SCIENTISTS' Nightstand

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Steven Nadler and Ben Nadler, 2017. Courtesy of Princeton University Press.

Adventures in a Less Fretful Cosmos: A Conversation with Brian Hayes

Dianne Timblin

Brian Hayes and mathematics go way back. As he notes in Foolproof, and Other Mathematical Meditations, *forthcoming in September, his first job out of high school involved hand-drawing the scales on electrical instruments, such as ammeters and voltmeters. He marked certain points according to technicians' calibrations; then he used interpolation to fill in intermediate points. (Yes, Hayes confesses, "I was a teenage angle trisector.") He joked with his supervisor about trisection, declaring, "We should get extra pay . . . for solving one of the famous unsolvable problems of antiquity." His supervisor, an amiable skeptic, doubted that accurate trisection was impossible—so in his spare time, Hayes outlined a proof. Although management remained unconvinced, Hayes, undeterred, has been exploring mathematics ever since.*

Hayes and American Scientist *go way back too. During the early 1990s he was the magazine's editor, and for more than two decades he authored* American Scientist's Computing Science *column, building a cult following with his penetrating, playful, finely wrought essays. He continues as the magazine's senior contributing writer while also working on a host of other projects. I was eager to talk with him about* Foolproof; *an excerpt from our conversation follows.*

One thing I enjoy about your writing is its scope: Your next topic could be anything from neuroscience to segregation to climate modeling. You've written previous books on mathematics and infrastructure. With *Foolproof*, you return to math. What drew you back?

I'm lucky to have wandered into a way of life that allows me to roam through all the sciences. I find fascinating stories in every corner. But mathematics does seem special. As "handmaiden of the sciences," it's a tool for making sense of the world we live in, but math also opens up a world of its own, where the objects of study have no necessary connection with the physical universe. The number 19 will always be a prime, no matter who is in the White House; 25 will be a square even when the Sun expires. Bertrand Russell called this mathematical realm "a less fretful cosmos," and I like to spend a little time there every day if I can.

The essays collected in *Foolproof* began as *Computing Science* columns in this magazine. How did you pick your favorites, and what changed when you transformed them into a collection?

An opportunity to revise is a great luxury. There's always something that needs correcting or improving. And it's not just a matter of my own second thoughts. Many of the most important changes and additions start with letters from readers. (*American Scientist* readers are the world's best in this respect.)

Some of the pieces needed serious updating. For example, a column from 1998 discusses self-avoiding walks: Think of tracing a route through a grid of city streets, with the rule that you never retrace your steps or cross your own path. The small community of people working in that field have made a lot of progress in the past 20 years, so this was a chance for me to learn new algorithms, rewrite a major section of the text, and create some new illustrations.

As for choosing which columns to include, I approached it like a greatest-hits album: You pick the best ones. (I also have a list of greatest flops, but I'm not going to publish those.) I would add that some magazine writing has a limited shelf life. In 2009 I wrote a column whining about the difficulty of displaying mathematical notation on the web. That problem was soon solved by a program called MathJax, so the column is of no ongoing interest.

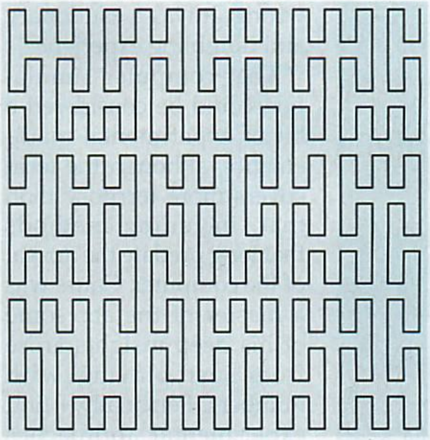
In your essay "Young Gauss Sums It Up," you examined more than 100 versions of a famous anecdote about how, as a schoolboy, Carl Friedrich Gauss solved a cumbersome mathematical problem. How did reader feedback change your approach in the updated version of the essay?

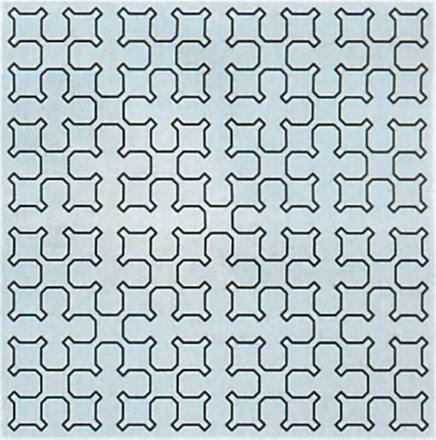
That story was very much a collaborative effort, and for me it's been a grand adventure.

