (1) *Market potential*: positive market environments, namely large and growing markets—markets where a strong customer need exists for such products, and where the purchase is an important one for the customer. Products aimed at such markets are more successful.
- (2) *Competitive situation*: negative markets characterized by intense competition, competition on the basis of price, high quality, and strong competitive products; and competitors whose sales force, channel system, and support service are strongly rated. Products aimed at such negative markets are less successful, according to the studies cited above.

The message is this: both elements of market attractiveness—market potential and competitive situation—impact the new product's fortunes; and both should be considered as criteria in any model or scoring scheme for project selection and prioritization.

### Tough Go/Kill Decision Points and Better Focus

Most companies suffer from too many projects and not enough resources to mount an effective or timely effort on each—a lack of focus. This stems from inadequate project evaluation and poor project prioritization. Project evaluations are consistently cited as weakly handled or nonexistent: decisions involve the wrong people from the wrong functions (no functional alignment); no consistent criteria are used to screen or rank projects; or there is simply no will to kill projects at all (Barczak, 1995; Cooper et al., 1998, 1999; Cooper, 1998; Cooper & Kleinschmidt, 1986, 1995a, 1995b, 1995c, 1996).

The desire to weed out bad projects coupled with the need to focus limited resources on the best projects means that tough Go or Kill and prioritization decisions must be made. Some companies have built *funnels* into their new product process via decision-points in the form of gates. At gate reviews, senior management rigorously scrutinizes projects, and makes Go or Kill and prioritization decisions based on visible Go/Kill criteria (see Figure 5 for sample Go/Kill criteria). Progressive businesses are also moving to portfolio management, which attempts to select the right set of new product projects in order to maximize the value of the portfolio, achieve the right balance of projects, and yield a portfolio of projects that supports the business's strategy (Cooper et al., 1997a, 1997b; Roussel et al., 1991).

### Quality of Execution

Certain key activities—how well they are executed, and whether they are done at all—are strongly tied to profitability and reduction in time-to-market. Particularly pivotal activities include: the vital homework actions outlined above; and market-related activities. But proficiency of most activities in the new product process impacts on outcomes, with successful project teams consistently doing a better quality job across many tasks (Cooper, 1999a, 1999c; Cooper & Kleinschmidt, 1986, 1995d, 1996; Mishra et al., 1996; Song & Montoya-Weiss, 1998; Song & Parry, 1996).

There is a *quality crisis* in product innovation, however. Investigations reveal that the typical new product project is characterized by serious errors of omission and commission:

- Pivotal activities, often cited as central to success, are omitted altogether. For example, more than half of all projects typically leave out detailed market studies and a test market (trial sell);
- Quality of execution ratings of important activities are also typically low. In postmortems on projects, teams typically rate themselves as 'mediocre' in terms of how good a job they did on these vital activities.

New product success is thus very much within the hands of the men and women leading and working on

projects. To improve quality of execution, the solution that leading firms in a variety of industries, such as DuPont, Procter & Gamble, Exxon, Bayer, Lego, ITT, International Paper and Pillsbury-General Mills, have adopted is to treat *product innovation as a process*. They have adopted a formal stage-and-gate product delivery process; they build in quality-assurance approaches, such as check points and metrics that focus on quality of execution; and they design quality in by making mandatory certain vital actions that are often omitted, yet are central to success.

### The Necessary Resources

Too many projects simply suffer from a lack of time and money commitment. The results are predictable: much higher failure rates (Cooper, 1998; Cooper & Kleinschmidt, 1995b, 1995c, 1996). Some facts:

- A strong market orientation is missing in the typical new product project. And much of this deficiency is directly linked to a lack of marketing resources available for the project;
- Another serious pitfall is that the homework does not get done. Again much of this deficiency can be directly attributed to a lack of resources: simply not enough money, people, and time to do the work.

The reason: as the competitive situation has toughened, companies have responded with restructuring and doing more with less, and so resources are limited or cut back (Cooper & Edgett, 2002). This short-term focus takes its toll. Certain vital activities, such as market-oriented actions and predevelopment homework are highly under-resourced, particularly in the case of product failures.

### Speed—But Not at the Expense of Quality of Execution

Speed yields: competitive advantage (the first on the market) (Song et al., 2000; Song & Montoya-Weiss, 1998); less likelihood that the market situation has changed; and a quicker realization of profits (Ali et al., 1995). So the goal of reducing the development cycle time is admirable. A word of caution here: speed is only an interim objective; the ultimate goal is profitability. While studies reveal that speed and profitability are connected, the relationship is anything but one-to-one (Cooper, 1995; Lynn et al., 1999). Further, often the methods used to reduce development time yield precisely the opposite effect, and in many cases are very costly. The objective remains successful products, not a series of fast failures! Additionally, an over-emphasis on speed has led to trivialization of product development in some businesses—too many product modifications and line extensions, and not enough real new products and new platforms (Cooper & Edgett, 2002; Crawford, 1992).

Some of the ways which project teams have reduced time-to-market have been highlighted above: a true

cross-functional team; solid up-front homework; sharp, early product definition (Rauscher & Smith, 1995); and better focus—doing fewer projects (Cooper, 1995, 2001; Cooper & Kleinschmidt, 1994). Other methods include:

- *Parallel processing*: activities are undertaken in parallel (rather than sequentially) with the team members constantly interacting with each other. New product rugby with time compression is the result;
- *Flowcharting*: the team maps out its entire project from beginning to end, and focuses on reducing the time of each element or task in the process;
- *A time-line and discipline*: project teams use computer software to plan their projects in a critical path or Gantt chart format. The rules are simple: practice discipline; the time-line is sacred; and resources can be added but deadlines never relaxed.

### A Multistage, Disciplined New Product Process

A systematic new product process—a *Stage-Gate™ process*<sup>3</sup>—is the solution that many companies have turned to in order to overcome the deficiencies which plague their new product programs (Cooper, 1998, 2001; Lynn et al., 1999; Menke, 1997). *Stage-Gate* processes are simply road maps or ‘play books’ for driving new products from idea to launch, successfully and efficiently. About 68% of U.S. product developers have adopted *Stage-Gate* processes, according to the PDMA best practices study (Griffin, 1997). And the payoffs of such processes have been frequently reported: improved teamwork; less recycling and rework; improved success rates; earlier detection of failures; a better launch; and even shorter cycle times (by about 30%).

### Doing Projects Right: A Stage-Gate™ Process or Road Map from Idea to Launch

A *Stage-Gate* process is a *conceptual and operational roadmap* for moving a new product project from idea to launch—a blueprint for managing the new product process to improve effectiveness and efficiency. The goals of a *Stage-Gate* process include:

- Doing projects right—such processes lay out prescribed actions and best practices as a guide to the project team;
- Building in the critical success factors—as was seen above, most project teams miss the mark on success factors 1–14. And so *Stage-Gate* processes attempt to build these in to every project by design.

*Stage-Gate* approaches break the innovation process into a predetermined set of stages, with each stage

consisting of a set of prescribed, cross-functional and parallel activities (see diagram below). The entrance to each stage is a gate, which serves as the quality control and Go/Kill check points in the process.

### The Stages

Stages are where the action occurs. The players on the project team undertake key tasks in order to gather information needed to advance the project to the next gate or decision point. Stages are cross-functional: There is no R&D or Marketing stage. Rather, each stage consists of a set of parallel activities undertaken by people from different functional areas within the firm, working together as a team and led by a project team leader. In order to manage risk via a *Stage-Gate* method, the parallel activities in a certain stage must be designed to gather vital information—technical, market, financial, operations—in order to drive down the technical and business risks. Each stage costs more than the preceding one, so that the game plan is based on incremental commitments. As uncertainties decrease, expenditures are allowed to mount: risk is managed.

### A Typical Stage-Gate™ Process

The general flow of the typical or *generic* stage-gate process is shown in Figure 3 (Cooper 2001). Here, following idea generation or Discovery, there are five key stages:

#### Stage 1. Scoping

A quick investigation and sculpting of the project. This first and inexpensive homework stage has the objective of determining the project’s technical and marketplace merits. Stage 1 involves desk research or detective work—little or no primary research is done here. Prescribed activities include preliminary market, technical and business assessments.

#### Stage 2. Build the Business Case

The detailed homework and up-front investigation work leading to a *business case*—a defined product, a business justification and a detailed plan of action for the next stages. This second homework stage includes actions such as a detailed market analysis, user needs and wants studies to build in voice of customer, concept testing, detailed technical assessment, source of supply assessment, and a detailed financial and business analysis.

#### Stage 3. Development

The actual design and development of the new product. Stage 3 witnesses the implementation of the Development Plan and the physical development of the product. Lab tests, in-house tests or alpha tests ensure that the product meets requirements under controlled conditions. The ‘deliverable’ at the end of Stage 3 is a lab-tested prototype of the product. While the emphasis in Stage 3 is on technical work, marketing and

<sup>3</sup> The term ‘Stage-Gate’ was coined by the author and first appeared in print in Cooper (1988). *Stage-Gate* is a legal tradename of the author. For more on *Stage-Gate™* methods, see Cooper (2001); also the *Stage-Gate* web-page: [www.prod-dev.com](http://www.prod-dev.com)

### Stage-Gate™: A five stage, five-gate model along with Discovery and Post-Launch Review

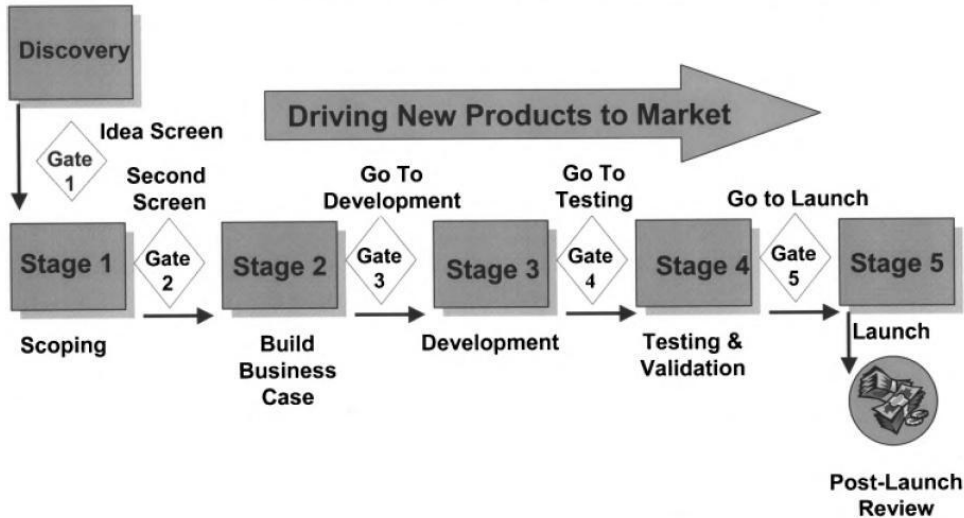


Figure 3. A typical Stage-Gate™ new product process.

Stage-Gate™ is a legal trademark of RG Cooper & Associates Consultants Inc.  
 Source: Cooper (2001).

operations activities also proceed in parallel. For example, market-analysis and customer-feedback efforts continue concurrently with the technical development, with constant customer opinion sought on the product as it takes shape during development. Additionally, the manufacturing (or operations) process is mapped out, the marketing launch and operating plans are developed, and the test plans for the next stage are defined. An updated financial analysis is prepared, while regulatory, legal, and patent issues are resolved.

#### Stage 4. Testing & Validation

The verification and validation of the proposed new product, its marketing and production. This stage tests and validates the entire viability of the project: the product itself, the production process, customer acceptance, and the economics of the project. A number of activities are undertaken at Stage 4, including in-house product tests (extended lab tests or alpha tests to check on product quality and product performance); user or field trials of the product (to verify that the product functions under actual use conditions, and to establish purchase intent); trial, limited, or pilot production (to test, debug, and prove the production process); pre-test market, test market, or trial sell (to gauge customer reaction and measure the effectiveness of the launch plan); and revised business and financial analysis.

#### Stage 5. Launch

Full commercialization of the product—the beginning of full production and commercial launch and selling.

Here the market roll-out or launch plan is implemented. Final production equipment installation and commissioning occurs, along with full production start-up. Finally, the post-launch plan—monitoring and fixing—is implemented, along with early elements of the life cycle plan (new variants and releases, continuous improvements).

Some 12–18 months after launch, the Post Launch Review occurs: the performance of the project vs. expectations is assessed along with reasons why and lessons learned; the team is disbanded but recognized or rewarded; and the project is terminated.

At first glance, this overview portrays the stages as relatively simple steps in a logical process. But what you see above is only a high-level view of a generic process. In an operational process in a real company, drilling down into the details of each stage reveals a much more sophisticated and complex set of activities: a detailed list of activities within each stage, the how-to's of each activity, best practices that the team ought to consider, and even the required deliverables from each activity in that stage (for example in the format of templates). In short, the drill-down provides a *detailed and operational road map* for the project team—everything they need to know and do to successfully complete that stage of the process and project.

#### The Gates

Preceding each stage is an entry gate or a Go/Kill decision point, shown as diamonds in Figure 3.

1. **Strategic:**
    - degree to which project aligns with BU's strategy
    - strategic importance
  2. **Product Advantage:**
    - unique benefits
    - meets customer needs better
    - value for money
  3. **Market Attractiveness:**
    - market size
    - market growth
    - competitive situation
  4. **Synergies (Leverages Core Competencies):**
    - marketing synergies
    - technological synergies
    - manufacturing / operations synergies
  5. **Technical Feasibility:**
    - technical gap
    - complexity
    - technical uncertainty
  6. **Risk Vs. Return:**
    - expected profitability (magnitude; e.g. NPV)
    - return (e.g. IRR)
    - payback period
    - certainty of return/profit estimates
- ✓ **The six Factors (in bold) are scored (e.g. 1-5 or 0-10) on a scorecard**
- ✓ **Factor scores must clear minimum hurdles**
- ✓ **Also added (weighted/unweighted) to yield the Project Attractiveness Score, which is used to make Go/Kill decisions & also to prioritize projects**

Figure 5. Best practice go-to-development decision criteria.

Copyrighted: Cooper, Edgett & Kleinschmidt (2002a).

the weighted addition of the factor ratings, and becomes the basis for developing a rank-ordered list of projects. Projects are ranked until there are no more resources.

Scoring models generally are praised in spite of their limited popularity. Research into project selection methods reveals that scoring models produce a strategically aligned portfolio and one that reflects the business's spending priorities; and they yield effective and efficient decisions, and result in a portfolio of high value projects (Cooper et al., 2002a).

#### Goal 2: A Balanced Portfolio

The second major goal is a balanced portfolio—a balanced set of development projects in terms of a number of key parameters. The analogy is that of an investment fund, where the fund manager seeks balance in terms of high risk vs. blue chip stocks; and balance across industries, in order to arrive at an optimum investment portfolio.

*Visual charts* are favored in order to display balance in new product project portfolios. These visual representations include portfolio maps or bubble diagrams (Figure 6).

#### Risk–Reward Bubble Diagrams

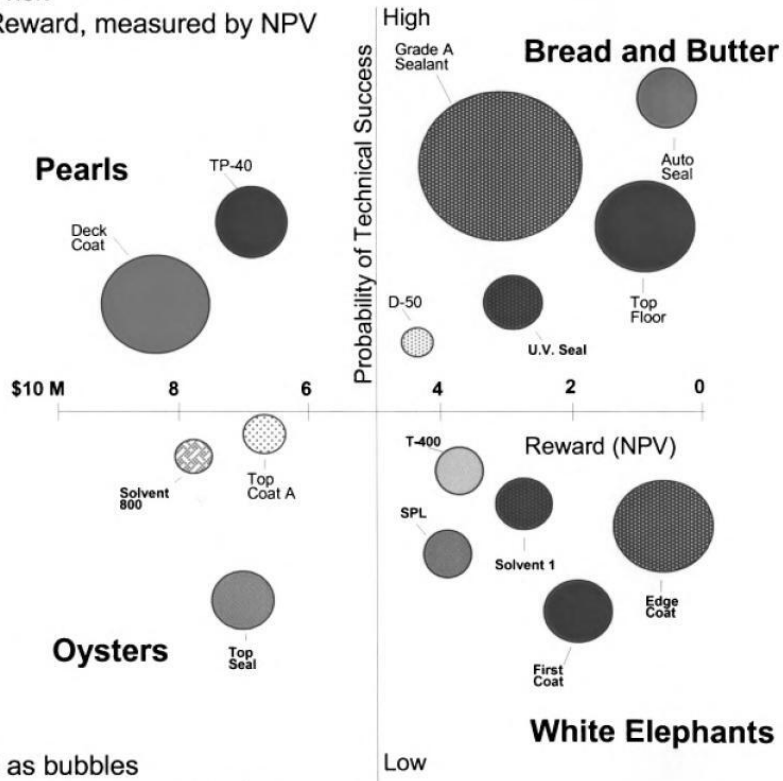
The most popular bubble diagram is a variant of the *risk/return chart* (see Figure 6). Here one axis is some measure of the *reward* to the company, and the other is a *success probability* (Cooper et al., 2002a; Evans 1996; Roussel et al., 1991). A sample bubble diagram is shown in Figure 6 for a business unit of a major chemical company. Note that the size of each bubble shows the annual resources spent on each project.

