INSIGHTS OF GENIUS

INSIGHTS OF GENIUS

*Imagery and Creativity
in Science and Art*

Arthur I. Miller

COPERNICUS
An Imprint of Springer-Verlag

To Norma

© 1996 Springer-Verlag New York, Inc.

Softcover reprint of the hardcover 1st edition 1996
All rights reserved. No part of this publication may be reproduced,
stored in a retrieval system, or transmitted, in
any form or by any means, electronic, mechanical,
photocopying, recording, or otherwise, without the prior
written permission of the publisher.

Published in the United
States by Copernicus, an imprint of
Springer-Verlag, New York, Inc.
175 Fifth Ave.
New York, NY 10010

Cover art (clockwise from top): Detail from Figure 3, p. 163, showing a bubble
chamber photograph of a collision between a neutrino and a proton;
Minkowski's sketches of space-time diagrams; Pablo Picasso, composition study
for *Guernica*, dated "May 1 37 (III)"

Library of Congress Cataloging in Publication Data

Miller, Arthur I.

Insights of genius : imagery and creativity in science and art /

Arthur I. Miller.

p. cm.

ISBN-13: 978-0-387-94671-9

e-ISBN-13 978-1-4612-2388-7

DOI: 10.107/978-1-4612-2388-7

Includes bibliographical references and index.

1. Physics—Methodology. 2. Science—Methodology. 3. Creative
ability in science. I. Title.

QC6.M44 1996

530'.01—dc20

96-14094

Text design by Irmgard Lochner

Printed on acid-free paper.

9 8 7 6 5 4 3 2 1

ISBN-13: 978-0-387-94671-9 SPIN 10527266

PREFACE

"For there are 'made' laws, 'discovered' laws, but also laws—a truth for all time. These are more or less hidden in the reality which surrounds us and do not change. Not only science but art also, shows us that reality, at first incomprehensible, gradually reveals itself, by the mutual relations that are inherent in things."

—Piet Mondrian, *Figurative Art and Nonfigurative Art*
(1937)

Scientists have always expressed a strong urge to think with visual images, especially today with our new and exciting possibilities for the visual display of information. We can "see" elementary particles interacting and "see" images of the brain. But "see" is a complex term.

Artists and scientists alike seek a visual representation of worlds both visible and invisible. They attempt to "read" nature. This book explores their efforts, with emphasis on the late nineteenth and twentieth centuries, the age of modern art and modern physics. Our journey will take us through the philosophy of

mind and language and into cognitive science and neurophysiology, as we seek the origins and meaning of visual imagery and, so too, of science.

Asking what visual representation means to science throws fresh light on such problems as

- What is the connection between common sense intuition and scientific intuition?
- By what means does physics progress?
- Are there limits to physics?
- What are the relations between art and science?

Today these problems are no longer solely grist for academic debates. Too often, the media portray science as a godless, dehumanizing exercise whose excesses undermine the very fabric of society. Studying scientists' personal struggles to understand nature, to convince their peers, to inform the public, and to deal with cultural reactions to their research gives us a much different picture.

I focus on physics for a number of reasons. Chief among them are its long history, its foundation rich in philosophical implications, and its interface with so many other scientific disciplines. Another, no less important reason is my familiarity with the subject, which enables me to draw upon significant cases of scientific research for the purposes of motivation and illustration. Toward writing a self-contained book, I have elaborated on a handful of concepts and principles chosen specifically because they pervade all of the physical sciences and so ought to be understood by everyone. Some of these concepts come from other disciplines such as cognitive science and mathematics, which often play a key role in the analyses to follow.

The book concentrates on intuition, aesthetics, realism, representation, and visual imagery. We explore their interrelations and how they became transformed both in order to advance science and in response to another key concept in this book, scientific progress. Allied to these concepts are the principles of causality, relativity, energy conservation,

PREFACE

entropy, and the correspondence principle. For example, exploring the origins of the principle of relativity entails investigating the transition from everyday common sense to the intuition of Galilean–Newtonian science with accompanying changes in our notion of cause and effect, or causality. Studying the origins of the principles of energy conservation and entropy leads us to the introduction of probability into the physical sciences with the allied concept of atomism, which opens the subject of scientific realism. The correspondence principle, introduced systematically into physics by Niels Bohr in 1913, turns out to be a key part of scientific progress, a concept whose exploration ties together many themes discussed thus far and introduces others such as metaphorical thought and theory of meaning from philosophy. The concept of aesthetics arises often in scientific creativity and in considerations of the relations between art and science. We will find that scientists' notions of an aesthetic can be articulated and bear similarities with the artists' notions. Larger issues emerge from discussions of these fundamental concepts and principles; these deeper topics include the meaning of science, the origins of scientific concepts and their relation to our cognitive apparatus, the origins of visual imagery and its role in thinking, particularly in creative scientific thought, the architecture of our mind that gives rise to our mental processes, and the relation between art and science.

