Introduction

Mircea Pitici

In the fourth annual volume of *The Best Writing on Mathematics* series, we present once again a collection of recent articles on various aspects related to mathematics. With few exceptions, these pieces were published in 2012. The relevant literature I surveyed to compile the selection is vast and spread over many publishing venues; strict limitation to the time frame offered by the calendar is not only unrealistic but also undesirable.

I thought up this series for the first time about nine years ago. Quite by chance, in a fancy, and convinced that such a series existed, I asked in a bookstore for the latest volume of *The Best Writing on Mathematics*. To my puzzlement, I learned that the book I wanted did not exist—and the remote idea that I might do it one day was born timidly in my mind, only to be overwhelmed, over the ensuing few years, by unusual adversity, hardship, and misadventures. But when the right opportunity appeared, I was prepared for it; the result is in your hands.

Mathematicians are mavericks—inventors and explorers of sorts; they create new things and discover novel ways of looking at old things; they believe things hard to believe, and question what seems to be obvious. Mathematicians also disrupt patterns of entrenched thinking; their work concerns vast streams of physical and mental phenomena from which they pick the proportions that make up a customized blend of abstractions, glued by tight reasoning and augmented with clues glanced from the natural universe. This amalgam differs from one mathematician to another; it is "purer" or "less pure," depending on how little or how much "application" it contains; it is also changeable, flexible, and adaptable, reflecting (or reacting to) the social intercourse of ideas that influences each of us.

When we talk about mathematics, or when we teach it, or when
we write about it, many of us feign detachment. It is almost a cultural
universal to pretend that mathematics is "out there," independent of
our whims and oddities. But doing mathematics and talking or writing
about it are activities neither neutral nor innocent; we can only do them
if we are engaged, and the engagement marks not only us (as thinkers
and experimenters) but also those who watch us, listen to us, and think
with us. Thus mathematics always requires full participation; without
genuine involvement, there is no mathematics.

Mathematicians are also tinkerers—as all innovators are. They try,
and often succeed, in creating effective tools that guide our minds in
the search for certainties. Or they err; they make judgment mishaps or
are seduced by the illusion of infallibility. Sometimes mathematicians
detect the errors themselves; occasionally, others point out the prob-
lems. In any case, the edifice mathematicians build should be up for
scrutiny, either by peers or by outsiders.

And here comes a peculiar aspect that distinguishes mathemat-
ics among other intellectual domains: Mathematicians seek validation
inside their discipline and community but feel little need (if any) for
validation coming from outside. This professional chasm surrounding
much of the mathematics profession is inevitable up to a point because
of the nature of the discipline. It is a Janus-faced curse of the ivory
tower, and it is unfortunate if we ignore it. On the contrary, I believe
that we should address it. Seeking the meaning and the palpable reason-
ing underlying every piece of mathematics, as well as conveying them
in natural language, are means that bridge at least part of the gap that
separates theoretical mathematics from the general public; such means
demythologize the widespread belief that higher mathematics is, by its
epistemic status and technical difficulty, inaccessible to the layperson.

Mathematics and its applications are scrutable only as far as math-
ematicians are explicit with their own assumptions, claims, results, and
interpretations. When these elements of openness are missing math-
ematicians not only fail to disrupt patterns of entrenched thinking but
also run the risk of digging themselves new trenches. Writing about
mathematics offers freedoms of explanation that complement the dense
texture of meaning captured by mathematical symbols.

Talking plainly about mathematics also has inestimable educational
and social value. A sign of a mature mind is the ability to hold at the

same time opposite ideas and to juggle with them, analyze them, refine them, corroborate them, compromise with them, and choose among them. Such intellectual dexterity has moral and practical consequences, for the lives of the individuals as well as for the life of society. Mathematical thinking is eminently endowed to prepare the mind for these habits, but we almost never pay attention to this aspect, we rarely notice it, and we seldom talk about it. We use contradiction as a trick of the (mathematical) trade and as a routine method of proof. Yet opposing ideas, contrasts, and complementary qualities are intimately interwoven into the texture of mathematics, from definitions and elementary notions to highly specialized mathematical practice; we use them implicitly, tacitly, all the time.

