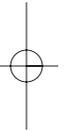
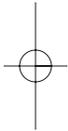


The Art of Scientific Innovation

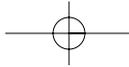
CASES OF CLASSIC CREATIVITY

Syed V. Ahamed and Victor B. Lawrence



Upper Saddle River, New Jersey 07458





Library of Congress Cataloging-in-Publication Data

Ahamed, Syed V., 1938-
The art of scientific innovation : cases of classic creativity / Syed V. Ahamed and
Victor B. Lawrence
p. cm.
Includes bibliographical references and index.
ISBN 0-13-147342-5
1. Technological innovations. I. Lawrence, Victor B. II. Title
T173.8.A32 2004
608-dc22

2004044276

Vice President and Editorial Director, ECS: *Marcia J. Horton*
Editorial Assistant: *Carole Snyder*
Vice President and Director of Production and Manufacturing, ESM: *David W. Riccardi*
Executive Managing Editor: *Vince O'Brien*
Managing Editor: *David A. George*
Production Editor: *Daniel Sandin*
Director of Creative Services: *Paul Belfanti*
Art Director: *Jayne Conte*
Cover Designer: *Bruce Kenselaar*
Art Editor: *Greg Dulles*
Manufacturing Manager: *Trudy Piscioti*
Manufacturing Buyer: *Lisa McDowell*
Senior Marketing Manager: *Holly Stark*



© 2005 Pearson Education, Inc.
Pearson Prentice Hall
Pearson Education, Inc.
Upper Saddle River, NJ 07458

All rights reserved. No part of this book may be reproduced, in any form or by any means, without permission in writing from the publisher.

Pearson Prentice Hall® is a trademark of Pearson Education, Inc.

The author and publisher of this book have used their best efforts in preparing this book. These efforts include the development, research, and testing of the theories and programs to determine their effectiveness. The author and publisher make no warranty of any kind, expressed or implied, with regard to these programs or the documentation contained in this book. The author and publisher shall not be liable in any event for incidental or consequential damages in connection with, or arising out of, the furnishing, performance, or use of these programs.

Printed in the United States of America

10 9 8 7 6 5 4 3 2 1

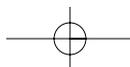
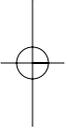
ISBN 0-13-147342-5

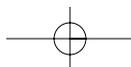
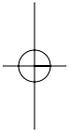
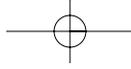
Pearson Education Ltd., *London*
Pearson Education Australia Pty. Ltd. *Sydney*
Pearson Education Singapore, Pte. Ltd.
Pearson Education North Asia Ltd., *Hong Kong*
Pearson Education Canada, Inc., *Toronto*
Pearson Educación de Mexico, S.A. de C.V.
Pearson Education—Japan, *Tokyo*
Pearson Education Malaysia, Pte. Ltd.
Pearson Education, Inc., *Upper Saddle River, New Jersey*





Dedicated to the International Community of Our Doctoral Students





Contents

FOREWORD vii

PREFACE ix

SYNOPSIS OF THE BOOK xiii

CHAPTER 1 Concepts and Perspectives 1

- 1.1 Creativity and Invention 2
 - 1.1.1 Evidence from History 3
 - 1.1.2 Generic Innovations from Recent Times 3
 - 1.1.3 Innovations, Adaptations, Improvisations, and Re-engineering 4
 - 1.1.4 Deathtrap for the Creative? 4
- 1.2 Concepts in Classic Inventions 4
- 1.3 Concepts in Modern Adaptations 5