#### Traditional Charts for Portfolio Management

There are numerous parameters, dimensions or variables across which one might wish to seek a balance of projects. As a result, there are an endless variety of histograms and pie charts which help to portray portfolio balance. Some examples:

*Project types* is of vital concern. What is the spending on genuine new products vs. product renewals (improvements and replacements), or product extensions, or product maintenance, or cost reductions and process improvements? And what should it be? Pie charts effectively capture the spending split across project types—actual vs. desired splits (Figure 7).

North-South axis is risk  
 East-West axis is Reward, measured by NPV  
 (reverse direction)



Projects are shown as bubbles  
 Bubble size = annual resources per project

Figure 6. A typical & popular risk-reward bubble diagram.

Source: Cooper (2001).

Markets, products and technologies provide another set of dimensions across which managers seek balance. Pie charts are again appropriate for capturing and displaying this type of data (again, Figure 7).

*Goal 3: Building Strategy into the Portfolio*

Strategy and new product resource allocation must be intimately connected. *Strategy becomes real when one starts spending money!* The mission, vision and strategy of the business are made operational through the decisions management makes on where to spend money. For example, if a business’s strategic mission is to ‘grow via leading edge product development’, then this must be reflected in the mix of new product projects underway—projects that will lead to growth (rather than simply to defend) and products that really are innovative.

*Linking Strategy to the Portfolio: Approaches*

There are three main ways to build in the goal of strategic alignment:

- (1) *Bottom up*—building strategic criteria into project selection tools: here strategic fit is achieved by including numerous strategic criteria into the Go/Kill and prioritization tools;
- (2) *Top-down*—Strategic Buckets method: this begins with the business’s strategy and then moves to setting aside funds—envelopes or buckets of money—destined for different types of projects;
- (3) *Top-down*—Product Roadmap: here the business’s strategy defines what major initiatives or platform developments to undertake.

*Bottom Up—Strategic Criteria Built into Project Selection Tools*

Not only are scoring models effective ways to maximize the value of the portfolio, but they can also be used to ensure strategic fit. One of the multiple objectives considered in a scoring model, along with profitability or likelihood of success, can be to maximize strategic fit, simply by building into the scoring model a number of strategic questions. In the

**Pie slices show actual annual spending breakdowns**

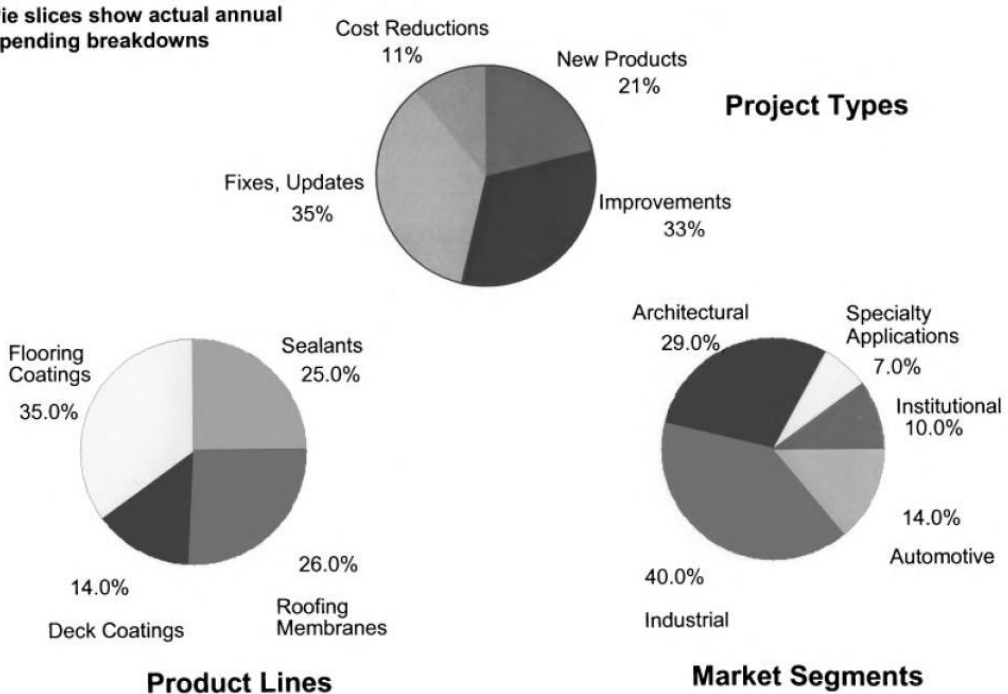


Figure 7. Breakdown of resources by project types, product lines & markets.

scoring model displayed in Figure 5, for example, three major factors out of six are strategic; and low scores on these will all but kill the project. Thus, projects that fit the business's strategy, offer competitive advantage, and leverage the firms' core competencies likely to rise to the top of the list. Indeed, it is inconceivable how any 'off strategy' projects could make the active project list at all: this scoring model naturally weeds them out.

*Top-down Strategic Approach—Strategic Buckets Model*

While strategic fit can be achieved via a scoring model, a top-down approach is the only method designed to ensure that where the money is spent mirrors the business's strategy (Cooper et al., 2002a). The Strategic Buckets model operates from the simple principle that *implementing strategy equates to spending money on specific projects*. Thus, setting portfolio requirements really means 'setting spending targets'.

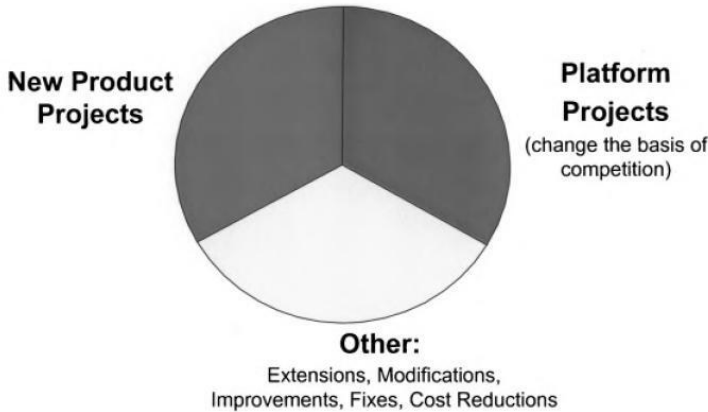
The method begins with the business's strategy, and requires the senior management of the business to make forced choices along each of several dimensions—choices about how they wish to allocate their scarce money resources. This enables the creation of 'envelopes of money' or 'buckets'. Existing projects are categorized into buckets; then one determines whether actual spending is consistent with desired spending for each bucket. Finally projects are priori-

tized within buckets to arrive at the ultimate portfolio of projects—one that mirrors management's strategy for the business.

In practice, senior management first develops the vision and strategy for the business. Next, they make forced choices across key strategic dimensions; that is, based on this strategy, development resources are split across categories on each dimension. Some common dimensions are:

- *Strategic goals:* Management splits resources across the specified strategic goals. For example, what percentage should be spent on Defending the Base? On Diversifying? On Extending the Base? and so on;
- *Product lines:* Resources are split across product lines: e.g. how much should be spent on Product Line A? On Product Line B? On C? A plot of product line locations on the product life cycle curve is used to help determine this split;
- *Project type:* What percentage of resources should go to new product developments? To maintenance-type projects? To process improvements? To fundamental research? etc;
- *Familiarity Matrix:*<sup>5</sup> What should be the split of resources to different types of markets and to

<sup>5</sup> The familiarity matrix was first proposed as a strategic tool by Ed Roberts (Roberts & Berry, 1983).



The business's strategy dictates the split of resources into buckets; projects are rank ordered within buckets, but using different criteria in each bucket.

Figure 8. Strategic buckets method of resource allocation.

Source: AlliedSignal-Honeywell; reported in: Cooper, Edgett & Kleinschmidt (2002a).

different technology types in terms of their *familiarity to the business?* (Roberts & Berry, 1983);

- *Geography*: What proportion of resources should be spent on projects aimed largely at North America? At Latin America? At Europe? At the Pacific? Or at global?

Now, management develops *strategic buckets*. Here the various strategic dimensions (above) are collapsed into a convenient handful of buckets. Then the desired spending by bucket is determined: the '*what should be*'. This involves a consolidation of desired spending splits from the strategic allocation exercise above. Next comes a gap analysis. Existing projects are categorized by bucket and the total current spending by bucket is added up (the '*what is*'). Spending gaps are then identified between the '*what should be*' and '*what is*' for each bucket.

Finally, projects within each bucket are rank-ordered, using either a scoring model or financial criteria to do this ranking within buckets. Portfolio adjustments are then made, either via immediate pruning of projects, or by adjusting the approval process for future projects.

A somewhat simpler example is shown in Figure 8. The leadership team of the business begins with the business's strategy, and uses the Mercedes-Benz emblem (the three-point star) to help divide up the resources. There are three buckets: fundamental research and platform development projects which promise to yield major breakthroughs and new technology platforms; new product developments; and maintenance—technical support, product improvements and enhancements, etc. Management divides the

R&D funds into these three buckets, and then rates and ranks projects against each other within each bucket. In effect, three separate portfolios of projects are created and managed. And the spending breakdowns across projects mirror strategic priorities.

The major strength of the Strategic Buckets Model is that it firmly links spending to the business's strategy; further, it recognizes that all development projects that compete for the same resources should be considered in the portfolio approach. Finally, different criteria can be used for different types of projects. That is, one is not faced with comparing and ranking very different types of projects against each other.

#### Top Down Strategic Approach—Product Roadmap

A product roadmap<sup>6</sup> is an effective way to map out a series of assaults in an attack plan. What is a roadmap? It is simply a management group's view of how to get where they want to go or to achieve their desired objective (Albright, 2001; Myer & Lehnerd, 1997). The roadmap is a useful tool that helps the group make sure that the capabilities to achieve their objective are in place when needed. Two useful types of roadmaps are the product roadmap and the technology roadmap:

- (1) The *product roadmap* defines the product and product releases along a timeline—how the product line will evolve over time, and what the next generations will be. It answers the question: what products? An example is shown in Figure 9. Here

<sup>6</sup> This section is based on Lucent Technologies. See R. E. Albright (2001). For more on platforms and roadmaps, see Myer & Lehnerd (1997).

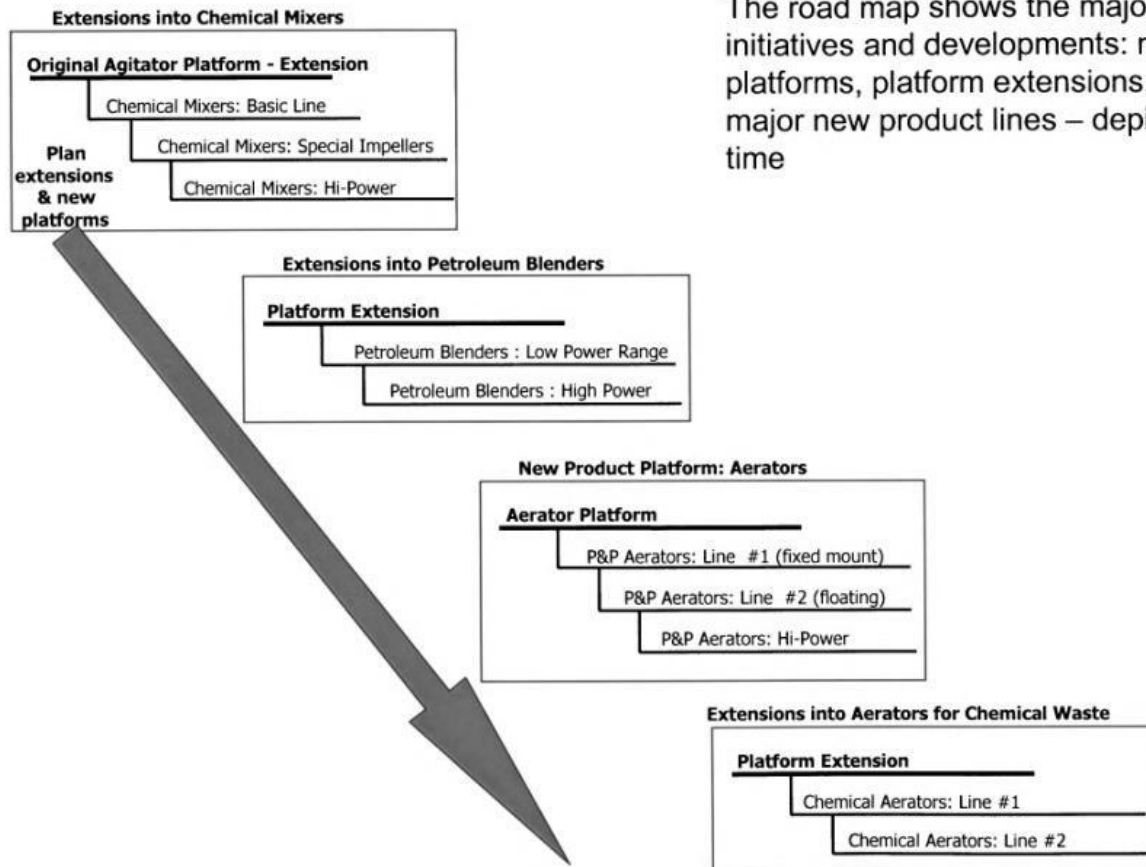


Figure 9. A product roadmap for a process equipment manufacturer.

Source: Cooper (2001).

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# Types of Innovations

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**Abstract:** Innovations can be of eight different types. Each represents a different kind of contribution. For example, a conceptual replication is a minimal innovation, repeating with minor variations an idea that already exists (e.g. Mercury's putting the 'Mercury' label on what is essentially an already-existing Ford car). Forward incrementations represent next steps forward along existing lines of progression (e.g. the 2001 version of a 2000 car). Redirections represent a totally different direction for products that diverge from the existing line of progress (e.g. electric cars). We will discuss the types of innovations and the circumstances leading to success.

**Keywords:** Innovation; Creativity; Incrementation; Propulsion; Redirection; Reinitiation; Replication.

## Introduction

In the erstwhile television series, *All in the Family*, there was an episode in which a character created a novel invention: a remote-control doorbell ringer. One could ring someone's doorbell remotely, so that one actually did not have to go up to the door of the person in order to ring the bell. It quickly became obvious that, although the invention was novel, it somehow was not creative. What it lacked was a second property of creativity beyond novelty: usefulness. All inventions and, indeed, innovations of any kind, start with some kind of creative enterprise, and the enterprise must produce work that is not just novel, but useful.

*Creativity* is the ability flexibly to produce work that is novel (i.e. original, unexpected), high in quality, and useful, in that it meets task constraints (Lubart, 1994, this volume; Ochse, 1990; Sternberg, 1988, 1999b; Sternberg & Lubart, 1995, 1996). The remote-control doorbell ringer was novel, but not useful for any particular task anyone could think up—at least on the show. Creativity is a topic of wide scope that is important at both the individual and societal levels for a wide range of task domains. At an individual level, creativity is relevant, for example, when solving problems on the job and in daily life. At a societal level, creativity can lead to new scientific findings, new movements in art, new inventions, and new social programs. The economic importance of creativity is clear because new products or services create jobs. Furthermore, individuals, organizations, and societies

must adapt existing resources to changing task demands to remain competitive. *Innovation* is the channeling of creativity so as to produce a creative idea and/or product that people can and wish to use.

Creativity may be viewed as taking place in the interaction between a person and the person's environment (Amabile, 1996; Csikszentmihalyi, 1996, 1999; Feldman, 1999; Feldman, Csikszentmihalyi & Gardner, 1994; Sternberg, Kaufman & Pretz, 2002; Sternberg & Lubart, 1995). According to this view, the essence of creativity cannot be captured just as an intrapersonal variable. Thus, we can characterize a person's cognitive processes as more or less creative (Finke, Ward & Smith, 1992; Rubenson & Runco, 1992; Weisberg, 1986, this volume) or the person as having a more or less creative personality (Barron, 1988; Feist, 1999). We further can describe the person as having a motivational pattern that is more or less typical of creative individuals (Hennessey & Amabile, 1988), or even as having background variables that more or less dispose that person to think creatively (Simonton, 1984, 1994, this volume). But we cannot fully judge that person's creativity independent of the context in which the person works.

For example, a contemporary artist might have thought processes, personality, motivation, and even background variables similar to those of Monet, but that artist, painting today in the style of Monet, probably would not be judged to be creative in the way

Monet was. He or she was born too late. Artists, including Monet, have experimented with impressionism, and unless the contemporary artist introduces some new twist, he or she will likely be viewed as imitative rather than creative. To a large extent, creative innovation starts with a decision to be creative and to think intuitively and ‘out of the box’ (see Root-Bernstein & Root-Bernstein, this volume).

### The Propulsion Model of Creative Contributions

Sternberg (1999c) has presented what he refers to as a propulsion model of creative contributions (see also Sternberg, Kaufman & Pretz, 2001, 2002). The idea is that creative contributions ‘propel’ a field forward in some way—they are the result of creative leadership on the part of their creators. The propulsion model is a descriptive taxonomy of eight types of creative contributions. Although the eight types of contributions may differ in the extent of creative contribution they make, there is no a priori way of evaluating *amount* of creativity on the basis of the *type* of creative contribution. Certain types of creative contributions probably tend, on average, to be greater in amounts of novelty than are others. For example, replications tend, on average, not to be highly novel. But creativity also involves quality of work, and the type of creative contribution a work makes does not necessarily predict the quality of that work.

