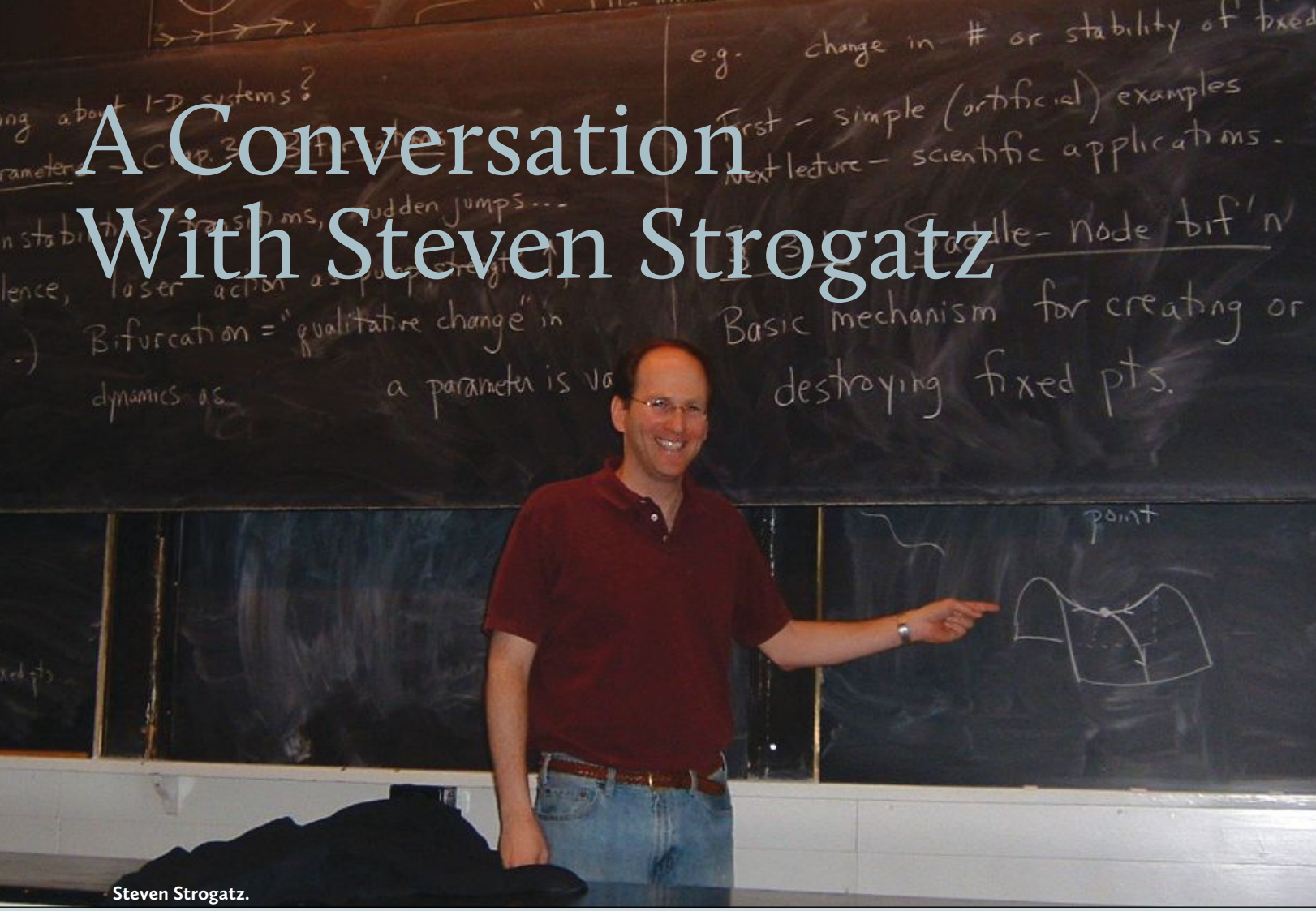
A Conversation With Steven Strogatz



Steven Strogatz.

Patrick Honner

For a mathematician, Steven Strogatz really gets around. Whether it's his popular *New York Times* series, his highly regarded books, his numerous appearances on RadioLab, or his frequent public lectures, Strogatz is out there, spreading the word about the wonders of mathematics. And the mathematical community could not have a better ambassador.

Steven Strogatz is the Jacob Gould Schurman Professor of Applied Mathematics at Cornell University. He studied at Princeton, Cambridge, and Harvard and taught at MIT before moving to Cornell in 1994. He is a renowned teacher and one of the world's most highly cited mathematicians. His honors include a Presidential Young Investigator Award, MIT's highest teaching prize, a lifetime achievement award for the communication of mathematics to the general public, and membership in the American Academy of Arts and Sciences. He is the author of several books, including *Nonlinear Dynamics and Chaos*; *Sync*; *The Calculus of Friendship*; and his latest, *The Joy of x*, which won the MAA's 2014 Euler Book Prize.