CHAPTER 2 Academic Setting 8

- 2.1 Basis and Motivation for the Book 9
 - 2.1.1 The Student Perspective 10
 - 2.1.2 The University Perspective 10
 - 2.1.3 Students and Mentors 11
- 2.2 Attitude Towards Research 11
 - 2.2.1 Motivation and Drive 11
 - 2.2.2 Doubt and Dilemma 12
- 2.3 The Flavor of Contribution 12
 - 2.3.1 The Major Breakthroughs 12
 - 2.3.2 Early Breakthrough Patents 13
 - 2.3.3 Recent Inventions 13
 - 2.3.4 Breakthroughs and Inventions 13
 - 2.3.5 Adaptations and Innovations 14
 - 2.3.6 Improvisations and Adaptations 14
 - 2.3.7 Reengineering and Improvisations 15
- 2.4 Student–Mentor Relationship 16
 - 2.4.1 The Mentor’s Roles and Responsibilities 16
 - 2.4.2 The Student’s Role and Responsibilities 16

- 2.4.3 The Abstraction of Creativity 17
- 2.5 The Climate for Creativity 18
 - 2.5.1 Inherent Personality Attributes of the Student 19
 - 2.5.2 Acquired Personality Attributes of the Student 21
 - 2.5.3 External and Contributing Circumstances 28
- 2.6 Milestones Along the Path 30
 - 2.6.1 The Systematic and Rigorous Rules of Engineering Sciences 31
 - 2.6.2 Slight Variations on a Basic Concept 31
 - 2.6.3 The Relaxation of Constraints 32
 - 2.6.4 The Recombination of Adaptations at Various Levels 32
 - 2.6.5 The Creation of Novelty 33
 - 2.6.6 Socially Significant Inventions 34

CHAPTER 3 Classic Breakthroughs 38

- 3.1 Telephony 43
 - 3.1.1 Improvement in Telegraphy (Bell, 1876) 44
- 3.2 Motion Picture Camera 50
 - 3.2.1 Kinetographic Camera (Edison, 1897) 51
- 3.3 Early Telecommunication Concepts 68
 - 3.3.1 Transmitting Electrical Signals (Marconi, 1897) 60
 - 3.3.2 Transmitting from a Distance (Tesla, 1901) 68
 - 3.3.3 Transmitting Through Natural Media (Tesla, 1901) 78
- 3.4 Television Systems 89
 - 3.4.1 Television Systems (Farnsworth, 1930) 90
 - 3.4.2 Images of Objects (Zworykin, 1935) 100
 - 3.4.3 Cathode Ray Tube (Zworykin, 1938) 104
- 3.5 Computer Systems 108

vi Contents

3.5.1 Stored Program Control (Von Neumann, 1946–1948)	109	4.1.7 The Quest for the Best	213
3.6 Semiconductor Era	112	4.2 The Crucial Difference	214
3.6.1 Transistor: Semiconductor Amplifier (Shockley, 1950)	113	4.3 Specific Conclusions for Students	215
3.6.2 Transistor: Three-Electrode Circuit Element (Bardeen, Brattain, 1950)	117	4.3.1 Unstructured Creativity	215
3.7 Masers	128	4.3.2 Structured Creativity	216
3.7.1 Maser Communications System (Schawlow, Townes, 1960)	129	4.3.3 The Practice of Invention/Innovation	216
3.8 Cancer Detection	139	4.3.4 Diagrams for Four Other Environments	224
3.8.1 Cancer Detection (Damadian, 1974)	139	CHAPTER 5 Epilog 227	
3.9 Glass and Fiber-Optics Technology	150	5.1 The College Perspective	228
3.9.1 Fiber Optics (Maurer and Schultz, 1972)	154	5.1.1 Abstract (Blending Intelligences)	229
3.9.2 Fiber Optics (Keck and Schultz, 1973)	162	5.1.2 Concepts of Group Creativity	229
3.9.3 Fiber Optics (Wolf, 1976)	173	5.1.3 The Mining of Generic Concepts	230
3.10 Intelligent Networks	177	5.1.4 Group Effort and Resulting Innovations	230
3.10.1 Data Base Communication (Weber, 1980)	180	5.1.5 Differences Between Brainstorming and Concept Mining	232
3.11 The Internet—A Breakthrough Without One Invention	195	5.1.6 Conclusions	232
3.11.1 The Aloha System—Another Alternative for Computer Communications	196	5.2 The Corporate Setting	233
3.11.2 The “Newer” Internet	203	5.2.1 A Historic Perspective	233
3.11.3 The Concept of an Intelligent Internet	204	5.2.2 A Current Corporate Perspective	234
3.11.4 The Success of the Internet	205	5.3 Creativity for Profit-Making	234
CHAPTER 4 Major Conclusions Derived from the Socially Significant Patents 208		5.3.1 Corporations, Innovations, and Social Progress	234
4.1 Common Factors of Seminal Patents	208	5.3.2 Personal Attributes, Group Dynamics, and Corporate Funding	236
4.1.1 Physical or Mathematical Basis	209	5.4 The Management of Research	238
4.1.2 The Intuitive Content	210	5.4.1 The Individual Scientist	240
4.1.3 Reality, Imagination, and Possibilities	210	5.4.2 The Management of Scientists	242
4.1.4 The Basic Social Need and Driving Force	211	5.5 Two Major Management Functions	243
4.1.5 The Opportunity for Originality	212	5.6 The Overall Corporate Research Model	246
4.1.6 Observation, Solution, and Generality	212	GLOSSARY 256	
		Cases of Classic Creativity 268	
		About the Authors 269	
		INDEX 271	