The eight types of creative contributions are:

- (1) *Replication*. The creative contribution represents an effort to show that a given field is where it should be. The propulsion is intended to keep the field where it is rather than moving it;
- (2) *Redefinition*. The creative contribution represents an effort to redefine where the field currently is. The current status of the field thus is seen from a new point of view;
- (3) *Forward Incrementation*. The creative contribution represents an attempt to move the field forward in the direction in which it already is moving, and the contribution takes the field to a point to which others are ready to go;
- (4) *Advance Forward Incrementation*. The creative contribution represents an attempt to move the field forward in the direction it is already going, but the contribution moves beyond where others are ready for the field to go;
- (5) *Redirection*. The creative contribution represents an attempt to move the field from where it is currently headed toward a new and different direction;
- (6) *Reconstruction/Redirection*. The creative contribution represents an attempt to move the field back to where it once was (a reconstruction of the past) so that the field may move onward from that point, but in a direction different from the one it took in the past;
- (7) *Reinitiation*. The creative contribution represents an attempt to move the field to a different and as yet not reached starting point and then to move the field in a new direction from that point;
- (8) *Integration*. The creative contribution represents an attempt to move the field by putting together aspects of two or more past kinds of contributions that formerly were viewed as distinct or even opposed. This type of contribution shows particularly well the potentially dialectical nature of creative contributions, in that it merges into a new Hegelian type of synthesis two ideas that formerly may have been seen as opposed (Sternberg, 1999a).

The eight types of creative contributions described above are viewed as qualitatively distinct. However, within each type, there can be quantitative differences. For example, a forward incrementation may represent a fairly small step forward for a given field, or it may represent a substantial leap. A reinitiation may restart an entire field or just a small area of that field. Moreover, a given contribution may overlap categories. For example, a forward incrementation may be the result of an integration of somewhat closely related concepts in the field.

Thus, when people are creative, they can be creative in different ways. The exact nature of these ways depends upon the theory of types of creative contributions one accepts. What is a creative contribution and why do we need a taxonomy of types of creative contributions? A consensual definition of a creative contribution is of something that is: (a) relatively original; and (b) high in quality vis-à-vis some purpose (see Sternberg & Davidson, 1994; Sternberg & Lubart, 1995, 1996). Starting with creative contributions rather than creative contributors can have several advantages. First, a given contributor may make a variety of different types of contributions. The contributor thus is not limited to any one of the eight types of creative contributions described in this book. Contributions may be primarily of a given type, but creators may not be. For example, much, but certainly not all of Picasso’s work, set off in strikingly original and bold directions. Through the proposed theory, one can evaluate individual works of a creator and not just the ‘average’ or typical type of work the creator produced. Second, even if contributors tend to have a type of contribution they make most often, observing differences in the types of contributions individuals make can help elucidate differences in the types of creativity the contributors typically tend to show. Third, the emphasis on contributions rather than creators underscores the point that people can modify the kinds of contributions they make. Someone early in a career may be afraid to depart too much from accepted ways of doing things, for fear that such a departure will put his or her career at risk of being derailed. Later in a

career, however, for example, after attaining tenure or, at least, financial security, the creator may be willing to take risks and make contributions that earlier he or she would not have felt comfortable making earlier. The creator's goals and purposes may change. Even from the days when composers had to compose music or artists had to paint works in order to please their royal patrons, creative individuals have always operated under societal constraints. Given the importance of purpose, creative contributions must always be defined in some context. If the creativity of an individual is always judged in a context, then it is important to understand how the context interacts with how people are judged. In particular, what are the types of creative contributions a person can make within a given context? Most theories of creativity concentrate on attributes of the individual (see Sternberg, 1988, 1999b). But to the extent that creativity is in the interaction of person with context, we would need as well to concentrate on the attributes of the individual and the individual's work relative to the environmental context.

How can one apply the propulsion model to invention? We consider this question next, reviewing inventions that represent each of the eight types of creative contributions listed above.

### **Examples of Each of the Types of Creative Propulsion**

#### *Replication*

In replication, inventors essentially duplicate an existing product, sometimes, with improvements in pricing or in quality. Many people are familiar with Altoids™, which are a particularly strong kind of breath mint. When these mints first came onto the market, they were an immediate hit. People quickly started buying them up. As so often happens when a product is successful, other manufacturers see money to be made by imitating the original product. One of the authors recently went to a drug store to buy a tin of these mints, and was only a bit surprised to see that, where before the one brand had had this particular section of the drugstore counter to itself, now it was sharing space with three competitors. As far as the author could tell, the three competitors basically had replicated the Altoids™ formula for success, with minor variations.

Such copies are commonplace in industry. The success in IBM personal computers rapidly gave rise to large numbers of replications, which were so similar to the original IBMs that they actually were (and still are) referred to as 'clones'. Kleenex™ tissue paper gave rise to large numbers of imitators, as did bran cereals with raisins. Sometimes the replicators ultimately achieve a larger market share than did the originators, typically when the new products are either notably better in quality or notably less expensive than the original product.

#### *Redefinition*

Video games have become an integral part of American culture. Just as the invention of the television in the 1950s redefined entertainment and indirectly influenced many arenas of American life, the introduction of the video game in the 1970s has initiated a change in the nature of childhood play throughout society.

Where did video games come from? Who first had the idea to make television interactive, to give people the power to control the action on the screen? The origins can be found in one of the first video games, Pong. Video games actually stem from a very simple concept invented in the 1950s by an unsuspecting physicist working at Brookhaven National Laboratories in Upton, New York, Willy Higinbotham. Higinbotham's original 'video game' was designed to add some spice to a public tour of his instrumentation laboratory. Because Brookhaven was involved in nuclear research, these tours were organized to show visitors that the research was entirely peaceful and posed no risk to residents. Higinbotham knew that the tour of the facility was not very exciting, so he toiled around with an oscilloscope and a simple computer, built a few controls with buttons and knobs, and created what can be considered the first video game. The game was conceptually very similar to Pong: one player presses a button to launch a ball from the left side of the screen, adjusts a knob so the ball clears a barrier in the middle of the screen, and a second player hits the ball back over the 'net'. With these modest beginnings, the video game industry was born.

Little did Higinbotham know that not only would his simple tennis game relieve boredom on the tour of his laboratory, but that players would form lines, eager to try their hand at the novel challenge. Before Higinbotham understood the potential of the demand he had created, marketers seized hold of the idea. In fact, Pong is simply a redefinition of Higinbotham's basic tennis game. The originators of Pong did not seriously revamp the design, but they did bring to it a new perspective. Realizing the game's potential for fascination (and remuneration), they grabbed their opportunity to latch onto the public's interest. As almost every American child can attest, their fascination has not waned, and the video game industry continues to profit (Flatow, 1992). Redefinitions are not limited, of course, to video games.

A split-second decision can also represent an attempt to redefine a field. Jenó Paulucci was a businessman who had just purchased Chun King, a canned food company. Paulucci wanted to use this company to sell his own food inventions, Cantonese vegetables with Italian spices. Paulucci had a meeting with the main buyer for a top food chain, and he was trying to sell his Chun King cans to be distributed by this chain. If the businessman was able to make the sale, his company would surely take off and become profitable; if not, it

would be a difficult task to maintain financial solvency.

Demonstrating his product, Paulucci opened up a can of chop suey vegetables—and saw a cooked grasshopper sitting right in the middle of the can. Paulucci had one brief moment in which the grasshopper was hidden from the buyer by the open can lid. What could he do? If the buyer saw the grasshopper, the sale would surely not go through—and Chun King's reputation would likely suffer. Think about what you might do in such a situation.

In those few seconds, Paulucci redefined his role as salesman. Not only was Paulucci responsible for presenting his product to a potential buyer, but his chances of making a sale would be increased if he could convince the customer that he was a consumer himself. A typical businessman might have either tried to surreptitiously remove the grasshopper from the can (and run a high risk of being caught) or tried to explain the many legitimate reasons why the dead grasshopper was not indicative of his company's product. Paulucci decided to attempt neither of these two strategies. Instead, he looked the buyer in the eye and said that the vegetables looked so good that he wanted to have the first bite himself. Paulucci took a large forkful of vegetables—including the fateful grasshopper—and ate the large bite with a big smile. He got the sale (Hay, 1988).

#### *Forward Incrementation*

In forward incrementation, a new product is invented that moves an existing product line to the next step consumers are ready to take. The invention of the incandescent lamp is a good example of the forward incrementation typical of normal science (Kuhn, 1970). Although Americans strongly associate the name of Thomas Edison (1847–1931) with the invention of the light bulb, Joseph Swan (1828–1914) of England deserves equal scientific credit for his work on the problem, as do many others who also contributed small steps along the way toward the successful product.

The first attempts at creating a light bulb can be traced to 1838, when Jobart “sealed a carbon rod inside a vacuum and watched it glow as a current was passed through it” (Clark, 1985, p. 220). By 1847, progress had reached a point where the concept of an evacuated bulb with a carbon filament had been solidified. But specific problems remained. Incandescent lamps in the mid-1800s burned for a very short period of time due to a combination of two factors. First, the filaments were not durable, and second, there was too much air inside the bulb (Yarwood, 1983).

As the technology was not yet available to create a vacuum inside the bulb, experiments focused on perfecting the filament. Swan experimented with a carbon filament treated in various ways, whereas Edison believed that a platinum filament was the answer. Earlier, he had worked with carbon unsuccess-

fully. In 1865, Hermann Sprengel introduced the mercury vacuum pump, and 14 years later, Edison devised and his group devised a vacuum pump combining the Sprengel and Geissler pumps. He finally met success with a carbon filament (Clark, 1985).

Step by step, scientists settled on the carbon filament and began to produce light bulbs in quantity by 1882. At that point, the only impediment to more widespread use of the bulbs was the lack of electrical wiring in homes and businesses. The next step of the path was cleared as Edison and his colleagues set out to create a system of electricity to bring power to cities. Even after Thomas Edison and Joseph Swan joined forces to create United Electric Company, experiments on metal filaments continued (Yarwood, 1983). Eventually, the tungsten filament became preferred because of its high melting point, and it remains the standard in the light bulbs of today.

Whereas some discoveries are characterized by distinct moments of insight that create a discontinuous path of progress, the light bulb is better viewed as the product of a scientific evolution directed by careful experimentation and simple trial and error. Such forward steps or incrementations are key to the progress of every scientific field.

Another example of a next step in science is Pasteur's development of vaccine therapy following his germ theory of disease. After the germ theory had described how airborne bacteria are the mechanism for the cause of disease, the next step was to extend the theory's implications for disease prevention, namely, vaccine therapy. The concept of vaccination did not originate with Pasteur (nor did pre-germ theory advances in sanitary practices in medical settings). For example, Edward Jenner had earlier discovered the effectiveness of using small amounts of cowpox to vaccinate humans against small pox.

Pasteur reasoned that the administration of similarly attenuated germs might prevent the development of bacterially caused diseases. His first attempt, using fowl cholera, proved a success. Although he at first did not realize that the attenuation was caused by prolonged exposure to warm air, later experiments with anthrax in cattle confirmed that time and heat did indeed sufficiently weaken the bacteria. Pasteur's great triumph of vaccine therapy was in a dire case of a young boy attacked by a rabid dog. After administering a culture developed from the brains of dogs and rabbits, the boy's survival was celebrated and the miraculous effectiveness of vaccination assured (Meadows, 1987).

Vaccine therapy was not a new idea to Pasteur, in that Jenner had already used it in the treatment of smallpox. In fact, ancient Chinese culture had already recognized this technique in the 10th century. Alchemists in China administered a smallpox vaccine by inserting slightly infected plugs of cotton into the noses of healthy individuals (James & Thorpe, 1994). But Pasteur extended this method to include new diseases

change in manufacturing whose impact reached beyond the automobile industry to include a broad range of industrial domains.

The increased use of mass production has influenced the nature of the industrial workforce and the economies of countries through the world, and has led to related techniques such as automatization. For example, factories rely primarily on unskilled or semi-skilled labor while machines have taken over the technical difficulties of the job. As mass-production facilities have become more ambitious, more elaborate supervisory hierarchies have become necessary, and positions for management specialists as well as distributors and salespeople have been created. Although Ford himself did not conceive of this evolution of manufacturing industry, his introduction of the assembly line and the technique of mass production may be considered the crucial step which led to a complete redirection in the field of manufacturing.

An invention that had redirective effects on the field of communication as well as on the wider social and intellectual world is the printing press with movable type. The first printed book dates to 9th century China although the printing press did not appear in Europe until the mid-15th century. Whether these developments were independent or related is of less concern than is the impact of the printed word on Western society at the time of its introduction.

Prior to the invention of movable type and the printing press, books were laboriously copied by hand. This process resulted in books' being rare and precious. When Johannes Gutenberg (1394/99–1467) introduced the concept of movable type in 1448 in Mainz, Germany, a revolution followed. Especially in Europe, the 26-letter alphabet was particularly well suited to the use of movable type. Any book could be reproduced by mixing and matching many multiples of these 26 basic prototypes. (This was not the case in China. Given the large numbers of characters used in the Chinese language, movable type was simply not as practical in China as it turned out to be in Europe (Cardwell, 1994)). It has been estimated that there were more books published in Europe between 1450 and 1500 than had been published in the previous 1,000 years (Yarwood, 1983).

The immediate and lasting effect of Gutenberg's contribution can be summarized as the grand facilitation of the dissemination of ideas. Gutenberg's process affected many aspects of culture, including the dissemination of information about religion. Perhaps the best-known printed volume associated with Gutenberg's name is his version of the Latin Bible. As a case in point, greater public access directly to scripture had revolutionary (or, at least, reformatory) effects on the culture at the time. As Bibles became more available, lay people who were not proficient in Latin wished to read the text in their native language. As Bibles became

available in the vernacular, the theology of the Church was also in a parallel transition. Martin Luther (1483–1546) advocated direct access to the scripture by lay people, preaching a new Reformation theology that argued for a direct and personal relationship with God (Rubenstein, 2000).

One of the most popular products of early presses were indulgences, certificates that could be purchased from the Catholic Church in exchange for an absolution of sins. Appropriately, the presses also helped disseminate the famous 95 theses against the sale of indulgences first posted by Martin Luther in 1517. Although such heretical theological ideas would normally have been discussed among Luther's colleagues at the university in Wittenberg, the printed versions of his theses no doubt spread his controversial ideas to others, gaining subtle support for his call for reform.

The invention of the printing press greatly facilitated the spread of ideas in an age of great progress. From the careful molding and casting of movable metal type to the printing and binding of the illustrative Gutenberg Bibles, the printing press has been pivotal in redirecting the history of European culture.

Another redirection occurred in the field of telecommunications with the invention of the telephone in 1876. During the 19th century, people communicated with one another over long distances using the revolutionary telegraph network. However, as the technique became more popular, supply could no longer meet demand. The problem was that only one message could travel over a given wire at any given time, and there simply were not enough wires to carry all the messages that people wanted to send. In 1872, the race was on to find a way to send more than one message simultaneously over the same wire (Flatow, 1992).

Alexander Graham Bell (1847–1922), a teacher who enjoyed tinkering, believed he might have a solution to this problem. Based on his experience with tuning forks, Bell reasoned that it might be possible to send two messages over the same wire. He experimented with tuning-fork transmitters set at different pitches and receivers in the form of reeds set to vibrate at the same frequency as the tuning forks. Once Bell was able to tune the reeds to resonate with the forks, he was able to show that his hypothesis was correct: each fork caused a response in its respective reed, and the two frequencies did not interfere with one another! This was Bell's harmonic telegraph (Flatow, 1992).

Follow-up experiments with his new musical instrument revealed that when the tuning fork was plucked, its tone was transmitted to the receiver. Bell's suspicions that speech could be transmitted similarly over wire were beginning to become plausible. Bell knew that he only needed a transmitter that could convert speech into electrical signals, and the telephone then could become a reality. Meanwhile, Elisha Gray, a successful inventor, had been working on the same

telegraph problem, and had obtained similar results. However, Gray was discouraged by businessmen and others who believed that the telephone would never be profitable. Unfortunately, Gray listened to the short-sighted businessmen, and his design of the telephone was set aside (Flatow, 1992).

This is the point where Bell's daring to defy the crowd paid off. Bell's recent breakthrough with the harmonic telegraph propelled him forward. Flatow (1992) writes, "Bell could no longer ignore (opportunity's) knock. He would give up on the telegraph and concentrate on the telephone" (p. 81). Rather than follow the path of normal science, working to perfect the telegraph system, Bell saw an opportunity to make a new contribution, one that could redirect the field toward a communication system based not on dits and dahs, but rather on the authentic human voice.

The rest of the story is well known. Bell patented his telephone in 1876, just hours before Gray's application arrived at the patent office (Flatow, 1992). A few years later, the invention of the microphone by David Hughes (1831–1900) greatly improved the quality of telephone communication and spurred its more widespread use. The first telephone lines were installed shortly thereafter in 1878 in New Haven, Connecticut. By the 1920s telephones had become a standard mode of communication (Williams, 1987). Although the telegraph did not immediately fall into disuse, the addition of the telephone pushed our communicative repertoire in a new direction.