The Ariadne's thread running throughout the book is that science has developed in a way that extends our intuition from common sense into an understanding of a world beyond our perceptions—a world where heavier objects fall at the same acceleration as lighter ones, where there is a relativity of space and time, and where there is a wave/particle duality. The final chapter extends this analysis to late nineteenth- and early twentieth-century art.

After touching on ancient science, Chapter 1 discusses Galileo and explores his use of thought experiments to abstract to possible worlds which turned out to be our own. This abstraction enabled Galileo to extend our intuition into a world in which there can be vacuums. For

such a world he made the dazzling hypothesis that all bodies would fall with the same acceleration regardless of their weight. There were no laboratory vacuums for Galileo to test out this hypothesis, which turned out to be correct.

We then proceed to Isaac Newton's genial elaboration and extensions of Galileo's groundwork into a magisterial theory that unified phenomena on the Earth and in the heavens, yielding as well a new concept of causality strikingly different from the one in Greek physics. With further thought experiments, Albert Einstein realized that our concept of intuition had to be transformed yet again in order to understand a world in which space and time are relative quantities. As in every case in this book, the analysis is carried out by bringing to bear notions from fields other than science, such as from philosophy and psychology, all the while placing figures such as Galileo and Newton in their societal context. In all situations investigated in Chapter 1, the visual representations scientists used are abstracted from the world of sense perceptions. This time-honored method worked again and again, and nothing succeeds like success.

In Chapter 2, however, the situation gets more complex because twentieth-century research into atomic physics revealed that this sort of visual representation is not only inappropriate, but also wrong. This situation led to further transformations in intuition, causality, substance, and visual representations for scientific theories. We are led to investigate how scientists use experiments to probe a world beyond appearances from which, in turn, arises the importance of a form of reasoning fundamentally different from deduction and induction. We delve into the concept of visual imagery that was of importance to physicists in the German-cultural milieu in which atomic physics was primarily developed during 1913 to 1927. This chapter presents a dispute over essentially aesthetic tastes in the polemic between Werner Heisenberg and Erwin Schrödinger over whether atomic physics should be based exclusively on particles or waves. The issue was decided in 1927 by further redefinitions of the concept of intuition brought about by Heisen-

berg's uncertainty principle and then Bohr's complementarity principle. We realize that we can trace how theories emerge from Newtonian mechanics such as special relativity and quantum mechanics by studying the particular values possessed by universal constants of nature characteristic of these theories: the velocity of light and Planck's constant. As a result of certain limiting cases of these constants, relativity and quantum mechanics revert back to Newtonian mechanics, which has become intuitive to us because it reflects the world of perceptions in which there is no relativity of space and time and no wave/particle duality. These limiting cases are studied with Bohr's correspondence principle.

Having traced transformations in the concepts of intuition and visual imagery, in Chapter 3 we look in more detail as to how this came about. From exploring how scientists use data for constructing theories and for defending them against competing ones, we realize that these procedures are far from straightforward and not amenable to being encapsulated by any one philosophical theory of scientific method. Specific instances from the research of Galileo and Einstein are discussed, in addition to the physics of electrons in the early twentieth century. We then explore the unlikely origins of two guiding principles in the sciences, the principles of relativity and conservation of energy. Chapter 3 concludes with a discussion of the desire for unification of known forces, which goes back to the very beginnings of science in ancient Greece and continues to be a guideline for scientists. The roots of these principles, and of unification, turn out to be entangled with religion and mystical philosophical beliefs.

Chapter 4 descends one level deeper, inquiring whether the universe is indeed an ordered one, as assumed by Galileo and Newton, among others. The first inkling that this is not the case was revealed through the emergence of the concept of entropy along with the entry of probability into science. Some scientists assumed that these two developments required everyone to take atomism seriously. The ramifications of entropy, with its message of a tendency of the universe toward disorder, went beyond science. Nevertheless, most physicists continued

to assume that the probabilities entering physics through gas theory, with its apparently attendant atomism, was just a reflection of our ignorance in tracing the paths of individual atoms. They believed that physics would revert to its completely deterministic basis as soon as Newton's mechanics was more finely tuned to apply to the atomic world. But this turned out not to be the case, as Chapter 2 discussed. Chapter 4 ends by examining how a new and intrinsic probability entered atomic physics along with wildly counterintuitive predictions, which have been established experimentally and thus call for yet further transformations of intuition.