Foreword

We are at present witnessing a major revolution in telecommunications. When it is over, practically everything about how we telecommunicate will have changed. Advances in computers and communications during the last century no doubt have played a critical role in spurring this revolution. Nevertheless, we might examine the inventions and innovations that were fundamental to this revolution and the type of research environment that led to these major developments.

During the last century, most industries provided strong support for their research laboratories; in particular, there was a rapid expansion of research facilities after World War II. While a number of important innovations occurred in industrial laboratories, in recent years the support for industrial research has been shrinking. This book, *The Art of Scientific Innovation: Cases of Classic Creativity*, thus has come out at an appropriate time.

In their book, the authors have addressed important and underlying issues of human creativity. The authors attempt to capture the individual motivations that led researchers towards their major contributions and to examine the social, academic, and corporate opportunities that foster and encourage these gifted individuals. The book includes a range of inventions, such as the invention of the telephone, the wireless, the transistor, and the laser. The authors correctly point out that no single invention triggered the Internet revolution. Such vast insight and trailblazing of the still undocumented path to inventions can be undertaken by only a few people in this world. I commend the authors for taking a bold step in writing a book that is likely to become useful to a large community of readers from both corporate and academic circles.

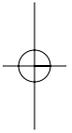
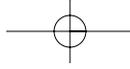
The book emphasizes the role of corporate and academic research in accelerating

the strides of technology and provides researchers and students with insights into the cooperative role of the machines and networks that invite the human spirit to the realm of innovation and creativity.

I am especially delighted that Professor Syed Ahamed and Dr. Victor B. Lawrence have taken the time and initiative to write this book. Syed has many years of experience in working with research students at the University of Hawaii, Polytechnic University, and the City University of New York. Victor has gained vast corporate research and development experience at AT&T Bell Laboratories and now Bell-Labs Lucent. Both Syed and Victor are prolific writers and inventors themselves. Syed has made contributions ranging from techniques for accelerating the convergence of nonlinear vector potential problems to the development of the architectures of wisdom machines. Victor has made contributions related to data communications, signal processing, speech codecs, and sensing networks for artificial intelligence.

Both authors are eminently suited to addressing the paradigm of change that is at work in making research and development a delicate and sensitive issue. These changes in society make computer systems, networks, and the working research environment essential in paving the way for new inventions and innovations. The ideas presented in this book will prove valuable to students, teachers, and leaders in industry in managing research to keep it productive.