#### *Reconstruction/Redirection*

One relatively recent invention that is based on an old idea is the amateur photographer's one-use camera. The small unit is purchased pre-loaded with film, and the film is developed simply by dropping off the whole camera at a camera center. The film processors remove the film from the camera, develop it, and return the prints to the customer. This convenient service saves consumers the trouble of carrying a fragile, expensive camera with them on vacation. It also gives a second chance to those vacationers who forgot their personal cameras at home. And it even allows newlyweds to collect candid shots of their friends and relatives at their wedding reception without having to hire a professional. You think this is a wonderful example of an invention for modern convenience? Think again.

Actually, the one-use camera was invented in 1888, one of the original Kodaks to be marketed to amateurs (Flatow, 1992). The first cameras for personal use were marketed under the motto, "You press the button, we do the rest", a slogan which would certainly apply to many of today's automatic cameras (Flatow, 1992, p. 49). Whereas early photography was characterized by its reliance on cumbersome equipment and dangerous chemicals, this new Kodak was improved for amateur use. Kodak's first personal camera was small and lightweight. Its film was stored in a compact roll

that could be unwound with a key, and the operation of the camera required no special chemicals or setup. Consumers bought a camera that was preloaded with a roll of film of 100 exposures. When the roll was shot, the entire camera was shipped to Kodak for processing and returned fully reloaded and ready to go. By 1900, Eastman Kodak had perfected their concept of the personal-use camera with the introduction of the Brownie camera. The six-exposure Brownie was cheap and extremely simple to use, and caught the imaginations of many Americans (Flatow, 1992).

The reinvention of the original Kodak as a modern one-use, disposable camera is an example of a creative reconstruction/redirection. The Kodak company recognized the potential of this old idea to move the field in a new direction. Whereas the original camera first enabled non-professionals to try their hand at photography, the modern reconstruction contributes in a different way. In the field of modern photography, it is no new concept that amateurs have access to quality cameras, so the creative contribution of the new Kodak original is its convenience. Now there is an option for people who seek an inexpensive, temporary solution to their photography needs. Wouldn't they be surprised to learn that a similar convenience existed at the turn of the century?

#### *Reinitiation*

Reinitiations are represented by inventions that take off in an imaginative and wholly new way. An especially creative reinitiation lies in the field of written language. Imagine you were raised to communicate in a language that was only spoken and that had no written form. Suppose you wanted to create a system to represent the sounds and meanings of your native tongue. Where would you start? How many symbols would you need to sufficiently record the multitude of nuances in your oral tradition?

This is exactly the challenge that Cherokee Native American Sequoyah took upon himself in 1809. Sequoyah grew up in Alabama and spent time fighting the white settlers in the early 1800s. In 1809, when Sequoyah was approximately 35 years old, he realized that the Cherokee language might suffer under the effects of the social upheaval taking place at the time, so he decided he would do what he could to preserve the oral tradition with which he and his people had been raised. Unfamiliar with any particular written language, English or otherwise, Sequoyah began to create symbols to represent the sounds of Cherokee.

As he noted the many sounds that were part of his spoken words, he took symbols found in printed materials, including some from the English, Greek, and Arabic alphabets to represent these sounds. In 1821, after 12 years of hard work, Sequoyah had created a list of 85 syllables, the Cherokee syllabary. Based on this syllabary, Sequoyah began to read and write and to teach others to do the same. By 1828, the *Cherokee*

*Phoenix* became the first Native American newspaper to be published. The fact that this written language was created single-handedly and in such rapid time is a feat of genius and perseverance (Zahoor, 1999).

The contribution of Sequoyah to the written language may be viewed as a reinitiation through the alphabets he employed in creating it. Sequoyah took letters from English, Greek, and Arabic and assigned to them entirely new Cherokee phonemes without any regard to their sounds in the original languages. Although there is no reason to believe that Sequoyah did this with the intent to reject the source alphabets, his new syllabary is effectively a reinitiation of the alphabets he drew on in creating his Cherokee syllabary.

Reinitiative contributions are often bold and daring gestures. Such contributions are often found in inventive performance and artistic production. One prime example can be found in sculpture, with Marcel Duchamp's 1917 *Fountain*. Duchamp's Dada piece is simply a urinal turned on its back. The very act of entering such a piece in an art show is a statement about art—Duchamp's sculpture made art-making focus on the definition of exactly what art is and what art can be. Duchamp's urinal became a piece of art, and he and his fellow Dada creators set the stage for other modern art that exists, in part, to challenge our ideas of what 'art' encompasses (Hartt, 1993).

Another radical reinitiator is one of Duchamp's friends, the composer John Cage. He often employed unconventional sound materials and spent a period in which his compositional process (and often performance) was determined entirely by chance. The philosophy that led Cage to compose in this unorthodox manner can be considered essentially a rejection of some basic tenets of the Western musical tradition, including the definition of music itself. Cage declared music to be all sound, including the whispers and heartbeats we perceive while silent. Cage's affinity for Eastern philosophy caused him to focus on the importance of awareness in the human experience, and he used his music to foster awareness in his listeners.

An illustration of this point is his piece *4' 33"*. The performance of this piece consists of four minutes and 33 seconds of 'silence', or rather, in Cage's terminology, 'unintentional sound'. In performance, the instrumentalist approaches her instrument, prepares to play, and proceeds to sit, motionless and without sound, for four minutes and 33 seconds. The only pauses are those indicated to signal the change of movement. The music, therefore, is that sound which exists in the environment during that period of time. Cage's statement is that there is music being played around us all the time; we must reject the notion of music as organized melody, harmony and rhythm to include all intentional sound, even the rush of traffic beyond the door and the buzzing of the fluorescent lights above our heads (Cage, 1961; Hamm, 1980).

A reinitiation in science was Lavoisier's invention of a revolutionary new chemistry. This reinitiation had an immediate and lasting impact on the field. In the 18th century, the predominant view of combustion was that of the German chemist Georg Stahl (1660–1734). Stahl's model of combustion was founded on the premise that combustible matter was composed of water and a substance called phlogiston. According to this early view, burning a metal resulted in the loss of phlogiston. Support for this theory was demonstrated by combining the oxide of a metal with a material containing phlogiston (for example, charcoal). This experiment would yield a pure sample of the metal, consistent with the theory that the addition of phlogiston could restore the initial substance (Meadows, 1987).

However, it became clear that chemical reactions of combustion yielded slightly heavier products, despite the claim that the process of combustion required the loss of matter, namely, phlogiston. This apparent paradox led many chemists of the day to attempt to explain the result in the context of phlogiston theory. However, Antoine Lavoisier (1743–1794) was skeptical enough of the vague and sparse evidence for the actual existence of this mysterious substance called phlogiston that he dared to discard the concept altogether. Lavoisier proceeded to explain how combustion could take place in its absence. Based on careful analysis, Lavoisier confirmed through observation that metals actually did gain weight during combustion. This result was attributed to the presence of oxygen during combustion. When a metal burned, oxygen in the air was consumed and was captured in the resulting compound, an oxide (Cohen, 1985).

The key failure of phlogiston theory is its lack of an understanding of the gaseous state. Early chemists did not consider air to play a role in combustion reactions. At most, the air was a mere waste bin for the phlogiston lost in the reaction. Lavoisier discovered that elements could exist in solid, liquid, and gaseous states. It was this realization that became the foundation of Lavoisier's chemical revolution. Lavoisier pointed out that air is composed of many different substances, one of which is oxygen.

In contrast to many reinitiative contributions, Lavoisier's revolution in the field of chemistry made an impact almost immediately. Through the introduction of a standardized chemical language, a new periodical in 1788, a textbook in 1789, and a host of disciples, the new chemistry became respected by all but a few skeptical scientists (notably, Joseph Priestly) within a few decades (Meadows, 1987). This revolution is known as the triumph of the Antiphlogistians (Cohen, 1985).

Lavoisier's opposition to phlogiston theory was not wholly a radical leap from the normal science of his time. There was no dearth of results in studies of

combustion that did not fully support phlogiston theory. However, Lavoisier's confident declaration of his rejection of this long-held theory and his suggestion of a plausible alternative view reinitiated the field of chemistry. Especially notable are Lavoisier's subsequent contributions to the field in terms of developing a standardized chemical language and his laying out a textbook describing the new chemistry (Meadows, 1987). In this way, the contribution of a new chemical theory was not merely a next logical step, but a reinitiation from a new starting point that rejected what had been crucial assumptions of the field.

While a reinitiation can certainly be the result of a great and world-class innovator, unemployed advertising men can have reinitiative ideas as well, if on a different scale. In 1975, Gary Dahl listened to his friends talk about how expensive and time-consuming it was to own a pet. Dogs and cats are not a simple responsibility, and even lower-maintenance pets like fish or birds require some time, effort, and money. It was at this point that Dahl had the idea that a pet did not have to be a living creature. And, in fact, he proceeded along in that direction to create an entirely new idea: a pet rock (Panati, 1991).

While primarily (of course) a parody of pet owners, the pet rock does represent an entirely new way of looking at what it means to own a pet. Dahl took the idea and expanded on it. He wrote an owner's manual (which included instructions on how to train the pet rock to roll over or play dead). He packaged it in a box with air holes, and he also sold pet food, in the form of rock salt (Panati, 1991). The pet rock, as many people know, became an instant success; it is one of the few fads that is still remembered years later. Dahl may not have even been intending to make a creative statement, but he did. He conceptualized the field of pet ownership as being in a different place, and then he showed a new way for that field to go. And, indeed, perhaps the current feelings of possessiveness and ownership that some people feel for their cars is not that far removed from the odd tenderness one might feel for a pet rock.

### *Integration*

An invention that is an integration is one that combines ideas from two distinct domains of invention. An example of an historical integration is the complex evolution of the Japanese written language. Originally, Japanese was strictly a spoken language, but around AD500, Japanese speakers began to use Chinese kanji (pictographs) to represent Japanese words. While written Japanese looked identical to the Chinese, any one character was pronounced in two different ways, one of which approximated the Chinese pronunciation, and the other of which corresponded to the Japanese word bearing the same meaning. Since 1945, close to 2,000 kanji have been designated as Kanji for Daily

Use in the Japanese language. These are the kanji that children learn in school today (Miyagawa, 2000).

By AD1000, however, the Japanese needed a supplemental system to represent Japanese words that had no Chinese counterpart. To meet this purpose, syllabaries called kana were derived from Chinese characters. Rather than representing the meaning of a whole word, a kana represents a syllable or sound. There are two systems of kana in modern Japanese. The first, called hiragana, originated with Buddhist priests. While they were translating Chinese works into Japanese, they began inserting syllables next to characters to designate a particular Japanese inflection or alternate meaning from the Chinese (Vogler, 1998). The second system of kana, katakana, is primarily used to represent foreign words.

The original use of Chinese characters to represent Japanese words may be viewed as a redefinition of sorts. That is, the meaning remained the same while the label, or way of reaching that meaning, changed. However, the entire Japanese language is best seen as an integration (and subsequent forward incrementation) of symbol systems. Specifically, the introduction of kana to modify kanji is a particularly good example of melding two representational systems into one entirely new system. The meanings of words with kanji and kana are not fully decipherable based solely on the kanji, evidence that a true integration has taken place.

An example of integration in science is Isaac Newton's (1642–1727) formulation of the universal law of gravity. In essence, this discovery was a synthesis of ideas proposed by thinkers such as Ptolemy, Copernicus, Kepler, Galileo, and Hooke. Newton succeeded in explaining how a singular concept of gravity could explain a variety of observations made by scientists past and contemporary. While Copernicus had dared to oppose the Ptolemaic notion that planets encircle the sun and Kepler had demonstrated that the orbits were elliptical, no one had been able to explain why such elliptical orbits would emerge. Newton discerned the mathematical rule by which elliptical orbits would result, thus explaining the relationship between planets and the sun. In his 1687 'The Mathematical Principles of Natural Philosophy', Newton described basic principles that could mathematically account for the diverse predictions made by Copernicus and Kepler.

This contribution is a grand synthesis. Not only did Newton bring together a variety of ideas to explain planetary motion. He also recognized the relationship of this phenomenon to another and essentially integrated the two problems by offering a single solution to both. Newton showed that his principles governing the movement of bodies in the sky could also account for a second, formerly unrelated, problem: that of the motion of objects on the earth. Essentially, Newton's universal law of gravity declared that matter attracts matter. That is, the sun attracts the planets just as the

Earth's gravity pulls on objects near its surface. By achieving this insight, Newton explained two major physical questions of his time with one universal law, an integrative contribution that has remained the basis of physics ever since.

### Conclusion

When we think about inventions, we tend to think about their differing primarily in terms of their novelty, their usefulness, or perhaps their profitability. The propulsion model of creative contributions may lead us to think about them in terms of the type of innovation they represent. How is the propulsion model useful in understanding invention?

First, at a theoretical level, the model may be useful in understanding how inventions differ from one another, not just in their level of creativity, but in the type of creativity they demonstrate in the first place. Using the propulsion model, it may be possible even to trace historically how inventions of different kinds have influenced the development of various kinds of technologies.

Second, it may help us understand why certain types of inventions are less readily accepted than others. Advance forward incrementations, for example, may be beyond people's ready grasp. Reinitiations as well may be difficult for people to understand or accept. Forward incrementations may have the best shot for a ready market, on average. But they have to move far enough. For example, new editions of existing software that seem to be only minor variants and small improvements do not tend to sell well, unless manufacturers rig other software so that it will work only with the newer versions (and thereby risk consumer resentment and possibly government intervention!). At the same time, software that is beyond people's ready capabilities for use may be equally unappealing, simply because it is too complex for most people to handle.

Third, at a practical level, the model may be of use to organizations that specialize in invention. In order to maximize their profitability, they may wish purposely to distribute the kinds of inventions they produce across the various types in order to maximize both short-term and long-term investments in inventions.

In conclusion, we offer the propulsion model of creative contributions as a means for understanding different kinds of creative contributions, in general, and inventions, in particular. We believe the model may help all of us understand not only what the kinds of inventions are, but why some inventions are more or less successful than others, often independent of their quality or level of novelty.

### Acknowledgments

Preparation of this chapter was supported by Grant REC-9979843 from the National Science Foundation

and by a government grant under the Javits Act Program (Grant No. R206R000001) as administered by the Office of Educational Research and Improvement, U.S. Department of Education. Grantees undertaking such projects are encouraged to express freely their professional judgment. This chapter, therefore, does not necessarily represent the positions or the policies of the U.S. government, and no official endorsement should be inferred.

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molded plywood, fiberglass, wire-mesh, and cast aluminum to make practical everyday objects such as furniture. Novelist Dick Francis says that whether you are trying to solve a mystery or write book, “You have to ask the right questions” (Francis, 1992, p. 288). Filmmaker Godfrey Reggio agrees. Commenting on his film ‘Koyaanisquatsi’ he cautioned viewers that it is not a solution to the world’s problems, but an unfolding question:

You know, the question is really more important than the answer. I can frame the question, but I don’t know the answer (Kostelanetz et al., 1997, p. 251).

In fact, the more important the question, the more important the ideas to which it will give rise. Sir Peter Medawar, whose research made possible medical transplant technologies, has written that scientists interested in important discoveries require important problems. “Dull or piffling problems”, he says, “yield dull or piffling answers” (Medawar, 1979, p. 13). And Werner Heisenberg, of uncertainty principle fame, stated another oft-repeated principle known to all scientists: “Asking the right question is frequently more than halfway to the solution of the problem” (Heisenberg, 1958, p. 35). One of the keys to creativity according to all of these people lies in the study of problem recognition and generation. It is not what we know, but what we do not know that drives inquiry in every discipline. Learning how to question deeply and well is therefore, as Socrates made clear 2,500 years ago, one of the most important keys for unlocking hidden knowledge and one that opens doors in every field of endeavor.

### **Nepistemology: The Types and Origins of Ignorance**

The philosophical study of what we do not know falls under the heading of *nepistemology*. Epistemology, as many people will be aware, is the study of how knowledge comes into being. Its complement, nepistemology, is the study of how ignorance becomes manifest. Despite the extraordinary importance of nepistemology, the field has little literature and even fewer practitioners. For some unfathomable reason, the existence of problems is taken for granted and their nature and origins generally ignored. In a world in which education, business, and government are focused on problem-solving, it is worth remembering that problems must be invented just as surely as their solutions. Because good solutions can be generated only to well-defined problems, problem recognition and problem generation is arguably a critical step. Failure to ask questions results in the stagnation of knowledge. Asking the wrong question yields irrelevant information. Asking a poorly framed question yields confusion. Asking trivial questions yields trivial results. However, learning to recognize what we do not

know, developing the skills to transform ignorance into well-defined questions, and being able to identify the important problems among them, sparks innovation.

Few programs in history have been designed specifically to teach problem generation. Socrates, of course, asked questions but it is not clear that he taught his students how to ask their own. The Bauhaus, a design movement based in Germany during the 1920s and early 1930s, certainly incorporated problem generation as a fundamental part of its Foundation Course. When assigned to design a table or paint a painting students were challenged to begin not by seeking answers, but by seeking questions: “what is a table? . . . what is a painting?” (Lionni, 1997, p. 166) Only by questioning the assumptions they brought to their work, they were taught, was it possible to produce innovative answers. Similarly, English sculptors such as Henry Moore, Jacob Epstein, and Barbara Hepworth reinvented sculpture by “asking themselves the question: ‘What do we mean by sculpture?’” (Harrison, 1981, p. 217). By returning to so-called primitive techniques of direct carving and structural rather than realistic forms, they discovered new questions about the nature of art and thereby new answers. Learning to ask the right question always opens up new possibilities (Browne et al., 1986).