Since atoms have played a central role in the transformation of intuition and the appearance of probabilities in physical theory, we must investigate further how we can argue that invisible entities can actually exist. This is the view of scientific realism explored in some detail in Chapters 5, 6, and 7. What emerges is that theories based on scientific realism make far-reaching claims such as the universality of science which can deliver absolute truth about the nature of physical reality. In contrast, antirealists claim that there are no such entities as electrons and no absolute truth, and some maintain that science may well be an artificial social construct. Comparison of these viewpoints opens up such problems as what we mean by the rationality and objectivity of science and so, too, the concept of scientific progress. The analysis in Chapter 5 necessarily takes us into the meaning of science and thus into criticism of science, which stems from the early nineteenth century to current postmodernism.

Weighing the comparative advantages of scientific realism and antirealism, I opt for the former. The burden of argument is heavy for the scientific realist. The reason is that logic is on the side of the antirealist, because of the underdetermination thesis (which is introduced in Chapter 3). According to this thesis, there are in principle an infinite number of scientific theories that can describe any set of experimental data. This holds for any science. So why should a single theory, with a claim

PREFACE

to the reality of unobservable entities, be taken as the correct one? The chapter presents arguments from science and philosophy, including experimental evidence for atomism in conjunction with the fertility of this concept, and the need for atoms in order to explain natural phenomena.

A further basis for scientific realism is presented in Chapter 6, which explores the relation between mathematics and physics. This age-old problem has been discussed from Plato, to Newton, to Poincaré, and to Einstein, and it surfaced again at the forefront of physics as a result of Werner Heisenberg's uncertainty principle paper of 1927 wherein he emphasized that mathematics is to be the guide toward understanding atomic physics. The nature of this relation is essential for establishing whether the mathematical formulation of physical theories is a means for understanding worlds beyond sense perceptions. This investigation takes us through Platonism into the cognitive status of science, the origins and testability of geometries, and then into inquiring into whether physics can generate mathematics, which is an important test as to whether mathematics is the fabric of nature.

In analyzing scientific progress and the usefulness of metaphors for extending scientific theories into new domains, Chapter 7 ties together all themes discussed thus far. A model for scientific progress is presented based in scientific realism and with proper philosophical and psychological dimensions in addition to important elements from cognitive psychology as well as Bohr's correspondence principle. The model takes into account transformations in intuition as well as in visual representation that emerged from research in atomic and then nuclear physics, culminating in the so-called Feynman diagrams that are generated by the mathematics of quantum electrodynamics. Specific examples are explored on which the model of scientific progress is based.

A great deal of weight has been placed on the role of visual representations in creative scientific thought as well as on the notion of visual imagery and thought experiments. Chapter 8 explores these issues with results from artificial intelligence, cognitive science, and neurophysiol-

ogy on how visual images are generated and manipulated. These views are compared with conclusions from previous chapters particularly to ascertain how they match results from the history of scientific thought and what light this subject can shed on general problems of visual imagery.

Thus far we have analyzed and explored the content and meaning of scientific theories, with some attention paid to their discovery. Chapter 9 focuses on creative scientific thought. In so doing it investigates theories of digital and analog thought and presents a model for creative scientific thinking based on results from previous chapters such as guidelines for constructing scientific theories. The model assumes the importance of unconscious parallel processing of information and is compared with the introspections of Henri Poincaré and Einstein, which are the centerpiece of this chapter. Their views on creativity, aesthetics, and intuition are compared and contrasted. This analysis sheds further light on the fascinating problem of why it was Einstein who formulated special relativity in 1905 and not Poincaré, despite both men having at their disposal the same experimental data and having arrived at the same mathematical formulation.