On top of being a prolific mathematician, author, and science communicator, Strogatz is a fun person to chat with. He recently took some time from his busy schedule to talk about mathematics, technology, education, and everything in between with Patrick Honner, a math teacher at Brooklyn Technical High School.

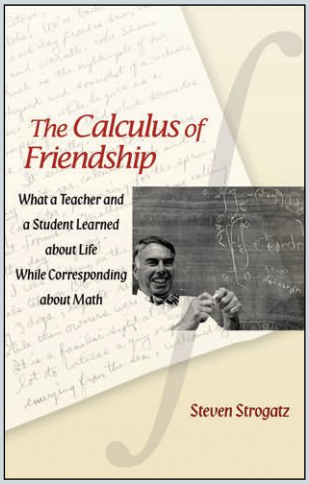
Patrick Honner: What kind of mathematician are you?
Steven Strogatz: I'm an applied mathematician. I work in differential equations, dynamical systems, and network theory, and I apply these and other mathematical ideas in a wide range of areas, like physics, biology, and the social sciences.
PH: You've recently taught differential equations and complex analysis at Cornell. What else do you teach?
SS: I teach all the way up and down the curriculum, from courses for freshmen to advanced graduate courses.

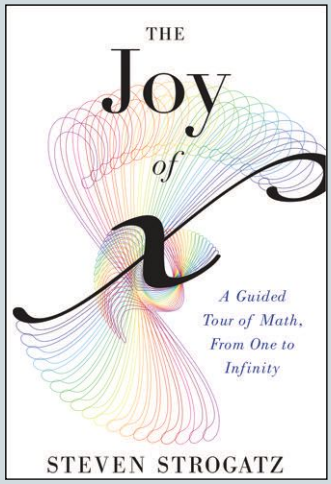
PH: What's your favorite course to teach?
SS: I like differential equations very much. It's got a lot of mathematical substance, a lot of great applications, and the people who take it are usually pretty into math. It's often sophomores, juniors, or whiz kid freshmen who are seriously interested in math and its applications. There's something for everyone in this course—but there is in all of math if it's approached the right way.
PH: You basically have a second successful career as a writer. How do you find the time and energy to do both things?
SS: It is hard to find time. I don't write at all times. Sometimes I have a writing project, and other times I'm recuperating from a writing project.

On the days that I'm writing a column for the *New York Times* or working on a book, I have a system. I force myself to keep my mornings open during the week as much as I can, because I write best in the morning. So for a few hours, say from nine o'clock to lunchtime, I won't check my email, I won't answer my phone, and I'll go to a place where people can't find me—like a library or up in my attic where the phone doesn't work.

And then I don't expect to do very much. In those three hours, I'm just going to fool around. I have to tell myself "I'm going to produce garbage," because if I tell myself "I'm going to produce something good," it feels very stressful, and I often can't do anything.
PH: Have you always thought of yourself as a writer? Did you write as a young person?
SS: I didn't see myself as a writer then, and I still don't now. I often smile when people act like I'm a writer, because I don't think I know exactly what I'm doing. In high school I certainly didn't understand how to write very well.

But there was one teacher who made a big difference: Mrs. Archibald. She used to write detailed corrections on my paper in red ink. It was so concrete and specific; I learned so much from her so quickly. I would take courses from her that I wasn't interested in, just because she was teaching them.
PH: Do you see writing and teaching as similar? Was writing *The Joy of x* like teaching? Or was it just writing? You're doing both, I guess.
SS: It's all teaching. The writing I like to do, at least in *The Joy of x*, is exactly what I think of as teaching.





I imagined the readers as my students.

David Shipley, the editor for my *New York Times* series, told me to think about readers like him: people who are well educated and curious and smart, but who aren't comfortable with math and never saw the point of what they learned in high school. So that series in the *New York Times*, which ultimately became *The Joy of x*, was writing in the service of teaching.
PH: Your friendship with Alan Alda has had a profound impact on your writing career. He famously played a role in the writing of *The Joy of x*, right?
SS: Right. When I had to visualize the reader, I would visualize Alan, because we had been through this many times.

> One of the great mistakes that a lot of teachers make is that they think, "I need to cover this material" instead of "I need to help this person who is my friend."