One of the very few contemporary questioning programs is ‘The Curriculum on Medical Ignorance’ founded by surgeons Marlys and Charles Witte and philosopher Anne Kerwin at the University of Arizona Medical School in Tucson, Arizona. The purpose of the program is to teach medical students how to recognize their own ignorance and that of other doctors in order to better define what still remains mysterious and take a first step towards enlightenment. The Wittes and Kerwin have identified six basic types of ignorance. (Witte et al., 1988, 1989). First, there are things we know we do not know (known unknowns, or explicit ignorance). A second type of ignorance consists of things we do not know we do not know (unknown unknowns, or hidden ignorance). The next kind of ignorance is that consisting of things we think we know but do not (misknowns, or ignorance masquerading as knowledge). Fourth, ignorance may be found among the things we think we do not know, but we really do (unknown knowns, or knowledge masquerading as ignorance). Next, some ignorance persists due to social conventions against asking certain types of questions in the first place (taboos, or off-limits ignorance). Ignorance may also persist due to refusal to look at some types of answers to perfectly legitimate questions (blinkers, or persistent ignorance).

Two essential points must be understood about this typology of ignorance. First, each distinct type of ignorance requires a different set of techniques in order to reveal itself clearly. Second, problem recognition and invention are active processes. Proficient questioners are those who can draw upon a wide

range of problem-finding tools and apply them appropriately to diverse questioning contexts. If nothing else, the Curriculum on Medical Ignorance reveals the poverty of simply asking 'why' or 'how' or 'what' for every observation one makes.

Explicit ignorance, the things we know we do not know, consists of questions and problems that experts in a field formally recognize because current explorations repeatedly fail to provide useful answers. Explicit problems from diverse fields include questions such as the following: How does the immune system differentiate 'self' from 'nonself'? Should animals have the same sorts of rights accorded to human beings? Does art progress or merely change to reflect the values of each new generation?

Explicit ignorance can be discovered using a wide range of proven approaches. One is to question the assumptions underlying the question. Some questions turn out to be unanswerable because they contain implicit concepts that are not valid. For example, what do we mean by 'progress' and how can we apply that term to art? What is a 'right'? Do 'rights' necessarily entail responsibilities? Can an animal that cannot understand or implement its obligations under the law be accorded 'rights' or must such rights reside in a legal guardian, as is the case for mentally incompetent human beings? Any problem, like these, that exists for any period of time demonstrates that the experts not only do not have the answer, but do not have the question. Persistence of questions implies a lack of proper question formulation. Questioning the question itself can often yield insight.

A second way to identify explicit ignorance is to focus on paradoxes. Paradoxes exist only where two or more well-formulated sets of knowledge come into conflict and thus represent the locus of the unknown. Such loci should be embraced, for where there are paradoxes, there is, as the physicist Neils Bohr repeatedly pointed out, hope of progress (Moore, 1966, p. 196).

A third method for recognizing explicit ignorance is to learn how to perceive the sublimity of the mundane. 'Sublimity of the mundane' refers to the inordinate beauty manifested in everyday things. Unfortunately, as practitioners of every discipline are all too well aware, that which is commonplace is easily overlooked or, in the terms of artist Jasper Johns, is recognized without being seen (Root-Bernstein et al., 1999, p. 32). Whether a person sets out to perceive what makes a flag flag-like, as Johns did in his art, or to ask why a banana turns brown but an orange does not, as biochemist Albert Szent-Gyorgyi did, such everyday problems, precisely because they are so commonplace, will also turn out to be fundamental. Johns's art has provided new insights into how we see, while Szent-Gyorgyi's researches on banana browning resulted in the discovery of vitamin C, for which he earned a Nobel Prize.

A final method for *revealing* explicit ignorance is to err. As Francis Bacon once wrote, truth comes out of error more rapidly than out of confusion. A clear mistake does far more good to any investigation by identifying the specific nature of the problem being addressed than any other method. Hence the trite (but true) aphorism that we learn best from our mistakes. People who never err not only never succeed, but have no mistakes (and hence generate no problems) from which to learn.

Hidden ignorance, the things we do not know we do not know, is perhaps the most difficult form of ignorance to discover precisely because it is not explicit. One of the most important characteristics of hidden ignorance stems from the fact that human beings tend to account for any phenomenon in any field in terms of what they already know. Thus, many forms of ignorance remain hidden simply because people are too proud to say the simple sentence, "I do not know". Instead, we tend to make up stories to hide our ignorance. For example, prior to the discovery of electricity, every culture attributed lightning to the wrath of the 'gods' rather than simply admitting ignorance. Similarly, prior to the discovery of germs, infectious diseases were attributed to bad air, bad water, and bad habits. No medical expert in any culture seems to have had the courage to simply admit that they did not really know how diseases spread.

To discover hidden ignorance requires very different methods than to address explicit ignorance. Hidden ignorance must be surprised. One way to surprise ignorance according to Sir Peter Medawar is to design research to challenge expectations. (Medawar, 1979, *passim*) His advice is predicated on the philosophy of science espoused by Sir Karl Popper, who maintains that theories can never be proven (because the observation you have not yet made may invalidate your position), but theories can always be *disproven*. The object of any research project in any discipline should therefore be to find the evidence that will disprove one's expectations. Physicians, for example, often call for tests to 'rule out' a possible but unlikely diagnosis. The specific way in which expectation is disproven will then reveal the nature of one's unsuspected ignorance.

Another method related to challenging expectation is to look for information where no reasonable person would look. There are many ways to implement this strategy but each entails to a greater or lesser degree the risk of appearing to be foolish or even crazy. The most acceptable method is to run many highly varied and even outrageous controls with any experiment. Winston Brill, a member of the National Academy of Sciences (USA), for example, recounts that his most important breakthrough occurred when he was designing a pesticide based on a particular theory of how its structure should look. He synthesized several versions of his compound in what he predicted to be active and inactive forms and also took a few chemicals off his

shelves at random to use as controls. None of the chemicals he had designed as a pesticide worked well, but one of his random choices was a stunning success, representing a new class of pesticides that no one could have predicted in advance (personal communication). Only by doing the unexpected can the unforeseen reveal surprises.

Another approach to revealing unknown unknowns is purposefully to turn things on their heads to yield a new perspective. The artist Wassily Kandinsky, for example, unthinkingly turned one of his early representational paintings upside-down and left it for several weeks. Re-entering his studio one evening, having forgotten about the painting, he suddenly became aware of it, illuminated by the setting sun, but did not recognize it or its content. All he saw was form and color. Suddenly he realized that it might be possible to create totally non-representational art, something that even the abstract painters of that time had not yet considered. By viewing his own work literally upside down he discovered that there was a whole realm of art that no one had realized was there, let alone begun to explore (Herbert, 1964, 32ff)

Playing contradictions (sometimes known as playing the devil's advocate) is another fecund source of unknown unknowns. Nothing reveals how little we know than to take a proposition such as 'the world is spherical' and assert instead that 'the world is flat'. As the novelist H. G. Wells pointed out a century ago, very few are the supposedly educated members of society who are able to produce evidence or experiments (especially ones that do not resort to the data gathered from space craft) that will clearly distinguish one of these possibilities from the other. (Wells, 1975, pp. 32–25) That which is obvious often becomes inobvious when its opposite is asserted, thereby raising questions and possibilities that would never otherwise come to light.

Finally, one can reveal hidden ignorance by drawing out the most absurd implications of any idea. Many children excel at this strategy, taking anything an adult says and applying it literally—too literally!—to any situation they meet. Much satirical literature ('Candide', Voltaire's send-up of rosy philosophical optimism as espoused by Leibnitz and Pope, is a good example) uses this strategy to reveal the limitations inherent in popular philosophies. What extrapolation of this sort reveals are the boundaries beyond which an otherwise quite reasonable proposition or method fails. The point at which it fails is often the point at which our ignorance begins.

Ignorance masquerading as knowledge, or mis-knowns, presents yet another class of problems. A classic example from medicine was the belief, rampant among physicians for most of the twentieth century, that stomach ulcers are due to mental stress or eating spicy foods or alcohol and can be treated only by a bland diet and relaxation techniques. Stomach ulcers

are, in fact, caused by the bacterium *Helicobacter pylori* and can be cured by a proper regimen of antibiotics. Stress, alcohol and spicy foods exacerbate the consequences of the bacterial infection. Thus, secondary factors were confused with primary causes.

Several methods exist for discovering that the king is wearing no clothes. One is to doubt all correlations. Everyone is taught that correlation is not causation, but in practice this warning is all too often ignored. In the case of ulcers, because spicy foods and alcohol exacerbated the symptoms, they appeared to be so highly correlated with the onset of ulcers that they were mistakenly identified as causative agents. Evidence that many people eat spicy foods and drink lots of alcohol without getting ulcers was ignored.

A second method for identifying mis-knowns is to question habit. For centuries, painters habitually propped their canvases up on easels in order to work on a surface perpendicular to their view. It took the courage of Jackson Pollock to take the canvas off of the easel and place it on the ground to experiment with the artistic possibilities of working in a new way.

Two additional methods also exist for identifying mis-knowns. Perhaps the most important is to doubt most those results or findings that accord best with our preconceptions. Those results or observations that best fit our preconceptions and expectations are the least interesting and yield the fewest questions and insights. Ignore them. They do not yield problems. The things that are the most interesting in terms of revealing ignorance are those that are the most disturbing or which conflict most clearly with strongly held beliefs or practices. Therefore, pay attention to the heretics, revolutionaries, and people stepping to their own drummer. Many of their ideas will be wrong, but many of the problems they reveal will be valid.

A related method for identifying mis-knowns is to collect anomalies. Anomalies are phenomena and observations that do not fit within the theoretical or explanatory structure of a field. They are the things that experts ignore as inconvenient nuisances. As philosopher Thomas Kuhn pointed out in his book *The Structure of Scientific Revolution* (1959) every great discovery has resulted from an individual paying attention to the anomalous results that most practitioners of a field have refused to countenance or have actively ignored because anomalies generate problems.

Finally, try doing the impossible. There are two kinds of impossible things: those that nature will not allow us to do (e.g. perpetual motion machines) and those that our predecessors have found beyond their means. The history of medicine is full of procedures that were declared to be 'impossible', such as blood transfusions and transplants, that are now part and parcel of everyday clinical practice. Indeed, the inventor of the instant camera and its Polaroid film, Edwin Land, advised innovators not to "do anything

that someone else can do. Don't undertake a project unless it is manifestly important and nearly impossible" (Root-Bernstein, 1989, p. 415).

Next we must deal with things we do not know that we know, or hidden knowledge. There is a story that one of the great eighteenth-century mathematicians sat down one day to try to calculate the perfect dimensions of a container for storing and shipping alcoholic beverages such as beer or wine. After taking into account the available materials, limitations imposed by the fact that the containers had to be carried by men from one place to another, and so forth, he generated his solution—only to find that he had described the wooden barrels already in use. Similarly, a recent study of medical treatments has found that many of the most 'innovative' are based on folk remedies that have been around for millennia. Just for example, honey pastes have been used since at least Babylonian times to treat severe wounds and burns and have recently been introduced in many hospitals to treat infections and ulcerations that are beyond the scope of current antiseptic, antibiotic, and surgical treatments. As both these cases show, the basic problem underlying hidden knowledge is that it exists either among people who are not considered to be valid sources of knowledge by disciplinary 'experts' or resides in historical documents bypassed by subsequent developments in the name of 'progress' (Root-Bernstein et al., 1997, Chapters 3 and 12).

The causes of hidden knowledge suggest solutions. The most obvious is to go outside the boundaries of acceptable disciplinary sources for information. Charles Darwin broke all of the standards of science in his day (not to mention social conventions) by writing to farmers, pigeon fanciers, horse breeders, and other non-scientists in order to discover the accumulated wisdom about artificial selection that existed outside of the academic community. The physicians who rediscovered the modern therapeutic uses of honey paid attention to non-traditional practitioners of their art such as family folk medical traditions or local traditional healers. Similarly, many innovators, such as the cubist artists Brach and Picasso and the modern composers Richard Reich and David Glass, having mastered formal Western techniques during their early training, then turned to non-academic sources of inspiration such as traditional African and Hindu arts.

Albert Szent-Gyorgyi, the Nobel laureate who discovered vitamin C, has suggested that another general way to reveal problems of unknown knowns is to go back and re-do classic experiments from 50 or 100 years ago using modern techniques (Root-Bernstein, 1989, p. 412). These re-creations, he says, almost always yield novel insights because the investigator brings to them different problems and theories that change their interpretation. Artists such as Henry Moore have similarly used ancient techniques such as direct carving, invented by Egyptian and Greek

sculptors, to revolutionize modern art by applying it to new materials.

Finally we reach persistent unknowns (taboos) and unacceptable or blinkered knowns. Both classes of ignorance are caused by the refusal to ask certain types of questions or to entertain certain types of answers. These classes of ignorance often result from social taboos or customs and sometimes from economic or political considerations as well. For example, many women living in underdeveloped nations (especially those dominated by Muslim sects) may not ask "How can I control my fertility?" Artists in the United States have met similar constraints on their ability to ask questions such as whether man has been formed in God's image or vice versa. And biomedical researchers studying AIDS have found it so unacceptable to ask whether the human immunodeficiency virus explains everything about AIDS that many have lost their funding and positions. The characteristic of taboo questions is that one risks one's career or even one's life by asking them.

Certain types of answers may also be avoided just as adamantly as certain kinds of questions. For example, alternative medical therapies are used by more than one third of European and American adults, but they are rarely subjected to the kind of double-blind controlled clinical trials that are required of pharmaceutical drugs. Both taboos and blinkered knowns help explain the situation. In the first place, it is not in the interest of purveyors of alternative medicines to have to meet the standards of either efficacy or purity set for pharmaceutical agents. In no case would meeting such standards increase their market share or profit margin and in many cases the standards might eliminate their product from the market. Thus, it is in the interest of these purveyors to foster the persistence of ignorance about their products. However, it is too expensive for Food and Drug Administrations or pharmaceutical companies to seek answers to issues of efficacy and safety. The only motive that these institutions have to test alternative medicines is to accredit them as prescription drugs. It costs, however, approximately one quarter to one half a billion U.S. dollars to obtain Food and Drug Administration approval for a new drug. In order to make such an investment worthwhile, a pharmaceutical company must be able to obtain patents on the drug and its manufacture so that other companies cannot take advantage of the work they have put into proving safety and efficacy. Unfortunately, alternative medicines are, by their nature, non-novel agents already in the public domain, and hence unpatentable. Thus, there is no business incentive to find answers to the problems posed by alternative medicine usage (Root-Bernstein, 1995, *passim*). We therefore persist in our ignorance about such therapies and will do so until other incentives make it worthwhile for us to seek answers.

Additional examples of blinkered answers can be found in various approaches to AIDS adopted around

the world. In Africa, for example, it is against the social mores of many men to use condoms, although they know that condoms are the most effective method of protecting themselves against AIDS. In some Muslim countries, AIDS-prevention counselors are not allowed to mention the fact that AIDS is spread most commonly by homosexual men and female prostitutes because neither group may be mentioned in conversation or print. Thus, programs that have proven to be very effective in controlling AIDS in some countries cannot be used in others because of such taboos.

Because the roots of taboo questions and blinkered answers are social, the methods for addressing it are also social—or, more accurately, anti-social. One of the most noteworthy aspects of many creative acts, whether in the sciences, humanities, social sciences or the arts, is that the people who carry them out are labeled heretics, provocateurs, misfits and worse. The greatest questioner of all time, Socrates, was put to death for the anti-social implications of his questions. Galileo was charged with heresy by the Catholic Church for daring to question the Ptolemaic view of the universe that underpinned Church doctrine. Darwin became a pariah among fundamentalists of many religions for questioning whether God had indeed created man in His image. Margaret Sanger and Marie Stopes, the revolutionaries who gave Western women contraceptive knowledge, each went to jail more than once. So did the many suffragettes who worked to give women the vote, simply for asking why women should not be able to do the things men do. One must have the courage of such people in order to break the taboos that prevent most of us from asking certain types of questions or facing the consequences of certain types of answers. The more dangerous the questions are to people in power, the greater the courage needed to ask them.

### Problem Evaluation and Classification

Now, once problems have been recognized or generated, they must be evaluated. Just as there are different kinds of ignorance, they yield a great diversity of kinds of problems. Problems can be classified according to *type*, *class*, and *order*. *Type* refers to the technique necessary to *solve* a problem. *Class* refers to the *degree* to which the problem is solvable. And *order* refers to the placement of a problem within the context of the universe of other related problems. While each of these concepts may initially sound very abstract and academic, each is, in fact, extremely useful in practice. Classifying problems allows each to be linked to an appropriate method for achieving a solution and allows links between problems to be explored explicitly.