As a reader of this book, you will have a rewarding task in identifying in the contributions some of the virtues I attribute to writing about mathematics—and perhaps many others. With each volume in this series, I put together a book I like to read, the book I did not find in the bookstore years ago. If I include a contribution here, it does not mean that I necessarily concur in the opinions expressed in it. Whether we agree or disagree with other people's views, our polemics gain in substance if we aim to comprehend and address the highest quality of the opposing arguments.

Overview of the Volume

In a sweeping panoramic view of the likely future trajectory of mathematics, Philip Davis asks pertinent questions that illuminate some of the myriad links connecting mathematics to its applications and to other practical domains and offers informed speculations on the multifaceted mathematical imprint on our ever more digitized world.

Ian Stewart explains recent attempts made by mathematicians to refine and reaffirm a theory first formulated by Alan Turing, stating, in its most general formulation, that pattern formation is a consequence of symmetry breaking.

Terence Tao observes that many complex systems seem to be governed by universal principles independent of the laws that govern the interaction between their components; he then surveys various aspects of several well-studied mathematical laws that characterize phenomena as diverse as spectral lines of chemical elements, political elections,

celestial mechanics, economic changes, phase transitions of physical materials, the distribution of prime numbers, and others.

A diversity of contexts, with primary focus on social networking, is also Gregory Goth's object of attention; in his article he examines the "small-world" problem—the quest to determine the likelihood that two individuals randomly chosen from a large group know each other.

Charles Seife argues that humans' evolutionary heritage, cultural mores, and acquired preconceptions equip us poorly for expecting and experiencing randomness; yet, in an echo of Tao's contribution, Seife observes that in aggregate, randomness of many independent events does obey immutable mathematical rules.

Writing from experience, Donald Knuth shows that the deliberate and methodical coopting of randomness into creative acts enhances the beauty and the originality of the result.

Soren Johnson discusses the advantages and the pitfalls of using chance in designing games and gives examples illustrative of this perspective.

John Pavlus details the history, the meaning, and the implications of the P versus NP problem that underpins the foundations of computational complexity theory and mentions the many interdisciplinary areas that are connected through it.

Renan Gross analyzes the geometry of the Jerusalem Chords Bridge and relates it to the mathematics used half a century ago by the French mathematical engineer Pierre Bézier in car designs—an elegantly simple subject that has many other applications.

Daniel Silver presents Albrecht Dürer's *Painter's Manual* as a precursor work to projective geometry and astronomy; he details some of the mathematics in the treaty and in Dürer's artworks, as well as the biographical elements that contributed to Dürer's interaction with mathematics.

Kelly Delp writes about the late William Thurston's little-known but intensely absorbing collaboration with the fashion designer Dai Fujiwara and his Issey Mayake team; she describes the topological notions that, surprisingly, turned out to be at the confluence of intellectual passions harbored by two people so different in background and living on opposite sides of the world.

Fiona and William Ross tell the brief history of Jordan's curve theorem, hint at some tricky cases that defy the simplistic intuition behind

it, and, most remarkably, illustrate the nonobvious character of the theorem with arresting drawings penned by Fiona Ross.

To answer pressing questions about the need for widespread mathematics education, Anna Sfard sees mathematics as a narrative means to comprehend the world, which we humans developed for our convenience; she follows up on this perspective by arguing that the story we tell (and teach) with mathematics needs to change, in sync with the unprecedented changes of our world.

Erin A. Maloney and Sian L. Beilock examine the practical and psychological consequences of states of anxiety toward mathematical activities. They contend that such feelings appear early in schooling and tend to recur in subsequent years, have a dual cognitive and social basis, and negatively affect cognitive performance. The authors affirm that the negative effect of mathematical anxiety can be alleviated by certain deliberate practices, for instance by writing about the emotions that cause anxiety.

David R. Lloyd reviews arguments put forward by proponents of the idea that the five regular polyhedral shapes were well known, as mathematical objects, perhaps one millennium before Plato—in Scotland, where objects of similar configurations and markings have been discovered. He concludes that the objects, genuine and valuable aesthetically and anthropologically, do not substantiate the revisionist claims at least as far as in the mathematical knowledge they reveal.

In the interaction between the material culture of mathematical instruments and the mathematics that underlined it from the 16th to the 18th centuries in Western Europe, Jim Bennett decodes subtle reciprocal influences that put mathematics in a nodal position of a network of applied sciences, scientific practices, institutional academics, entrepreneurship, and commerce.