Throughout the book thus far the concept of representing the world about us has been central and we have mentioned problems that scientists and artists share. That there were close relations between art and science in the Renaissance is incontestable. With the appearance of Newtonian science in the late seventeenth century, and with it the onset of the Age of Rationalism, many educated people considered science to be the only pursuit of absolute truth. This view began to change noticeably by the end of the nineteenth century. What I mean by relations between art and science is that at the end of the nineteenth century both subjects happened to be moving toward greater abstraction. Why? Chapter 10 concentrates on this fascinating topic. It returns to concepts discussed with relation only to science, such as intuition and aesthetics, and opens them up here, taking into account the differences and similarities between art and science. The discussion of aesthetics is

PREFACE

then expanded by defining it in more detail and comparing how it is used by artists and scientists. The interplay between art and science, which we discuss in some depth, concerns the development of Cubism by Pablo Picasso and Georges Braque, and influences on them, like Paul Cézanne. Then we move to elaborations of Cubism toward nonfigurative art by Juan Gris and Piet Mondrian, among other artists such as the Abstract Expressionist Mark Rothko. In order to seek deeper insights into scientific progress, we compare histories of art with histories of science. We find many similarities between artistic creativity and creative scientific thought, particularly the role of unconscious parallel processing of information.

I wrote *Insights* for lovers of science, be they educated lay readers, students, professional scientists, or artists. Especially important to me are science students and the growing number of lay readers for whom science has become a passion. I hope that *Insights* amplifies their interest by answering some of their questions while whetting their appetite for others. I hope that professional scientists, who often can spare little time for historical and philosophical literature, will find in *Insights* the kind of foundational analysis that gives new awareness into the philosophical underpinnings of their work.

Having based the material in Chapter 10 on firm historical and artistic investigations grounded in the results of previous chapters, I believe that my analyses of aesthetic ideas and the differences and similarities between art and science will interest artists and art historians. I think everyone agrees that part of the intellectual and emotional adventure in art and science resides in the ultimately one-on-one struggle with nature. In this arena barriers between disciplines dissolve.

While the laws of science per se make no statements on ethics, morals, or religion, its practitioners sometimes do. By and large, scientists have been in the vanguard of the fight to defend purely speculative thought against accusations of religious or political sedition. In reply to antisience currents in France in 1902, the great mathematician—

philosopher–scientist Henri Poincaré rose to science’s defense in “Science for its own sake.” His words convey the intensely personal endeavor demanded by art and science:

It is only through science and art that civilization is of value. Some have wondered at the formula: science for its own sake; and yet it is as good as life for its own sake. . . . Thought is only a gleam in the midst of a long night. But it is this gleam which is everything.

With Poincaré’s passionate message in mind, let us explore how artists and scientists seek a visual representation of our universe.

—Arthur I. Miller
Department of Science & Technology Studies
University College London

ACKNOWLEDGMENTS

I have thought about this book a great deal for well over a decade, during which I have had the pleasure to teach some of the material and to discuss much of it with numerous colleagues. Let me reserve mention here to those who have been of great help on the manuscript itself. I should like to thank Brian Balmer, Hasok Chang, A. R. Jonkheere, Allistair McClelland, David Miller, Steven Miller, Constantine Moutoussis, Piyo Rattansi, Jon Turney, and Scott Walter. For comments on Chapter 5 it is a particular pleasure to thank Marcella Pera. On Chapter 6 I acknowledge conversations with Marcus Gi-

aquinto, Jeremy Gray, and Andrew Gregory. For sharing their expertise with me on vision which helped to get Chapter 8 into shape I am most grateful to J. Michael Brady, Michael Duff, and Semir Zeki. Chapter 10 was a difficult one and I deeply appreciate criticisms from David Bindman, Bernard Cohen, Nathan Cohen, John Golding, Norma Miller, and Sarah Wilson.

It is more than appropriate for me to express my gratitude to my publisher at Springer-Verlag, Jerry Lyons, to Theresa Kornak for invaluable production editorial assistance, and to William Frucht for his insightful editing.

CONTENTS

PREFACE

vii

ACKNOWLEDGMENTS

xvii

1

COMMON SENSE AND SCIENTIFIC INTUITION

At the Beginning / The Mindset of Renaissance Scientists /
Galileo's Imagination / Conceptual Frameworks and
Common Sense / Galileo and Newton Become Common
Sense / The Waviness of Light Waves / Life on a Moving
Platform / A Problem with Relative Motion / Another
Way to Think About Relative Motion / Time and Light /
Concluding Comments

1

2

THE INTUITION OF ATOMS

But Is Light Really a Wave? / The Visual Imagery of
Intuition / Atoms and Solar Systems / Atomic Intuition and
Visualization / Visualization Lost, Intuition Redefined /
Intuitivity: The Central Issue / Another Redefinition of
Intuition / Visualization Regained, in Part / Extending
Intuition: Bohr's Correspondence Principle /
Concluding Comments