Just as it is true that not all forms of ignorance can be recognized or discovered in the same way, not all problems can be solved using the same methods. There are, in fact, at least ten types of problems, each distinguished by the manner in which it must be

addressed in order to achieve a solution. The ten basic problem types are: (1) problems of definition; (2) problems of theory; (3) problems of data; (4) problems of technique; (5) problems of evaluation; (6) problems of integration; (7) problems of extension; (8) problems of comparison; (9) problems of application; and (10) artifactual problems (Root-Bernstein, 1982, *passim*; Root-Bernstein, 1989, p. 61). Readers will immediately recognize a significant overlap in the terminology and concepts embedded in this typology of problems with the typology of innovation types proposed by Sternberg et al. in this volume. The type of problem an innovator chooses to address therefore determines the type of innovation she or he produces.

Problems of definition concern the purity of the language and its meaning as used by any given discipline. Representative issues include ‘what is velocity’ or ‘what is a legal right’ or ‘what is beauty’. Such questions cannot be addressed by experiment or observation or any form of research. Such definitions may be determined axiomatically in the same way that we accept definitions of basic concepts such as the numbers one, two, three, etc. or when we state that velocity is distance traveled divided by the time of travel. Definitions may also be addressed by means of a process, such as the legal system that determines whether something is a right.

Problems of theory or explanation involve any attempt to find or make sense of the relationships in existing data or observations that are currently incomprehensible or anomalous. Theory problems require the recognition or invention of a pattern that makes coherent sense of available information.

Problems of data involve the collection of experiences or information relevant to addressing some particular kind of ignorance. Relevant techniques include observation, experiment, and any kind of playing with materials that yields novel data.

Technique problems are those that concern the manner in which novel data, observations or effects are to be achieved. Such problems generally require the invention of instruments, methods of analysis or display, or techniques that allow new phenomena to be observed or created.

Evaluation problems arise when it is necessary to determine how adequate a definition, theory, observation or technique may be for any given application or situation. For example, is any particular observation an anomaly or an artifact of the way in which the observation was made? Evaluation problems require the invention of criteria and methods for evaluation. One might, for example, consider the entire field of statistics to be a set of solutions to evaluation problems.

Problems of integration often involve contradictory or paradoxical situations in which it is not obvious whether two theories, data sets, methods, or styles of research are compatible. For example, is there any

Bernstein, 1989, p. 63). A problem of theory may require the invention of a new method for gathering relevant data and need to be solved in order to determine the feasibility of some practical application. An ordered problem tree allows investigators and inventors to determine which problems need to be solved in what order, using what methods. More importantly, a problem tree illustrates the degree to which any specific problem is more or less general and more or less connected to other problems of various types and classes.

Ordered problem trees are particularly useful for evaluating claims of significance. It is common for investors in new technologies and for funding agencies offering grants to require inventors to provide a justification of the utility of the work they propose to carry out. Thus, a cell biologist may justify the utility of his or her studies of cell division by the fact that cancer cells divide abnormally and therefore research on cell division may yield a cancer cure. Such claims may or may not be accurate, since the number of problems that need to be solved to link basic bench research with a clinical application may be so large as to be beyond reason. The degree of ignorance that must be addressed can only be evaluated when an ordered problem tree has been constructed to demonstrate the types, classes, and number of related problems that define the general problem area.

### Problem Evaluation

An understanding of how problems are generated and the various types, classes, and orders into which they can be categorized provides useful information about how important or trivial any given problem is likely to be. Once again, there is virtually no formal research on this subject, but it is probably fair to say that what are called 'important' problems are those that are completely solvable for a large class of cases, and that this property of solvability is directly related to the ability to construct a very strongly connected problem tree that links many types of problems robustly. But the fact that problem evaluation requires a detailed understanding of where any given problem exists within a tree of other linked problems should warn us that there is nothing intrinsic to any given problem that makes it important or not. A seemingly trivial problem may provide the key to solving an entire problem tree of great significance; or a seemingly important problem may provide only a trivial answer because it can yield only a specific answer that connects with and informs no other problem. Many problems that may appear to be intrinsically interesting or worthy of attention (e.g. world peace) may be dependent on so many sub-problems of such an intractable nature (local economic conditions and resources, cultural habits, education, etc.) that there is no practical way to address them. Working directly on sub-problems may be a more practical goal.

However, the irresolvable nature of general or even specific problems should never be a barrier to problem-generating activities. The most important problems are always those that need to be solved and cannot be. Simply perceiving the detailed nature of such nested problems can be of practical value in and of itself. One of the strategies employed by creative people in every field is to construct a problem tree in order to identify the critical problems that cannot yet be addressed and, having identified and characterized these gaps in our knowledge, wait until answers are supplied by someone else. When these sub-problems are finally addressed, the problem tree becomes complete, and the importance of what may have appeared to be very trivial, individual problems suddenly takes on vast significance. One of the characteristics of the most innovative people is to discover the world in a grain of sand.

Another characteristic of great questions is that they are bold or even dangerous and it takes at least a modicum of bravery or bravado to pose them. Solving daring problems is of course important, but daring to pose them in the first place is still the key to making breakthroughs in any field. Many people are capable of solving well-defined problems, since solutions, as Einstein and his collaborator Leopold Infeld wrote,

may be merely a matter of mathematical or experimental skill. To raise new questions, new possibilities, to regard old problems from a new angle, requires creative imagination and works real advance in science (Einstein et al., 1938, p. 5).

Thus, learning how to pose the most insightful, provocative, and challenging questions is surely an art as much in need of training and practice as those arts devoted to problem-solving.

But in the end, the creative urge to generate problems comes down to motivation. What makes an explorer in any discipline is their attraction to the mysterious, the incomprehensible, the paradoxical, the unknown. As Albert Szent-Gyorgyi, a Nobel laureate in Medicine and Biology wrote,

A scientific researcher has to be attracted to these (blank) spots on the map of human knowledge, and if need be, be willing to give up his life for filling them in (Root-Bernstein, 1989, p. 407).

Fellow Nobel laureate and physicist I. I. Rabi agreed: "The only interesting fields of science are the ones where you still don't know what you're talking about" (Root-Bernstein, 1989, p. 407). Thus, the most creative people are always explorers quite literally in the way that Magellan, Columbus, or Lewis and Clark were explorers, aiming for the regions of our most manifest ignorance.

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# The Role of Flexibility in Innovation

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**Abstract:** Flexibility is the ability to change. Innovation involves different types of change. In this chapter we will examine the importance of flexibility for different aspects of innovation. Different types of flexibility will be considered throughout the chapter, such as adaptive flexibility (the ability to change as a function of task requirements) and spontaneous flexibility (the tendency to change for intrinsic reasons, to try out a variety of methods). Finally, we will discuss how different types of flexibility can be important at different stages in the innovation process.

**Keywords:** Innovation; Flexibility; Creativity.

## Introduction

Have you ever wondered why the dinosaurs did not make it? According to recent evidence, dinosaurs' living conditions changed brutally after a comet hit the earth, putting a great deal of dust and debris in the atmosphere. Being unable to adapt to the new, darker and colder climatic conditions, they became extinct. Sometimes survival depends on flexibility. And what about the earliest human beings who made it through the Ice Age, populated the earth from Africa to Iceland and became a dominant species? Often prosperity also depends on flexibility.

Flexibility can be defined as the capacity to change (Thurston & Runco, 1999). This may be either a change in how one approaches a situation in the external environment (adaptive flexibility) or a natural tendency to change for intrinsic reasons (spontaneous flexibility).

Flexibility may vary from one species to another, or from one individual to another; some species are more flexible than others in general. Within each species, some individuals will be able to adapt to even the most difficult circumstances whereas others will not. This is true for organizations as well. Some organizations are like dinosaurs, slow to react to a changing environment, whereas others are, like our ancestors, able to adapt. Even Microsoft, one of the largest world corporations faced a threat to its survival when at one point, its management found out that a rival Netscape had 700 people working on Internet applications, while it had only four; Microsoft managed to rebound in this

case in six months. This ability to adapt quickly and effectively to the environment is particularly important nowadays given the speed of technological evolution and globalization. All this puts pressure on individuals, companies and societies to make changes and to be adaptable if they are to survive and prosper (Mumford & Simonton, 1997).

As important as flexibility is for survival and prosperity under pressure, it does not directly cause it. There are mediating behaviors involved. One candidate is innovation. Innovation is typically defined as the generation, acceptance and implementation of new ideas, processes, products or services (Kanter, 1983). It is through the implemented novel productions (economic, social or technological) that an individual or an organization can survive and prosper when the environment changes, through productions that are appropriate to the new environment (economic, social, or technological). In this chapter we suggest that flexibility influences innovation in several important ways, and research supporting this assertion will be presented. Three approaches to creativity and innovation will be presented successively: the creative person, the environmental press and the creative process. We start by examining flexibility as a characteristic of the innovator him- or herself, that is, the cognitive and conative factors that relate to flexible thinking and the creation of new ideas, new productions. (It is important to note that though we speak of the innovator, the discussion can refer to either a single person or a group of people

working together.) Then we will consider flexibility as a characteristic of the environment, the audience for innovations, the ways that individuals, embedded in cultural contexts, differ in their readiness to accept new ideas and innovations. Finally we will discuss how different types of flexibility (adaptive and spontaneous) can be important at different stages in the innovation process. We conclude by discussing several issues concerning the implications of the study of flexibility for individual and group innovation, but also for the organizational culture that can either facilitate or block innovation.

Before beginning an examination of flexibility and innovation, it is important to note that creativity, defined as an ability to produce work that is novel and appropriate (Amabile, 1996; Lubart, 1994), is a phenomenon closely related to innovation, and sometimes the terms are used interchangeably (West & Richards, 1999). Thus, in this chapter we do not draw a distinction between creativity and innovation.

### Flexibility as a Characteristic of the Innovator

#### *Cognitive Aspects*

Flexibility is widely regarded as a cognitive ability important to creativity and innovation (Chi, 1997; Jausovec, 1991, 1994; Runco & Charles, 1997; Runco & Okuda, 1991; Thurston & Runco, 1999; Torrance, 1974). For example, for Thurston & Runco (1999), flexible cognition can facilitate creativity in several ways, such as helping to change strategies to solve a problem more effectively or to see a problem from a new perspective. It can also help one to switch easily between conceptual categories thus facilitating the production of diversified ideas. A flexible person can avoid getting stuck on one part of a problem, or can let go of the problem for a while when stuck and come back to it later. In discussing flexibility as a cognitive ability, research distinguishes adaptive flexibility and spontaneous flexibility, each facilitating creativity in a different way.

*Adaptive flexibility* involves changing perspectives on the problem, redefining it, or changing one's strategy to solve it when old perspectives or strategies have proven unsuccessful. For example, the candle task (Duncker, 1945), requires the participant to fix a candle on a wall without the wax dropping on the floor using only a candle, a box of matches and a box of tacks. Many people cannot find the solution to this problem because they try to attach the candle itself on the wall and consider the box as simply a recipient that holds the matches and/or the tacks provided. Once they change their perspective on the box, it becomes apparent that fixing a box on the wall with a few tacks and putting the candle in or on the box solves the problem perfectly. The change in perspective involves redefining the box as a support rather than a container, which then leads to an adaptive solution. Inflexibility in

one's conception of a common object, such as a box, is called 'functional fixedness' in the literature.

A number of authors have drawn attention to how adaptive flexibility in response to environmental constraints can lead to creative and innovative outcomes. For Barron (1988) an important ingredient of creativity is "seeing in new ways" (p. 78). According to Runco (1999) changes in perspective are related to both artistic and scientific creativity. Lipshitz & Waingortin (1995) call these changes in one's point of view on a problem 'reframing', which when applied to real-world problems, can lead to innovative solutions. For example, a hotel manager received frequent complaints about the elevators being too slow. He could follow the (very expensive) suggestion from an engineer to replace the elevators with a faster model, but decided to get a second opinion from an industrial psychologist. For the psychologist the problem was "not slow elevators but bored people" (Lipshitz & Waingortin, p. 153). He suggested installing large mirrors in front of the elevators so that people could pass the time watching themselves or others. The manager opted for this (much cheaper) solution and heard no more complaints about slow elevators. Thus, taking a different perspective on the problem led to an innovative and low-cost solution. The iMac from Macintosh is another example. In their design conception and publicity campaign, the computer is seen from a different point of view—as a decorative object rather than merely as an information-processing machine.

Flexible strategy use has also been found to characterize creative problem-solving as shown by gifted persons (Jausovec, 1991, 1994). Jausovec (1991) studied the relationship between flexible strategic thinking and problem-solving performance in two studies. In the first study, he compared the responses of gifted students to those of average and poor students on a number of tasks designed to provoke two types of rigid answers: response set and perceptual set. Response set is the inability to break a habit and use a different strategy to solve the task when there is a better way of solving it, and perceptual set is the tendency to see a problem just from one perspective. Gifted students showed fewer rigid answers than both average and poor students, who did not differ among themselves.

In the second study, the gifted and average students verbalized their strategies for solving both open and closed problems. Closed problems are stated in clear terms so that there is no need to redefine them, and they also have a single correct solution. Open problems are often less clearly stated, so clarifying what the goals are is part of the solution, and they do not usually have a single correct solution, but rather several solutions that work (Jausovec, 1994). Convergent thinking and logic are efficient strategies for solving closed problems, whereas divergent thinking and redefinition of the problem are more helpful for solving open

problems (Jausovec, 1994). Jausovec (1991) identified the following strategies from students' verbalizations: subgoals (breaking the problem into smaller problems), working backward, modeling (making a simplified representation of a complex information), inference, trial and error, goal discovery, memory recall (recalling relevant knowledge from memory), generating analogies, and finally intuition and insight. The results showed that gifted students used more varied strategies than average students when solving the problems, and they also used them more selectively, applying different strategies to different problems depending on the requirements of the task. Thus, gifted students were more flexible in their strategy use.

Kaizer & Shore (1995) found also a tendency for competence in mathematical problem-solving to be associated with flexible strategy use. When comparing the performance of more and less competent mathematics students on mathematical word problems, the more competent students alternated between appropriate strategies (verbal or visual) to solve the problems, whereas the less competent were as likely to resort to trial and error as to use one of the appropriate strategies. Taken together, these studies suggest that adaptive flexibility may play a key role in problem-solving because it facilitates the use of a variety of strategies in response to the requirements of the task.

*Spontaneous flexibility* is the capacity to find a variety of solutions to a problem when there is no external pressure to be flexible. For example, in divergent thinking tasks, a participant may be requested to find as many ideas as possible concerning an object or a situation. However, whether the ideas generated come from one or many different categories of use depends on the individuals' natural, spontaneous flexibility of thought. The tendency to change conceptual categories easily and to cover many different categories in the responses indicates spontaneous flexibility. It is integrated in the scoring system of Torrance's (1974) Test of Creative Thinking (TTCT).

For example, in one version of the 'unusual uses' task, participants are asked to indicate uses for a cardboard box. The (spontaneous) flexibility score corresponds to the number of conceptual categories from which the responses are drawn. A flexible answer to the box task would be, for example, three ideas (make a toy house, play kick the box and store old clothing) all belonging to different categories (the categories of construction, box as toy and box as container, respectively). A rigid answer would be three ideas (put shoes in a box, put pencils in a box, put toys in a box), all belonging to a single category (box as container).

One important question explored in research is how flexibility facilitates the generation of new ideas. Several authors have drawn attention to the flexibility of existing knowledge structures as a source of new ideas, and the rigidity of it as an obstacle to creativity (Chi, 1997; Mumford, Baughman, Maher, Costanza & Supinski, 1997; Mumford & Gustafson, 1988). Knowledge is structured into conceptual categories—in groups of entities (concepts or images) that people believe belong together. The facility by which people work with different categories is thus an indicator of the flexibility of their knowledge structures.

For Chi (1997), the essence of creativity is the flexibility with which people cross category boundaries. She represents knowledge as stored on distinct associative trees. These trees can be a barrier to creativity because it is difficult for many people to move from one tree to another—from one category to another. When a concept on one knowledge tree is re-represented in the context of another tree, the result can be a new idea. For example, when the sound of footsteps in the snow is re-represented in the context of pop music, the result can be an original song (Björk, 2001, see Fig. 1).

Similarly, for Perkins (1988), crossing significant boundaries is central to creativity. For example, the impressionists crossed paradigm boundaries in the arts

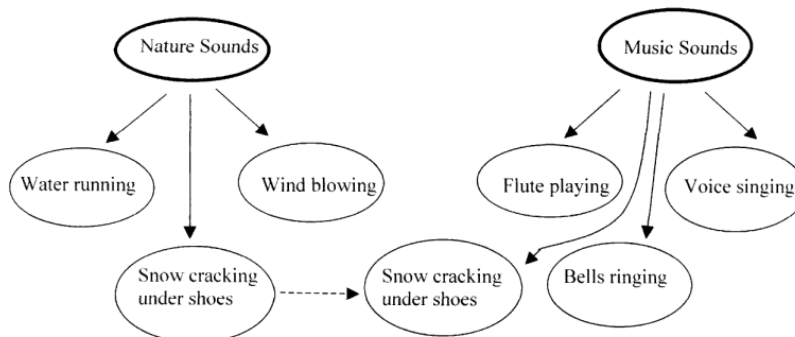


Figure 1. Example of two conceptual trees: nature sounds and music sounds. Flexibility involves considering (either spontaneously or purposefully) a knowledge element in a non-habitual conceptual tree, which may in turn lead to creative, innovative ideas.

such as productivity, quality of products, innovation and job satisfaction. These outcomes in turn influence both the resources and the climate.