Frank Quinn contrasts the main features of mathematics before and after the profound transformations that took place at the core of the discipline roughly around the turn of the 19th century; he contends that the unrecognized magnitude of those changes led to some current fault lines (for instance between teaching and research needs in universities, between school mathematics and higher level mathematics, and others) and in the future might even marginalize mathematics.

Prakash Gorroochurn surveys a collection of chance and statistics problems that confused some of the brilliant mathematical minds of the

past few centuries and initially were given erroneous solutions—but had an important historical role in clarifying fine distinctions between the theoretical notions involved.

Elie Ayache makes the logical-philosophical case that the prices reached by traders in the marketplace take precedence over the intellectual speculations intended to justify and to predict them; therefore, the contingency of number prices supersedes the calculus of probabilities meant to model it, not the other way around.

Finally, Kevin Hartnett reports on recent developments related to the *abc* conjecture, a number theory result that, if indeed proven, will have widespread implications for several branches of mathematics.

Other Notable Writings

This section of the introduction is intended for readers who want to read more about mathematics. Most of the recent books I mention here are nontechnical. I offer leads that can easily become paths to research on various aspects of mathematics. The list that follows is not exhaustive, of course—and I omit titles that appear elsewhere in this volume.

Every year I start by mentioning an outstanding recent work; this time is no exception. The reader interested in the multitude of modalities available for conveying data (using graphs, charts, and other visual means) may relish the monumental encyclopedic work *Information Graphics* by Sandra Rendgen and Julius Wiedemann.

An intriguing collection of essays on connections between mathematics and the narrative is *Circles Disturbed*, edited by Apostolos Doxiadis and Barry Mazur. Another collection of essays, more technical but still accessible in part to a general readership, is *Math Unlimited*, edited by R. Sujatha and colleagues; it explores the relationship of mathematics with some of its many applications.

Among the ever more numerous popular books on mathematics I mention Steven Strogatz's *The Joy of X*, Ian Stewart's *In Pursuit of the Unknown*, Dana Mackenzie's *The Universe in Zero Words*, Jeffrey Bennett's *Math for Life*, Lawrence Weinstein's *Guesstimation 2.0*, Norbert Hermann's *The Beauty of Everyday Mathematics*, Keith Devlin's *Introduction to Mathematical Thinking* and Leonard Wapner's *Unexpected Expectations*. Two successful older books that see new editions are *Damned Lies and Statistics* by Joel Best and *News and Numbers* by Victor Cohn and

Lewis Cope. An eminently readable introduction to irrational numbers is appropriately called *The Irrationals,* authored by Julian Havil. A much needed book on mathematics on the wide screen is *Math Goes to the Movies* by Burkard Polster and Marty Ross.

Two venerable philosophers of science and mathematics have their decades-long collections of short pieces republished in anthologies: Hilary Putnam in *Philosophy in an Age of Science* and Philip Kitcher in *Preludes to Pragmatism.* Other recent books in the philosophy of mathematics are *Logic and Knowledge* edited by Carlo Cellucci, Emily Grosholz, and Emiliano Ippoloti; *Introduction to Mathematical Thinking* by Keith Devlin; *From Foundations to the Philosophy of Mathematics* by Joan Roselló; *Geometric Possibility* by Gordon Belot; and *Mathematics and Scientific Representation* by Christopher Pincock. Among many works of broader philosophical scope that take mnemonic inspiration from mathematics, I mention *Spinoza's Geometry of Power* by Valtteri Viljanen, *The Geometry of Desert* by Shelly Kagan, and *The Politics of Logic* by Paul Livingston. Two volumes commemorating past logicians are *Gödel's Way* by Gregori Chaitin and his collaborators, and *Hao Wang* edited by Charles Persons and Montgomery Link. And a compendious third edition of Michael Clark's *Paradoxes from A to Z* has just become available.