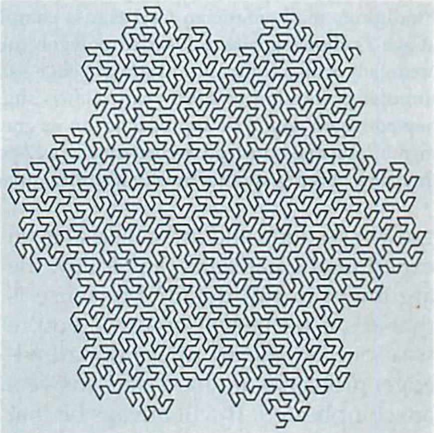
When I started work on it for the *American Scientist* column, sometime in 2005, I prowled library stacks looking for versions of the anecdote. According to my notes, I visited 18 libraries in cities all up and down the East Coast, plus one more in Natchitoches, Louisiana. Friends further afield—especially in Germany—tracked down a few more items for me. (Incidentally, I have always welcomed any excuse to go to the library; it allows me to feel I'm being diligent and productive without actually having to write anything.)

After the column was published, I received a deluge of new leads, both from old friends and from readers I had never met. Most of that new material was found on the internet. Some of those volunteers proved to be very creative in searching Google Books and other online archives. By the time I began revising the manuscript for publication in book form, I had about 50 new examples. Furthermore, several of those tellings of the story were crucial early publications.

Having digitized text available online has made a huge difference in this kind of scholarship. It's not just a matter of convenience—of not having to travel to New York or Boston or Natchitoches to find a volume on the shelves. What's more important is that the text is searchable. If you can formulate the right query, you can find anecdotes about Gauss in books you never knew existed.







From *Foolproof*, by Brian Hayes, 2017, MIT Press. Images courtesy of the author.

In a chapter called "Crinkly Curves," Brian Hayes discusses *space-filling curves*, pathways so twisty and tortuous that they eventually touch every point in an area of the plane. In 1890, Giuseppe Peano proposed the first space-filling curve (*above*), dividing a square into nine smaller squares, each containing the same pattern of perpendicularly connected line segments. Waclaw Sierpiński developed a curve in 1912 (*above, right*) that fills a square by repeating a pattern fitted to triangular subdivisions. Bill Gosper introduced the *flowsnake* pattern at right in the 1970s; it breaks out of the box, so to speak, by filling a roughly hexagonal space. From *Foolproof*.

The discovery of all this new material has changed my understanding of how the story has been passed down to us. There's a sinister aspect I never would have guessed. The first telling of the story—and the ultimate source of all the others—was a rather obscure memorial volume written by a colleague of Gauss's shortly after his death in 1855. In my first survey of the literature I found only a few other accounts until well into the 20th century, but now I have several more links in the chain of transmission.

The sinister part is that some of them appear in works that have an anti-Semitic slant. For example, one telling features in an 1894 collection of essays on "the German Jewish question and the reform of German universities." As far as I can tell, Gauss himself never expressed anti-Semitic sentiments, and he was on friendly terms with Jewish colleagues. He got mixed up in this ugly business long after his death, when racist propagandists offered him up as a "pure" German genius. It's a strange detour for a story we now tell to schoolchildren.

In your book's title essay, you discuss how mathematicians grapple with proofs so complex that they may take many years to confirm. You mention that the traditional approach to proof now coexists with *experimental mathematics*. What is the difference?

Yes, mathematics has had some famous problems that stood unsolved for centuries: *Fermat's last theorem* (about the equation $x^n + y^n = z^n$), the *Kepler conjecture* (about stacking spheres), and the *four-color theorem* (about coloring countries on a map). And once someone comes up with a proof, checking its correctness often turns out to be another daunting task that can take years to settle. Right now several dozen mathematicians are struggling mightily to digest a huge purported proof of something called the *abc conjecture*, which connects the additive properties of numbers ($a + b = c$) with the multiplicative properties (the prime factors of a, b, and c). They've been going at it for five years and the end is not in sight.

Is this a crisis? Is the whole enterprise of mathematics going to bog down or stall out because proofs are

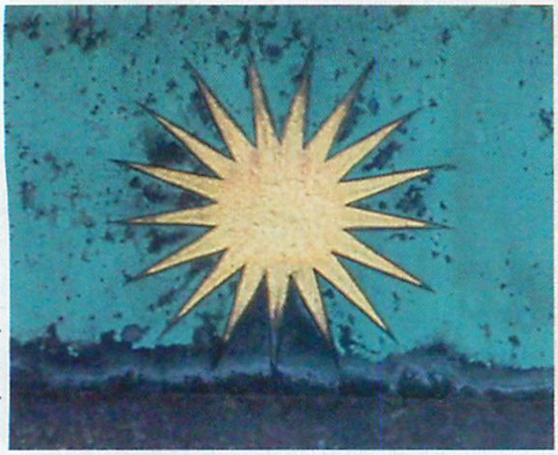


Photo by Brunswyk, Wikimedia Commons

Prodigious mathematician Carl Gauss completed a proof at age 19 showing how a 17-sided polygon could be drawn accurately with a compass and straight edge—the first breakthrough of its kind in 2,000 years. Gauss suggested that a heptadecagon would be appropriate for his gravestone, but a memorial statue is instead decorated with a 17-point star. How this came about is another murky historical question.

growing so long and intricate that even expert mathematicians can't follow the argument in full detail? My sense is that it's a perpetual crisis. If you're way out on the frontiers of knowledge, problems are hard and answers are complicated. It will always be that way. We might as well get used to it. Anyway, it's not the proofs of deep, breakthrough theorems that concern me; they get plenty of scrutiny.