A number of authors have suggested that one of the hallmarks of corporate cultures that support creativity and innovation is their flexibility or, in other words, their lack of rigidity. For example, for Hisrich (1990), flexibility is one of the common characteristics of companies that have an excellent reputation, as they show the ability to adapt to changes in the marketplace. According to this author, traditional corporate climates emphasize cautiousness and avoiding risks; they favor conservative decisions, and are rigid in the sense that they are hierarchical with established lines of authority, instructions and working hours. Furthermore, short-term gains are preferred over long-term potential as each manager protects his or her own job. This emphasis on not making any mistakes hinders creativity and reduces flexibility. A climate that nurtures innovation tends to have a relatively flat (non-hierarchical) organization with teamwork, sponsors and mentors that facilitate communication, trust and cooperation. In addition, it has a long-term vision, goals and action plans to follow them up. Actions are rewarded, suggestions and experimentation are welcome, and creation and development in all areas is supported.

The willingness of managers and other employees to change their ways of doing things and thereby to take some risk is important in order for new ideas to be translated into action. For example, in interviews with research and development scientists focusing on qualities of the environment that either facilitate or inhibit creativity, Amabile (1988) found that an overemphasis on maintaining the status quo—the unwillingness to change anything—was a frequently mentioned obstacle to organizational creativity.

In two empirical studies, Ekvall (1991) identified features of a creative or innovative climate in organizations and in organizational departments. The first study compared the creative and innovative climate in 27 Swedish organizations, evaluated (by product innovation criteria) as being either innovative or stagnated. The second study compared the creative climate of organizational departments in an American industrial company that had been evaluated by independent judges as being either innovative or stagnant. The result of both studies went in the same direction. The innovative organizations and the innovative departments were rated higher on all aspects of creative climate measured (challenge, freedom, idea-support, trust, dynamism, playfulness, debates, risk-taking and idea-time) and had less conflict than the stagnated organizations and departments. In terms of organizational culture, three types of profiles were identified. These profiles reflected value orientations that were focused differentially on either structure, people or change. Of the three, the change-oriented cultures were the most flexible. Change-oriented cultures were

characterized by entrepreneurial and transformational management, in which the manager is more a leader who sets goals and makes tasks meaningful rather than one who gives instructions and makes decisions.

Furthermore, in a meta-analysis of organizational innovation, Damanpour (1991) found several potential determinants of innovation that relate to flexibility. The first was functional differentiation, or the existence of differentiated units of professionals, who work explicitly on elaborating, introducing, and influencing change. The second was lack of formalization with a low emphasis on strict rules. The third determinant was a positive managerial attitude toward change. A manager who is favorable toward change creates a good climate for innovation, especially useful during the implementation stage, when conflict resolution and coordination of efforts are important. Of these three determinants, a significant positive relationship to innovation was observed empirically for functional differentiation and positive managerial attitude towards change.

Large organizations in particular have rigidity problems that can be obstacles to innovation. According to Rosenfeld & Servo (1991) increasing size is related to depersonalization and decreased communication. Both invite the risk of becoming rigid as each individual has less impact and there is less interaction between divisions. Remaining open to change while maintaining organizational integration becomes more difficult with increased size. Innovation should be possible however, despite size, if an organization uses its human resources in a flexible manner. One approach to achieve this involves managing properly innovative individuals inside organizations, as well as other key players in the process of innovation, such as technological gatekeepers, sponsors and champions. Technological gatekeepers are experts on technology that will give their opinion on whether an innovation is cutting-edge technology or not. Champions are the advocates of the innovator when facing the organization, supporting the new idea (see also Hausschildt, this volume), and sponsors are senior, higher-status members of the organization, who dispose of material and human resources and use them to develop an idea. Flexibility is also a desirable characteristic for these different actors in the innovation process. For example, Howell & Shea (2001) found that the tendency to seek information from diverse sources was positively related to champion behavior. Breadth of interests or spontaneous preference for variety led people to scan diverse domains in search for information that could become critical to identify a promising innovation opportunity. Champions, thus, did not stick to subjects relevant to their own job, but showed interest in a variety of other topics. For organizations to identify people capable of facilitating innovation, it is important for them to have a flexible attitude towards the employee—to be able to set a formal job description aside for a while and see a

person from a different perspective. Finally, some authors (e.g. Hammer, 2001) point out that innovation that depends on exceptional persons identified as champions is *not* well managed. Rather, everyone in the company has to have the flexibility to adopt the role of innovation generator, champion and implementor within a well-described innovation process such as product development (see also a later discussion of the system for managing ideas). In a similar vein, observers of the creative and innovative practices in business (e.g. Hamel, 2000; Peters, 1999) point out that companies that have a large flexibility in terms of job contents independent of one's title or function are often the most innovative. Such organizational flexibility allows them to assemble teams for innovative projects based on employees' intrinsic motivation and not on the organizational rigidified role.

We have seen different ways in which flexibility and the willingness to change are important for innovations, but how can we help organizations to be more flexible, more open to change? We will now examine some of the efforts that have been made to stimulate innovation in organizations, in particular those pertaining to being flexible.

#### *How Can We Facilitate Innovation Through Flexibility?*

As important as it is for organizations to have creative individuals on board, going against the stream in a rigid, hierarchical and authoritarian structure can be difficult. In order to facilitate the task for innovators, several authors have suggested how flexibility could be increased, both at the organizational and at the individual level.

Burnside (1990) presents a model of how to improve organizational climates for creativity. Central to this model is goal clarity, both in the long term and in the short term, in order to channel employee's creativity. A clear long-term goal is a specific idea of where the organization is attempting to go in the future, whereas clear short-term goals are smaller concrete objectives in order to get there. After goal-setting, three important components in motivating an employee to be creative are challenge, freedom and encouragement. A challenging task is meaningful and interesting to the employee. Challenge suggests that the task will require the employee to go beyond established knowledge or known skills, moving the individual into his/her 'zone of proximal development'. The employee has freedom when he or she is given maximal autonomy to decide how to do the task, and encouragement is provided by the manager who helps the employee to build courage to come out with his or her ideas and to take risks. Part of encouragement is accepting mistakes when an employee is willing to learn a lesson from an error.

To help create these conditions in large organizations, some have adopted a decentralized structure called an 'office of innovation', first developed by the

Eastman Kodak Company. The office of innovation is not attached to a particular department, and also works independently from the human resource department, allowing for input from all departments and the flow of ideas between them. In the office of innovation, facilitators receive and look for individuals who play different roles in the innovation process (technological gatekeepers, sponsors and champions) in all departments of the organization (Rosenfeld & Servo, 1991). This decentralization increases flexibility in the organizational structure as it goes beyond department barriers in the conscious effort to innovate.

Fernald (1989) describes other examples of how different organizations have made an effort to stimulate creativity and innovation. At Intel, engineers are encouraged to meet with their engineer-peers to practice 'constructive confrontation' (p. 211), in order to eliminate bad ideas and make good ideas better. In these meetings, ideas are examined in a critical light, thus putting them in a different perspective. In this way, the engineers practice deliberately engaging their cognitive flexibility by changing their point of view on a problem in a group context.

Saturn Corporation illustrates an organization (General Motors) that considers flexibility and change necessary to be productive and innovative. In order to produce cars capable of competing on the world market, Saturn departs considerably from the traditional, hierarchical corporate structure. First, it considers its employees as creative and innovative people, capable of taking well-considered risks. Second, it keeps the bureaucratic structure as lightweight and flat as possible. For example, all employees contribute to the decision-making process, all are salaried personnel with a part of their earnings tied to the company's profit, and job classifications are limited and simple (Fernald, 1989). In 2001, however, General Motors made a decision to bring its Saturn division closer to its other divisions which lead many industry observers to question if its culture could survive in the long run.

A more global approach to achieve innovation through both specific organizational processes and flexible management of human resources is proposed in the *System for Managing Ideas* (SMI, Getz & Robinson, in preparation). SMI—a set of idea management processes and of human resource management practices aimed to encourage, act upon and recognize employees' ideas—is increasingly found in excellent companies known for the creativity and innovation of their employees. The essential belief on which SMI is founded is that if employees are not creative, it is not their fault (lack of necessary personal traits and abilities), but the company's which does not manage its employees' creative potential properly. According to the SMI, every employee is viewed as potentially creative, each to a different degree. Thus, SMI's set of practices aims to make every one's potential a reality—

mood effects on creative problem-solving. Last, but not least, we will place the discussion of mood effects on creativity in the larger context of process of innovation.

### From 'Cold' to 'Hot' Cognition

In psychology, there has always been a tendency to drive a wedge between cognition and emotion, in the sense that they are seen as two distinct, separate systems, that may run exclusively on their own wheels, but sometimes may interact in different ways (e.g. Forgas, 2000a).

### The 'Cold' Approach

This general position has, to a large degree, dominated traditional cognitive approaches to the study of creativity, and cognitive theories of creativity are consequently largely focused on elucidating 'cold' cognitive mechanisms and strategies involved in creative thinking. In Newell, Shaw and Simon's classical work on creativity conceptualized from a cognitive information processing perspective, there is a passing mention of the importance of 'motivation' and 'persistence' as one of the important defining criteria. However, the remainder of the treatment of the subject is almost entirely concentrated on identifying the most relevant heuristic strategies that are used by problem-solvers in handling the creativity aspect of problem solving (Newell, Shaw & Simon, 1979). Along similar lines, Weisberg (this volume), argues uncompromisingly that the traditional, well-known mechanics of ordinary problem-solving is the only road that takes us to the peak levels of creativity, excluding any privileged role of affect in the process of creativity that other theorists would like to grant (e.g. Getz & Lubart, 1999; Getz & Lubart, 2000; see also Root-Bernstein & Root-Bernstein, this volume).

Also in the most recent, sophisticated 'creative cognition' approach launched by Finke, Ward & Smith (1992) and Smith, Ward & Finke (1995), where the concepts, theories and methods of cognitive science are applied as a platform for a rigorous study of creativity, the focus is exclusively on identifying the kind of cognitive mechanisms that are at work when people are engaged in creative endeavours. No place in their theories has been given to the 'hot' dimension of cognition, that is fueled by desires, affect and mood.

Indeed, as Forgas (2000a) points out, in the classical cognitive tradition there has generally been a tendency to think of affect as a 'subtractive' factor that is 'dangerous' in the sense of having the potential to subvert efficient cognitive processing. More recently, we see this perspective expressed in theories espoused by Ellis & Ashbrook (1988) and Mackie & Worth (1991), where both positive and negative affect are regarded as states that take up scarce processing capacity.

### Cognition is Heating Up

During the last 20 years, however, we also have seen an increasing interest in embracing the concepts of emotion, affect and mood within more integrated cognitive theories, like the associative network theory (Bower, 1981). Here affective content is also granted a potentially positive function, in providing extra cues in memory. On this perspective, openness to feelings may become a useful adjunct to the machinery of effective, rational thinking. This perspective is also adopted specifically with regard to creativity by Getz & Lubart (1999), in their elegant Emotional Resonance Model of Creativity.

Of particular relevance to the area of creativity is also the view put forward in one of the most prominent theories in the field advocated by Forgas (1995, 2000b). In his Affect Infusion Model (AIM), a core thesis is that tasks that require elaborate and constructive processing—exactly what is likely to be needed in the open and unstructured problem spaces that require creative thinking—there will be more reliance on affectively primed information, and greater influence of affect and mood states on performance. Such effects are held to be both detrimental and facilitative of performance, partly due to the kind of information processing that is triggered by the particular affective state in question with regard to the task at hand.

Following Forgas (2000a) we may regard the division of labor between the different emotion concepts in the way that affect is a general, superordinate concept, where mood refers to long-term, relatively stable affective states, and emotions constitute more short-lived, specific affective episodes.

Research on affect and creativity has been focused largely on the effect of positive and negative mood, compared to a neutral state on a large variety of creative task performances (Russ, 1993, 1999).

### Mood and Creativity: A Straight or a Crooked Relationship?

We may start out by asking if the research done so far gives us a fairly clear and consistent picture of the impact of mood and creativity, or if moderating contingencies is the rule rather than the exception.

In spite of many differences regarding the theoretical interpretations of mood effects on cognitive performance in general (Forgas, 2000a; Hirt, 1999; Hirt, McDonald & Melton, 1996; Martin & Stoner, 1996), a specific position has frequently been cited as a valid general conclusion on the relationship between mood and creative problem-solving. This is the conclusion that *positive mood facilitates creative problem-solving* (e.g. Benjafield, 1996; Hirt, 1999; Hirt, McDonald & Melton, 1996; Isen, 1993, 1999; Isen & Baron, 1991; Shapiro & Weisberg, 1999; Shapiro, Weisberg & Alloy, 2000).

results showed that positive mood was significantly *negatively* related to task performance. In a second study, subjects were given the same insight tasks. Positive and negative mood, as well as arousal, were measured by way of the Russell scale, as in the first study. In addition, positive, negative and neutral mood were experimentally induced by way of short video-clips. Both error rates and solution latencies were recorded as measures of performance. Natural positive mood measured by the adjective checklist was again found to be significantly negatively related to task performance. Moreover, experimentally induced positive mood subjects were found to be the poorest problem solvers compared to control, neutral and negative mood subjects, in that particular rank order. These findings argue strongly against any simple and unconditional proposition stating that positive mood facilitates creative problem-solving. Interestingly, no mood effects were observed on the control tasks, indicating that the mood selectively operated in the creative problem-solving tasks, in general line with Affect Infusion Theory (Forgas, 1995, 2000a).

Closely related, in a series of experiments, Gasper (in press) was able to empirically cash in on the hypothesis originally proposed by Kaufmann & Vosburg (1997), to the effect that induced positive mood, as compared to induced negative mood, promotes the Einstellung effect in problem-solving in selected tasks in the Luchins tradition.

A key task in the new 'creative cognition' tradition explored by Finke & Slayton (1988), Finke, Ward & Smith (1993) and Smith, Ward & Finke (1995), is the so called 'creative mental synthesis' task. Here the subject is presented with randomly generated shapes and alphanumeric figures, such as a line, a square, or the capital letters L, D, and X. The task is to combine a given number of such elements into a recognizable pattern. An example of a very easy task is giving the subjects a J and a D, and asking them to combine them into a meaningful figure. No doubt, you have already constructed the umbrella that most people easily can visualize. This task can be made very difficult by adding the number of elements to three and five, and can be scored on both correspondence (how well integrated the different constituent elements are), and creativity (how original and ingenious the configuration of the elements are).

Anderson, Arlett & Tarrant (1995) directly investigated the effect of mood on performance in this task by way of comparing induced positive, negative and neutral mood to various indicators of problem-solving performance. The Velten (1968) mood induction procedure was employed, where the subjects were given 60 statements, happy or sad, and asked to experience each statement fully. The results showed that positive mood had a significantly negative effect on performance, in particular compared to the neutral mood condition. Anderson, Arlett & Tarrant (1995) claim that the results

show positive mood to have a detrimental effect on the constraining of elements into a whole pattern, by settling for solutions with poor correspondence and lower creativity.

In line with such findings, in a recent experiment, Kaufmann & Vosburg (2002) found a crossed interaction between mood and early vs. late idea production. Positive mood subjects scored significantly higher in early production, whereas negative and neutral mood subjects significantly outperformed the positive mood subjects in late production. Indeed, the positive mood condition seemed to produce a steep response gradient held by Mednick (1962) to be characteristic of non-creative individuals (cf. Martindale, 1990; Fasko, Jr., 1999), whereas the negative/neutral conditions were closer to the flat association gradient typical of creatives.

Recently, Szymanski & Repetto (2000) also reported that induced negative mood facilitated creative problem-solving, measured by a story-telling task. In a fresh study conducted in a field situation, George & Zhou (2001), in close line with our arguments above, make the observation that "people in positive moods . . . may evaluate the status quo positively as well as their own ideas which may cause them not to put forth high levels of effort to make suggestions for significant improvements that are, in fact useful" (p. 3). They base their study primarily on the contextual Mood-as-Input Model advocated by Martin & Stoner (1996, 2000). From this vantage point they suggest that under important contextual conditions conducive to creativity and conducive to facilitating the effects of mood states, such as perceived recognition and rewards for creativity as well as clarity of feelings, negative mood will tend to facilitate, whereas positive mood will be detrimental to, creativity. Creativity was measured by supervisory ratings. The negative mood hypothesis was supported but only weakly. However, there was a clearly significant detrimental effect for positive mood on creativity, in support of the theoretically derived hypothesis. Such findings, at the very least, clearly warn against any general and straightforward conclusion to be drawn from such findings as reported in the frequently cited study by Isen, Daubman & Nowicki (1987).

Among the results referred above, the Kaufmann and Vosburg findings seem particularly difficult to reconcile with the classical findings reported by Isen, Daubman & Nowicki (1987), where performance on a task strongly similar to the ones used in Kaufmann and Vosburg experiments was facilitated by positive mood. There is, however, one potentially critical difference between the Isen et al. and Kaufmann and Vosburg study that may account for the discrepant findings. In the Isen et al. experiments, the task was solved in a practical setting that allowed the subjects continuous feedback on their solution attempts. In the Kaufmann and Vosburg studies, the tasks were performed in

importance whereas creative problem-solving is concerned, and that a limitation in variables to be dealt with at this stage of the inquiry is needed. This caveat also applies to the further examination of variables within the four dimensions.