In the history of mathematics, a few books focus on particular epochs—for instance, the massive *History of Mathematical Proof in Ancient Traditions* edited by Karine Chemla and the concise *History of the History of Mathematics* edited by Benjamin Wardhaugh; on the works and the biography of important mathematicians, as in *Henri Poincaré* by Jeremy Gray, *Interpreting Newton,* edited by Andrew Janiak and Eric Schliesser, *The King of Infinite Space* [Euclid] by David Berlinski, and *The Cult of Pythagoras* by Alberto Martínez; on branches of mathematics, for example *The Tangled Origins of the Leibnizian Calculus* by Richard Brown, *Calculus and Its Origins* by Richard Perkins, and *Elliptic Tales* by Avner Ash and Robert Gross; or on mathematical word problems, as in *Mathematical Expeditions* by Frank Swetz. An anthology rich in examples of popular writings on mathematics chosen from several centuries is *Wealth in Numbers* edited by Benjamin Wardhaugh. Two collections of insightful historical episodes are Israel Kleiner's *Excursions in the History of Mathematics* and Alexander Ostermann's *Geometry by Its History.* And an intriguing attempt to induce mathematical rigor in historical-religious controversies is *Proving History* by Richard Carrier.

The books on mathematics education published every year are too many to attempt a comprehensive survey; I only mention the few that came to my attention. In the excellent series *Developing Essential Understanding* of the National Council of Teachers of Mathematics, two recent substantial brochures written by Nathalie Sinclair, David Pimm, and Melanie Skelin focus on middle school and high school geometry. Also at the NCTM are *Strength in Numbers* by Ilana Horn; an anthology of articles previously published in *Mathematics Teacher* edited by Sarah Kasten and Jill Newton; and *Teaching Mathematics for Social Justice,* edited by Anita Wager and David Stinson. Other books on equity are *Building Mathematics Learning Communities* by Erika Walker and *Towards Equity in Mathematics Education* edited by Helen Forgasz and Ferdinand Rivera. In a niche of self-help books I would include Danica McKellar's *Girls Get Curves* and Colin Pask's *Math for the Frightened*. A detailed ethnomathematics study is Geoffrey Saxe's *Cultural Development of Mathematical Ideas* [in Papua New Guinea]. And a second volume on *The Mathematics Education of Teachers* was recently issued jointly by the American Mathematical Society and the Mathematical Association of America.

In a group I would loosely call applications of mathematics and connections with other disciplines, notable are *Fractal Architecture* by James Harris, *Mathematical Excursions to the World's Great Buildings* by Alexander Hahn, *Proving Darwin* by Gregory Chaitin, *Visualizing Time* by Graham Wills, *Evolution by the Numbers* by James Wynn, and *Mathematics and Modern Art* edited by Claude Bruter. Slightly technical but still widely accessible are *Introduction to Mathematical Sociology* by Phillip Bonacich and Philip Lu, *The Essentials of Statistics* [for social research] by Joseph Healey, and *Ways of Thinking, Ways of Seeing* edited by Chris Bissell and Chris Dillon. More technical are *The Science of Cities and Regions* by Alan Wills, and *Optimization* by Jan Brinkhuis and Vladimir Tikhomirov.

I conclude by suggesting a few interesting websites. "Videos about numbers & stuff" is the deceptively self-deprecating subtitle of the Numberphile (http://www.numberphile.com/) page, hosting many instructive short videos on simple and not-so-simple mathematical topics. A blog that keeps current with technology that helps teaching mathematics is Mathematics and Multimedia (http://mathandmultimedia.com/); also a well-done educational site is Enrich Mathematics (http://nrich.maths.org/frontpage) hosted by Cambridge University.

Two popular sites for exchanging ideas and asking and answering questions are the Math Overflow (http://mathoverflow.net/) and the Mathematics StackExchange (http://math.stackexchange.com/). The Parameterized Complexity (http://fpt.wikidot.com/) page offers a useful forum of information and instruction for those interested in mathematical connections to computing, psychology, and cognitive sciences. A brief history of mathematics is available on the Story of Mathematics (http://www.storyofmathematics.com/index.html) site. Many institutions host a wealth of materials on their internet sites; I mention here the Harvey Mudd College (http://www.math.hmc.edu /funfacts/), the Clay Mathematics Institute (http://www.claymath.org /index.php), and the Cornell Mathematics Library (http://mathematics .library.cornell.edu/).

I hope you, the reader, find the same value and excitement in reading the texts in this volume as I found while searching, reading, and selecting them. For comments on this book and to suggest materials for consideration in preparing future volumes, I encourage you to send correspondence to me at Mircea Pitici, P.O. Box 4671, Ithaca, NY 14852.

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