In everyday life people don't often frame their thoughts in terms of stating and proving theorems, but we all use mathematical tools to answer questions and solve problems. When you're working on the Sudoku puzzle in the daily newspaper, you might persuade yourself that a certain cell can only correctly contain the number 3. If your reasoning is sound, then you have just proved a theorem! The trouble is, getting proofs correct can be a very ticklish business. I, for one, have an embarrassing record of clumsy mistakes.

What inspired me to write that essay was a little problem in probability theory. For two years in a row the baseball World Series was won in a clean sweep—four games to none. "What are the odds of that?" I wondered. So I tried to work it out and got a certain answer. Then I tried another method and came up with a different number. And then a third answer. Finally, I wrote a small computer program to simulate the contest, and with the computer results in hand I eventually figured out which of my analyses was correct and where the others went wrong. It was a cautionary and humbling experience.

That computer simulation could be considered a bit of experimental mathematics, although the term covers more territory than that, including methods that long predate the arrival of the computer. Gauss was a master of the art; some of his deep insights arose from just playing with numbers. Personally, I find experimental approaches suit my habits of thought and help cover up some of my deficiencies. But no one in mathematics believes they will ever push proof off the pedestal.

Proof is a big part of what distinguishes mathematics from other scientific pursuits. In physics or biology you don't prove that a hypothesis is true; you merely run experiments that fail to prove the hypothesis is false. In mathematics we can make positive assertions of truth. In an era of "alternative facts," it's comforting to have at least a little corner of the universe that offers that kind of certainty.

Of Atoms and Anvils

HERETICS! The Wondrous (and Dangerous) Beginnings of Modern Philosophy. Steven Nadler and Ben Nadler. 184 pp. Princeton University Press, 2017. $22.95.

What do the contentious treatises penned by a passel of 17th-century European philosophers have to do with how science is practiced in the 21st century? Much more than you might think.

At a glance, the disciplines of philosophy and science may not seem to impinge much on one another: Today, their most significant intersection is ethics. But in the West, science and philosophy were originally conjoined. The term *philosophy* sprang up around 1300 CE to refer to bodies of knowledge; for a time, the boundaries between disciplines remained indistinct. Eventually, the phrase *natural philosophy* emerged to represent study of the material realm—that is, any item, phenomenon, creature, or effect that is observable, whether it's a spruce needle, a lightning bolt, a hedgehog, or the trajectory of a breeze. Only in the late 16th century did the term begin to represent a specific discipline; even then, connections remained between scientific investigation and philosophic inquiry.

So before science was called *science* (a term that didn't take on its contemporary meaning until the 1800s), it was called *natural philosophy*, and the 17th century was its adolescence. These were the formative years of the Scientific Revolution, a movement that, in its turn, strongly influenced the Enlightenment. European scholars began to lay out foundational theories as part of a wider effort to grasp the basics of existence itself. In so doing, they generated theories that still inform our notions of what science is, what science isn't, the role of science, and how scientists ought to regard their work.

A critical part of the process was the exchange of ideas among scholars: As they read one another's books and shared manuscripts, scholars attached themselves to the ideas they agreed with, argued against and rejected those they disagreed with, and added their own ideas to the mix. The progression was heady, contentious, and far from linear.

In *Heretics!*, philosophy professor Steven Nadler and his son, illustrator Ben Nadler, remind readers of the vital connection between these 17th-century thinkers and how we continue to view science and its intersections with other fields. Their entertaining and thoughtful account of the European philosophical scene circa 1600–1703 presents a parade of philosophers—from Galileo Galilei, Francis Bacon, and René Descartes to Blaise Pascal, Robert Boyle, and Isaac Newton—as they exchange ideas, navigate alliances, and engage in scholarly feuds.

The Nadlers tell this story in graphic-novel style, and it's a winsome approach. The book aims to present and contextualize a century's worth of thought experiments about the properties and interactions of the cosmos, God, the human mind, the human body, and natural phenomena. No small task. By associating these ideas with distinct personalities and placing those personalities in conversation, the author and illustrator make their topic highly engaging while retaining sufficient complexity. They also take