### Mood and Problem Perception

The issue of problem perception (or problem representation) is thought to be highly important in the study of problem-solving. What happens at this stage may to a strong degree determine the further processing of the problem and, ultimately, the success of solving the problem (cf. Simon, 1979), particularly with regard to *creative* problem-solving (Getzels & Csikszentmihalyi, 1976; Hayes, 1978; Kaufmann, 1988; Unsworth, 2001). There are many important sub-issues in this regard (cf. Runco, 1994), but here we will concentrate on the more general level of perception of the problem. A highly important aspect of problem representation that may be intimately linked to affect and mood states is the so-called 'valence' of the problem, in the sense of classifying the problem as an 'opportunity' or as a 'threat' (e.g. Jackson & Dutton, 1988; cf. Ginsberg & Venkatraman, 1992; Thomas et al., 1993).

A problem perceived as an opportunity is seen as positive, controllable and involving a potential gain, whereas a problem perceived as a threat is seen as negative, uncontrollable and involving a potential loss. A number of studies have demonstrated predictable differences in information processing as a consequence of defining the problem as threats or opportunities (e.g. Thomas et al., 1993). Seeing the problem as an opportunity results in more open information processing and stronger belief in one's own ability to solve the problem. In contrast, a threat representation leads to more restricted information search and to a more pessimistic outlook on one's ability to solve the problem (Jackson & Dutton, 1988).

From the theory presented above, it follows that positive mood should promote a frame of mind that is conducive to perceiving a problem as an opportunity, whereas negative mood should increase the likelihood of perceiving the problem as a threat. Jackson & Dutton (1988) make this assumption on a more intuitive basis. In a recent study by Mittal & Ross (1998), this posited link between mood states and the valence in categorizing the problem has been directly tested.

Mittal & Ross used business scenarios as problem situations, where the demographics of the customer base of a company was changing significantly. Mood was manipulated by presenting half of the subjects with a sad story and the other half with a happy story. Among the many interesting findings observed in this study, significant differences in issue interpretation in a strategic decision context were observed in the two mood groups. Subjects in a positive mood were more

likely to interpret the strategic issue as an opportunity compared to negative mood subjects.

### Mood and Solution Requirements

Again it should be emphasized that there are many different issues that are important in this category. A cardinal consideration may, however, be said to reside in the distinction between optimizing vs. satisficing criteria originally proposed by Simon (e.g. 1956) and further developed by Simon (1977) and March (1994). Rather than viewing these criteria as distinct categories, we have previously argued that it is more convenient to regard them as opposite, extreme points on a continuum (Kaufmann, 1996; Kaufmann & Vosburg, 1997, 2002; Vosburg & Kaufmann, 1999). At the satisficing end of this continuum, the individual is held to construct a very simplified mental model of the solution space and accept the first solution that meets the corresponding aspiration level for an adequate solution. At the optimizing end of the continuum, the individual will attempt to perform an exhaustive search and rational evaluation of the expected utilities of all alternative solutions available. Kaufmann & Vosburg (1997) and Vosburg & Kaufmann (1999) posited that positive mood will promote a satisficing strategy of solution finding, whereas negative mood will be more appropriate under optimizing conditions. In their experiments, the tasks employed ranked extremely high in solution requirements (highly ingenious and unconventional solutions were required to fulfill all the solution requirements). They explained their findings that positive mood was detrimental and negative mood facilitative of finding the ingenious, 'ideal' solutions with reference to the hypothesis that positive mood promotes a satisficing and negative mood an optimizing solution strategy.

One important determinant of solution criteria along this continuum is the degree to which the task environment is perceived as satisfactory or problematical. Carrying this argument a step further, we may also argue that satisficing vs. optimizing criteria will be applied in the course of solving a problem, and that different individuals may settle for solutions of highly different quality. From the theory presented above, it follows that being in a positive mood would lead to perceiving a task as less requiring of high-quality solutions than when being in a negative mood, where a stricter criterion for an acceptable solution is more likely to be upheld. We argued above that this mechanism is the likely explanation for the 'paradoxical' mood effects observed in the Kaufmann and Vosburg study cited above. Also, we have seen above that Anderson, Arlett & Tarrant (1995) made similar observations and interpretations of a significant negative effect of positive mood on performance in the creative mental synthesis task.

We may now posit the general principle that positive mood will promote a satisficing strategy of solution

Dimensional thinking must also be learned by doing. One must learn how to translate a three-dimensional object into two dimensions by drawing or photographing it. One must learn how to transform the information given on a two-dimensional blueprint or assembly diagram into the three-dimensional object. Such skills can be acquired through formal classes in drafting and modeling, or through informal experience building furniture, knitting, sewing, or doing any other craft. Perhaps most challenging is learning how to transform a linear set of mathematical symbols into a graph or physical model of the equation—an exercise that was once common in geometry and algebra classes and which should be re-instituted universally.

Playing, and the modeling that it so often entails, is especially important to the exercise and training of intuition. Most innovators build models of sorts, play with a wide variety of games and tools, and generally have extensive experience with making things of all sorts. Carl G. Jung, the famous psychologist, recalled untold hours building models of castles as a teenager. He then took up painting, through which he discovered the function of mandalas (world images) as models for the psychological lives of his patients. Einstein, of course, spent his most creative years in a patent office, daily analyzing and playing with models of inventions. Many artists and writers, including Claes Oldenberg and H. G. Wells, created entire imaginary civilizations with which they played as children and teenagers and from which they subsequently drew novel ideas for their arts as adults. Alexander Calder, as mentioned above, modeled a circus and derived from his experience not only contacts with the art world, but specific ideas about how to design moving sculptures. Such experiences are common among imaginative people. Indeed, one of the few good correlations that exists to predict which individuals will be creative reveals that they have, often from childhood, *made* things with hands and mind.

Just as all roads lead to Rome, all the experiences gained from the exercise of imaginative thinking tools lead towards synthesizing, that ability to pull together all one imagines with all one knows, that drive to meld sensual knowledge with received wisdom into a unified knowing that we have called *synosia*. We are often most aware of the ‘rational’ or sense-making character of synthetic breakthroughs in human thought—for instance, the explanatory power of Alberti’s drawings in perspective or Einstein’s theory of relativity, but non-rational feelings and perceptions play an equally important role in the generation of synthesis. There is that deeply troubling sick feeling in the pit of one’s stomach when one looks at a situation and knows that something is wrong; or the unmatched ‘high’ that accompanies the ‘Aha!’ of an unexpected insight. For mathematician-philosophers Bertrand Russell and Norbert Wiener, creative work almost always began with feelings of physical discomfort evoked by certain

unsolved problems in mathematics (Hutchinson, 1959, p. 19; Wiener, 1956, pp. 85–86; Wiener, 1953, pp. 213–214). Equally physical, orgasmic feelings of relief and achievement attended the solution of those problems. Nobel laureate Sabrumanyam Chandrasekhar has called this “shuddering before beauty” (Curtin, 1982, p. 7).

Ultimately, all thinking tools, but especially modeling, playing, transforming, and synthesizing, give birth to the inarticulate sense-making called intuition. Intuition involves non-explicit expectations of what should happen when something is tweaked, of how a system will behave when it is twisted, of what kind of response a person will give in a particular situation. We build vague models of how things work and people behave based on our experiences. These models often owe a great deal to playing with tools, games, people, and systems to find out how they respond to various stimuli. We develop a ‘feel’ for what should happen. But because we have not analyzed our experience in any formal way, we cannot explain the resulting ‘intuitions’. They remain what philosopher and physicist Michael Polanyi has described as ‘personal knowledge’—pre-verbal understanding that yields insight before it yields the means to explain insight. Though personal knowledge is just that, personal and unspeakable, it is nonetheless valid and useful. In fact, Neils Bohr used to chide his students with the comment, “You’re not thinking; you’re just being logical!” (Frisch, 1979, p. 95). His colleague Enrico Fermi was known to dismiss mathematical ‘proofs’ of concepts with the comment that his ‘intuition’ told him they were wrong. Because Fermi had so much experience actually doing physics, building, making and inventing things, most of his colleagues trusted his intuitions, which were often right (Wilson, 1972). Learning to pay attention to that which moves us—to an accumulation of unarticulated but felt experience that forms our intuition—is key to creative work (Root-Bernstein, 2002).

### Intuition and the Future of Innovative Education

Having placed intuition on a comprehensible footing, and outlined its role in the comprehensive, creative knowing that is *synosia*, we can now think about the educational implications such recognition must imply. Education in every discipline rightly emphasizes analytical, logical, technical, objective, descriptive aspects of each field. These inform the nature of public discourse between practitioners and their formal communication of disciplinary knowledge. But, as must by now be evident, the subjective, emotional, intuitive, synthetic, sensual aspects that make up the private human face of all creative inquiry deserve equal educational recognition. It is this human face, after all, that fuels desire to discover, to invent, to know. Without it, creative work has no motivation, no driving force. This is not to argue that practice of imaginative

thinking and the exercise of intuition is of greater import than mastery of the logical, analytical, technical aspects of any discipline. Far from it. Innovation is possible only when individuals emotionally engage in a subject and intuit novel ideas *and also* evaluate ideas and results logically and translate them into forms appropriate for communication and analysis by other people. Synosia cannot do one without the other, nor can an education that truly seeks to prepare students for innovation and invention.

Unfortunately, not only does our education system generally ignore the emotional and subjective aspects of creativity, so do the cognitive sciences. This is too bad, for theories in cognitive psychology do not mirror so much as they inform educational practice. And as mathematician Seymour Papert of MIT makes clear, the enormous impact cognitive theories often have on educational practice can be to the detriment of innovation. He writes:

Popular views of mathematics, including the one that informs mathematical education in our schools, exaggerate its logical face and devalue all connections with everything else in human experience. By doing so, they fail to recognize the resonances between mathematics and the total human being which are responsible for mathematical pleasure and beauty . . . (Papert, 1978, p. 104).

Papert finds grounds in this oversight to question the validity of cognitive theories as they inform education:

Implicit in the confrontation of these views of mathematics is a broader question about the legitimacy of theories of psychology, often called cognitive, which seek to understand thinking in isolation from considerations of affect and aesthetics (Papert, 1978, p. 104).

Papert has a point. The separation of cognition from somatic sensation and aesthetic feeling is both inaccurate and inappropriate: inaccurate, for if, as Einstein and McClintock both said, one must become a piece of nature in order to discover the hidden mysteries of nature, then the oversight of imaginative and intuitive thinking undermines our understanding of creative endeavor; inappropriate, because the same dualistic divorce of mind and body, emotion and reason, has had a deleterious effect on education. Psychologist Jeanne Bamberger has documented just how harmful. She studied a group of Boston teachers and some of their students who were considered bright but who performed poorly in school. Teachers and students were brought to Bamberger's Laboratory for Making Things in Cambridge, Massachusetts where they were asked to build mobiles. Most of the children had no difficulty building mobiles, but when asked how they did it and what physical principle they used, they were unable to answer. As one young man said, he "just knew . . . I

had a feeling of it, like on a teeter totter" (Bamberger, 1991, p. 38). The teachers, however, had learned the principle underlying mobile construction, which is the same as balancing two weights on a lever: 'weight times distance must be equal on both sides of the fulcrum'. They, however, were mostly unable to implement this principle in practice, and few built a functional mobile (Bamberger, 1991, p. 44). There is something obviously wrong with an educational system that can produce students unable to explain how they do what they do and teachers unable to do what they can explain.

The crux of the matter with education lies in the dissociation of mind from body and thus sciences from arts. For most of the twentieth century, psychology was dominated by an over-simplified use of Lewis Terman's theory of intelligence, which relied solely upon verbal and mathematical measures of problem-solving ability (Seagoe, 1975). Practitioners overlooked the fact that Terman himself had actually found that for very creative people, but not for average people, verbal and mathematical scores were sufficient to predict high achievement on visual, analogical, mechanical, physical and other tests. Initially, at least, communication skills with words and numbers were understood as predictors/indicators for some of our most important imaginative thinking skills: visualizing or imaging, analogizing, modeling and body thinking. As Terman's work affected the field, however, the communication skills that predicted creative intelligence took precedence over the imaginative substance of that intelligence—as evidenced by the heavy testing of verbal and mathematical skills at all levels of schooling.

Unfortunately recent multiple intelligences theories such as Howard Gardner's (1983) threaten to exacerbate the problem by focusing much-needed attention on a broader set of communications skills such as kinesthetic, musical, verbal, visual, and inter-personal abilities without simultaneously distinguishing them from creative thinking skills. The fact that people can be highly verbal, extraordinarily artistic, or wonderfully musical and at the same time have little or no creative ability seems generally to have been overlooked or ignored. Most creative people are, in fact, polymathic and utilize their skills in multiple domains (see Root-Bernstein, 'The Art of Innovation', this volume).

Bamberger, Papert and others point the way towards a more balanced view of innovative thinking by forcing us to look at mind as part of the body. Neurologists such as Antonio Damasio (1994) remind us that people who, for reasons of disease or accident, lose emotional affect also lose their ability to act reasonably. Rational decision-making, he argues, cannot be divorced from emotional affect. The anecdotal reports of so many of the world's most creative people are finally finding an analytical basis.

The implications of these findings for cognitive sciences and education cannot be underestimated. What they tell us is that any theory of mind that claims to account for creative thinking must describe the sensual, emotional, and somatic manifestations of thought as well as their analytical, objective, and communicable formulations. Moreover, the transformational process by which ideas are translated from their personal, bodily forms into formal languages for communication must be made explicit. Educationally, each of these points has equivalent importance. Words and numbers are not sufficient to produce innovative people, nor are the tools for thinking that we have outlined here. Tools for thinking are necessary to develop the sensual, emotional, bodily forms of thinking from which new ideas emerge, but tools for thinking are not sufficient for communicating these ideas to other people. In order to provide a complete education, tools for thinking need to be taught in an integrated fashion with a variety of expressive skills—verbal and mathematical, to be sure, but also bodily-kinesthetic, visual-spatial and others that pertain to Gardner's multiple domains. Translating and transforming skills that link imaginative tools to expressive modes and expressive modes one to another are equally necessary. Only when mind and body, synthesis and analysis, personal thought and public communication skills are all part and parcel of cognitive studies and educational practice will an enhanced capacity for innovation become available to everyone.

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# Stimulating Innovation

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**Abstract:** Innovation is critical for maintaining competitive advantage in a high-tech global economy, especially for organizations or nations that do not possess low-cost labor forces. Many studies on innovation attempt to identify endogenous and exogenous variables that impact innovation (Kostoff, 1997a) in order to better understand the environment that promotes innovation. The author's recent efforts have focused on developing processes for enhancing innovation that exploit the transference of information and insights among seemingly disparate disciplines.

**Keywords:** Innovation; Discovery; Cross-discipline knowledge transfer; Literature-based discovery; Text mining.

The objective of this chapter is to describe how innovation can be promoted through the enhancement of discovery by cross-discipline knowledge transfer. The approach developed entails two complementary components—one literature-based, the other workshop-based. The literature-based component identifies the science and technology disciplines related to the central theme of interest, the experts in these disciplines, and promising candidate concepts for innovative solutions. These outputs define the agenda and participants for the workshop-based component. An example of this combined approach is presented for the theme of Autonomous Flying Systems. The hybrid approach appears to be an excellent vehicle for generating discovery and enabling innovation. However, it requires substantial time and effort in both phases.

## Introduction

Innovation reflects the metamorphosis from present practice to some new, hopefully 'better' practice. It can be based on existing non-implemented knowledge, discovery of previously unknown information, discovery and synthesis of publicly available knowledge whose independent segments have never been combined, and/or invention. In turn, the invention could derive from logical exploitation of a knowledge base, and/or from spontaneous creativity (e.g. Edisonian discoveries from trial and error).

The process of innovation is of immense social interest and impact. Classical studies by Mansfield

(1980, 1991), Griliches (1958, 1979, 1994), and Terleckyj (1977, 1985) focused on the relationship between innovation and micro- or macro-economics. Studies by Wenger (1999) on combined visualization/brainstorming techniques, Patton (2002) and Taggar (2001) on the impact of group stimulation to creativity, Chen (1998) and Siau (1996) on contributions of electronic technology to creativity, and books by Boden (1991) and DeBono (1992) on mental processes in creativity, focused on the process of creativity and its contributions to innovation. Large-scale studies by the Department of Defense (DoD, 1969), Illinois Institute of Technology Research Institute (IITRI, 1968), Battelle (Battelle, 1973), and the Institute for Defense Analysis (IDA, 1990, 1991a, 1991b) focused on identifying the environmental and management conditions most conducive to innovation. Recent symposia have focused on the relation of innovation to: technology policy (Conceicao, 1998, 2001); technology forecasting (Arciszewski, 2000; Grupp & Linstone, 1999), competitive advantage (Hitt et al., 2000); and economic growth and impact (Archibugi & Michie, 1995; Spender & Grant, 1996; Van de Klundert et al., 1998). Yet both the process and impacts of innovation remain poorly understood.

One of the least studied components of innovation is the discovery and synthesis of publicly available knowledge whose independent segments have never been combined; i.e. the transfer of information and understanding developed in one or more disciplines to other, perhaps very disparate, disciplines. With the

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