37

3

SCIENTIFIC METHODS

The Verdict of Experiment or Not? / Data, Data
Everywhere . . . / Unwanted Precision / Picking and
Choosing Data / Sociology Influences Science / The
Principle of Relativity / Conservation of Energy / Heat Is
Energy / Unification of the Sciences

71

4

FATIH IN AN ORDERED UNIVERSE

Certainty and/or Knowledge? / The Sign of the Time / Carnot's
Imaginary Engine / The Birth of Uncertainty / A Mal du Siècle
Over the Fin de Siècle / Causality in Quantum Physics / The
Image of Light / Quantum Effects and the Corsican Brothers

105

5

SPEAKING REALISTICALLY ABOUT SCIENCE

Let's Have a Reality Sandwich / Atoms in Antiquity / Doubts
About Atomic Reality / Positive Thinking / A Mach Attack /
Planck Converts to Atomism / Atomic Vindication / On Mach's
Philosophical Heirs / Boredom Relieved, Momentarily /
Scientific Realism / Scientific Antirealism / The Social Side of
Science / Antirealism and Scientific Practice / The Chic of
Antirealism: Postmodernism / The Two Cultures / Some Very
Modern Postmodernists / Back to Reality

129

6

THE REASONABLE EFFECTIVENESS OF MATHEMATICS IN PHYSICS

Mathematics and Physics / Pythagoras's Preestablished Harmony /
Newton, Einstein, and Minkowski's Dream / Kant, Geometry, and

the Cognitive Status of Science / The "Right" Sort of Statement /
 Non-Euclidean Geometries and Euclidean Prisons / Poincaré, The
 Origins of Geometry, and the Boundaries of Thought / Testing
 Geometry / Twentieth-Century Atomism, The Platonic Turn /
 Can Physics Generate Mathematics? Minkowski in Reverse

177

7

SCIENTIFIC PROGRESS AND METAPHORS

The Pervasiveness of Metaphors / The Interaction View of
 Metaphor / Metaphors and Models of Scientific Thought /
 Metaphor and the Emergence of Scientific Knowledge /
 Meaning and Antirealism / Language and Realism / Relativism
 in Language and Science / Metaphors, Language, and Realism /
 At a Loss for Words / Metaphors and Analogies in Particle
 Physics / Do Scientists Actually Use Metaphors? / A Platonic
 Interlude / Another Nobel Prize Metaphor / Metaphors and
 Scientific Progress / Why Did Physics Develop As It Did? /
 How Science Advances

217

8

VISUAL IMAGERY IN SCIENTIFIC THOUGHT

Some Background to Mental Imagery / Visual Imagery and
 Computational Psychology: A Study in Architecture / The
 Imagery Debate / A Model of Mental Processing and Its Critics
 / Vision / Gestalt Psychology and Vision / The Present Status
 of the Imagery Debate / The Misuse of Language in Visual
 Imagery / Thought Experiments / Visual Imagery, Cognitive
 Science, and the History of Scientific Thought / The History
 of Science and the Imagery Debate

263

9

SCIENTIFIC CREATIVITY

Creativity and Digital Thought / Creativity and Analog
 Thought / A Model for Network Thinking / Why Poincaré and

Einstein? / Poincaré and Edouard Toulouse / Portrait of the
 Mathematician / The Scientific Creativity of Henri Poincaré /
 Poincaré and Creativity Research Circa 1900 / Intuition and
 Logic / Poincaré on Intuition, Aesthetics, and Mental Imagery /
 Poincaré Introspects / Four-Dimensional Aesthetics / Poincaré
 and Relativity / Einstein and Max Wertheimer / A Portrait of the
 Physicist as a Young Man / Einstein in Love / The Creativity of
 Albert Einstein / Einstein Introspects on Intuition and Aesthetics /
 Aesthetics / Poincaré's and Einstein's Creative Thinking

325

10

ART, SCIENCE, AND THE HISTORY OF IDEAS

Aesthetics in Art and Science / One Person's Aesthetics and
 Intuition May Not Be Another's / Science as Aesthetics /
 Cubism and Quantum Mechanics / Physicists Re-Represent /
 Feynman Diagrams, Representation, and Gestalt Psychology /
 The Deeper Structure of Data / Art in the Twentieth Century /
 Picasso, Geometry, and Cubism: Relations Between
 Developments in Cubism and Science / Picasso, Braque, and
 Space / Cubism and Relativity / Figurative to Nonfigurative,
 Objects Disappear / Art Theory and Science Theory /
 Creativity in Art and Science / Searching for Reality

379

CONCLUSION: THE NEW SCIENCES

441

BIBLIOGRAPHY

447

INDEX

467