BISHNU S. ATAL
*Laureate (2003), Franklin Institute Award
Retired Director, AT&T Labs Research
and Affiliate Professor
Department of Electrical Engineering
University of Washington
Seattle, WA*



Preface

Creativity can be a controversial topic. It has drawn considerable attention during the latter half of the 20th century. Stemming from imagination, creativity extends into the realm of finding new principles, concepts, relationships, and ways to solve problems. There is no precise scientific definition of the underlying concepts dealing with creativity, nor is there a standard operating procedure for the practice of creativity. As a result, we have used utmost discretion in keeping subjective opinions out of the material presented here. However, we were constrained by our own perceptions and judgments in selecting the breakthrough patents included in this book.

There is good reason for stressing the breakthrough nature of the earlier patents and the nature of innovations commonly documented in the later patents. Whereas we live in an information-rich society influenced by the existence of high-speed networks, the Internet, and instant access to information, earlier scientists lived in an information-poor, but imagination-rich, society. This leads to basic differences in the nature and thought embedded in the creative process. This shift in paradigm is a major focal point of the book. It is possible to find more diversity in the thought process than what meets the eye on an initial reading of the patents presented in the book. The comparison of fundamental concepts on which these patents are based provides substantial insight into the inventors' thought processes and intentions.

It is our objective to make this material available to those students and those individuals starting new careers in research and development who intend to make a genuine

contribution to knowledge. Such contributions naturally vary from area to area, specialty to specialty, and discipline to discipline. However, the creative process as a broad concept unifies all scientific activity. We attempt to capture one such portrait of creative activity in the area of technology and present it as a possible guide and strategy in the evolving knowledge society. In addition, in the context of mentoring others who are working towards their advanced degrees, we feel we can substantiate the statements in the patents presented in this book and discuss the circumstances that led to these inventions.

We feel certain that many other authors writing on the art of innovation would present the material in a different manner. Nevertheless, it is our hope that the book will serve to help students and those dedicated to enhancing the contour and structure of relational knowledge by exploring the creative frontiers of great scientific minds. This is a highly variable and personalized activity and there is no intellectual highway. Many times, it takes many decades of effort and sometimes it requires a quantum leap. The mental process in this area is too complex to be described with mathematical precision or to be documented in complete detail. However, a certain amount of logical and inductive reasoning applies, and sometimes extrapolation and predictive reasoning become the only way out. Imagination, the use of creative graphics, portrayals of scenarios, and the consolidation of mental objects encountered in analyzing and solving mathematical equations, expressions, and identities all can help. It is the structure and the interaction that become the solution to the riddle of scientific invention.

x Preface

Even so, scientific invention is more than a riddle. Numerous factors combine to provide the circumstances and the environment that surround the time and location of an invention. The personalities and genetic predispositions of the scientists, their sensitivities, their acquired training and traits, and their opportunities and interactions all play a decisive role in the chain of events that culminates in an invention. The most sophisticated software provides no match for the mental activity that leads to invention. Otherwise, inventions would become programmable.

However, today the sophistication of software and of the processing power of computers does allow investigating patterns and recycling ideas. The underlying similarities in syntactic pattern recognition are within striking distance of the door to creativity. In a sense, the definition of creativity defies programmability. However, the element of chance that used to be buried in the subconscious of scientists now becomes an exhaustive search in a very close region of investigation. Then again, the close man-machine interplay may just be the initial barrier, and the machine may end up exploring the most promising venues. Two such examples that have substantially influenced the research community are Atal's algorithms for the predictive coding of human speech and Karmarkar's algorithm for the efficient solution of large linear programs. In both instances, the convergence of human ingenuity and the (almost) boundless computational power of the computer are evident. The outcome of both of the contributions is remarkable.

In the first case, the predictive coding techniques for speech retrieve the symbolic characteristics of the vocal tract that produced the initial segment of speech. The temporary storage of these characteristic parameters and their subsequent use in digitally encoding the speech greatly reduce the bit-rate requirements for encoding the rest of the speech. Predictive

coding is successfully deployed to carry telephone conversations over wireless media, where the bandwidth is somewhat limited.

In the second example, the search for optimized solutions is based on Karmarkar's algorithm. The process uses the interior-point method to solve very large linear-programming problems. This algorithm provides solutions much more quickly than earlier ellipsoid methods. Very large optimization problems are quickly solved. In a sense, part of the solution lies in the correct formulation of the problem and in the correct choice of variables for which the optimization problem in polynomial time is going to be solved. When the initial knowledge bases/databases are empty, the ingenuity of the human is the last and only recourse for innovation or invention. Sometimes the genius or the circumstance lies here. In a very realistic sense, Atal's predictive technique and Karmarkar's computational approach would assume a highly different flavor of human thought from Louis Pasteur's observation of the interdependence between cowpox and smallpox.

Computer-aided creativity, though not an impossibility, is a contradiction in terms. On one hand, creativity is the highest state of intellectual activity. On the other hand, modern machine intelligence is presently competing with the intricacy of the human thought process. Random coincidences, correlation, and events are more systematically and expeditiously analyzed by machines than by humans. The machine searches are far more extensive and global than a chance phenomenon in the human mind. Knowledge banks derived from machine searches and pattern recognition are much more systematic and programmable than the scrap papers on which human beings write. There is good reason to believe that the nature of research will undergo an evolution of the type that computer-aided design (CAD)/computer-assisted manufacturing (CAM) has brought to industry.

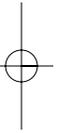
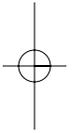
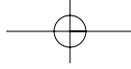
In academia, the scenario is as follows: Whereas the research student will still perform the intellectual activity, the machines will provide the tools and process knowledge and information based on documented and available literature. The reward is the increased number of inventions and level of innovation, at the expense of not challenging the documentation and literature itself or the manner in which inventions are developed and deployed. A short spurt of pseudo-innovations may become eminent. The surest dead end of long-term creativity is an overreliance on computer-aided creativity and machine-assisted pattern recognition without an awareness of the genesis of the patterns being investigated and matched. Computer-generated music, for example, can drown the senses rather than incite the genius that lies dormant within the mind.

The adaptive processing of knowledge, tempered by the judicious use of wisdom, is likely to be a human activity for a long time. Whereas computer-based innovation is likely to become boring and mundane, the human mind can “invent” new dimensions in creativity

that intensify the process. We dare these students pursuing an advanced degree to overcome the boredom of computer-aided creativity. We believe that reinventing the innovative process can be at least twice as challenging and can lead to a unique mode of thinking that still needs investigation. The patterns of thought from one inventor can become manifest as the program in an integrated circuit (IC) chip in another inventor’s device. In some instances, social and technological changes force past inventions (e.g., the abacus) to return as reincarnated superinventions (e.g., handheld computers).

SYED. V. AHAMED
*Graduate Center
of the City University of New York*

VICTOR B. LAWRENCE
*Vice President
Advanced Communications Technology
Bell Laboratories
Lucent Technologies*



Synopsis of the Book

This book deals with cases of classic creativity and emphasizes the proven contributions of scientists from the late 19th and 20th centuries. These inventions have left an imprint on the direction of science and technology of later years. Our focus is on the fields of computers and communications stemming from their precursors: physics and electrical engineering. The topics are vast, and many of the major inventions in other sciences are not covered here intentionally.

This book also deals with some of the more recent patents and stresses the emerging inventions that may affect the direction of change for the 21st century. The influence of the information age on creativity is analyzed in the context of the instant access to thousands of very well organized databases and information bases around the world. The inventions we present in this volume have not weathered the test of time. However, it is an educated guess on our part, and we hope that these inventions will be educational to students on their journey into the realm of creativity. We have limited some of these inventions to those of our colleagues because we know a great deal about these inventions and about the circumstances that led from the realization of a concept to the development of a device intended to serve a commercial or a social need.

As educators, we have attempted to make this book meaningful to doctoral students in four distinct ways and by consolidating the most important topics within five chapters. It is our intent that students become familiar with the methodology and drive behind the major inventions of the last century and become effective contributors to the sciences and disciplines of the 21st century.

First, the key attributes of our best students are presented in the context of the academic and intellectual environment of most modern universities. While the personal attributes of each advanced student are unique, general shared attributes can be isolated and identified. The object is to identify attributes that students can make a conscious effort to capitalize on and enhance. From our experience, attempting to encourage unwilling or unmotivated students to attain an advanced degree can be futile. On the other hand, willful direction from a mentor and students' self-imposed strengthening of these individual attributes can improve students' creative talent and intellectual capacities. This could be a lifelong contribution that a mentor can make for the student. This material is presented in Chapter 2.

Second, we have included patents in this book either in their entirety or in edited versions. It is our hope that readers will analyze the inventors' words with a view toward understanding the personal goals and motivating factors that underlie these patents. Study of these patents can lead to an understanding of the native reasoning behind the inventions, the inventions' connections to society, and, in some cases, the mathematical foundation of the inventions, stated in these patents in the words of the inventors. It is also our intent that students gain insight into what makes inventors invent by reading these original patent applications. The 16 patents presented in the book provide a representative sampling of the different formats of creativity of the individual scientists.

Third, we differentiate between unstructured creativity and structured creativity for our students. Whereas a flash of inspiration (in

xiv Synopsis of the Book

the mind of the gifted inventors) may bring the full-fledged patent and its final embodiment to some special people, most scientists struggle to translate an idea into a tangible product or a concept that can make a worthwhile contribution to society. If the former flash of inspiration is unstructured creativity, the later process of conceiving something novel and toiling ceaselessly towards perfecting it is the structured creativity. All the scientific discipline and mathematical precision would be needed in making a brilliant invention. Generally, there are no significant patents at the two extremes of creativity. The relative proportion of the two types of creativity, unstructured and structured, differs from one inventor to the next and from one patent to the next. A portrait of this blending process is captured in the words the inventors chose to include in their patents.

Fourth, we present the major commonality in the patents: the creative force within the inventors' personalities and the social pressures of their own times, which together have had a profound effect on the scientific community and have brought innumerable rewards to society. However, more than that, we try (as we understand it) to tie generic and scientifically proven axioms of science or mathematics to the inventions themselves. Making these connections is quite challenging, and we

suggest that readers not take our word for it, but instead reinvent the inventions as a painter would repaint or as a poet would rerhyme.

In many cases, the creativity of scientists becomes apparent in numerous dimensions. For the gifted, the desire to create something is a strong drive that cannot be abated. In a sense, such a drive can become an obsession. The undisciplined and creative mind is a gift, and scientists who understand how best to use this gift can provide great benefits to their contemporaries and to future generations. The blend between the (instinctual) drive and the formality of its presentation to a scientific community is a personality attribute that can result from rigorous training. The role of the mentor also becomes crucial in making the dissertation a scientific contribution, in addition to making the product a financial success. It is our hope and intent that this book will provide a sense of direction to students who hope to unearth their own gifts and then develop an ethical ability to deploy these gifts as many scientists of previous generations have successfully done. A sense of excitement accompanies the invention or the discovery with an equally strong drive to perfect the representation (or the symbolism) of truth manifest as invention. In some notable cases, the truth lives on long beyond any product of the invention.

“Science is too important to leave to the scientists,” says Mike Stubbs, director of FACT. “Science has kind of become a new church, but it’s clear now that technology has not been applied to everyone in society to their benefit. We need voices from the arts and sociocultural disciplines to provoke important debates.” As the artist Thomas Struth says, “My feeling is that somehow, since the 1980s, politics are always running behind the development of technology, and it’s very hard to create a legal framework to control what’s happening.”