When we get together, Alan likes to talk about science. He hardly wants to talk about anything else. He wants to hear about the latest developments in the world of science. He's very knowledgeable and well read on science, but when it comes to math, he always feels like he doesn't have anything to say. He wants to understand math, but he doesn't have the background. So I try to guide him through things like Euclid's proof that there are infinitely many primes.

Having had this experience of talking about math with a dear friend who doesn't have a good math background, I realized that that's how I should approach the reader. If you think of the reader as a friend, you instinctively do everything right as a teacher. You won't be condescending. You won't assume things that the person doesn't know, because you're being sensitive. This is someone you care about. So you try to

Steven Strogatz, left, with Alan Alda.

anticipate what their questions could be. I like to think about all my teaching that way.

One of the great mistakes that a lot of teachers make is that they think, "I need to cover this material" instead of "I need to help this person who is my friend." In some sense, I sympathize: If there's a test at the end of the year, then you do have to cover a certain amount of material. You [as a high school teacher] know this better than I do.

PH: But teachers need to understand that, although they may teach a subject, ultimately they teach students.

SS: Yes, that's a very important difference.

PH: You're very active on Twitter [as @stevenstrogatz]. What do you like about it? What do you see as the potential for social networking in terms of teaching and science communication?

SS: I like Twitter a lot. I'm surprised at how much I like it. Twitter reminds me of my Uncle Jack. Uncle Jack was the kind of guy who would clip things out of the newspaper and mail them to me with a line on the top that said, "I saw this about nuclear energy. I thought you'd be interested."

PH: He was tweeting you links 40 years ago.

SS: Yeah, that's how it was done. On Twitter, I have 500 different clipping services: people suggesting things for me to read. If I follow the right people, it works. And likewise, I'm somebody else's clipping service.

There's also the conversation. It's been wonderful getting to know some teachers on Twitter—to plug in to what's going on in high schools and elementary schools. It feels like a community. We couldn't reach each other as easily otherwise. I get why they call it a social network: It *is* social.

PH: Speaking from the teacher side of things, being able to interact with mathematicians like you, John Allen Paulos, Edward Frenkel, and many others, is a powerful resource. We're sharing and getting ideas for the classroom.

SS: We have all of these different societies—for applied mathematicians, for research mathematicians, for college teachers, for high school teachers—but we're fractionalized. Twitter is a place where we can all come together.

PH: It also seems like there's been an upswing in quality science communication, and Twitter is a place you can find it.

SS: Yes, it is. It's the golden age of science communication. There used to be a time that if you wanted to read about math, it seemed like the only resources were Martin Gardner in *Scientific American* and Ivars Peterson in *Science News*. But now, every day there's good stuff to read, and there are a lot of great young writers writing for online magazines. I'm learning a lot; it's fantastic.

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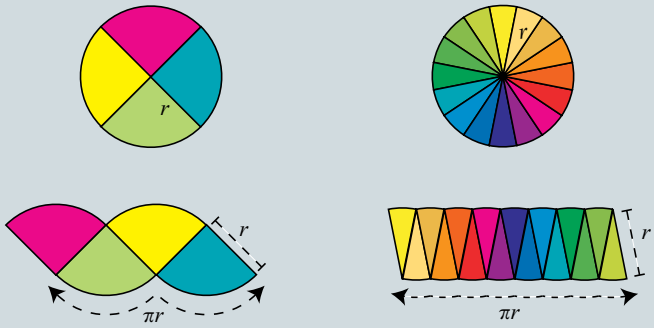
PH: You were recently quoted in a piece about the beauty of math. What's your go-to story to convince someone that math is beautiful?

SS: I usually show the argument about the area of a circle that goes back to Archimedes. By slicing the circle into lots of little sectors and rearranging them, you can make what looks like a rectangle [as illustrated in figure 1]. And in the limit, using infinitely thin sectors, it *is* a rectangle! I showed this in my *New York Times* piece "Take It to the Limit," and it got a very big reaction. That column made it to the number one most emailed.

It only takes about five minutes, but I've found



Margaret Nelson

Figure 1. Sectors of a circle converge to a *πr* by *r* rectangle.

that showing someone that proof almost invariably convinces them that math is beautiful and scintillating. It's just a great argument. There's a moment of revelation: It looks like the proof isn't going anywhere at first because you haven't used enough sectors. But once you draw enough, and it becomes clear this shape is converging to a rectangle, there's a big "Aha!" for most people.

PH: Is it important to spread the idea that math is beautiful?

SS: Yes, but there can be something off-putting about emphasizing the idea that math is beautiful. If you don't get it—if you don't see it yourself—you feel left out.

PH: It's like a clique.

SS: Yeah. It has the empathy problem that I'm always talking about. By emphasizing that math is beautiful, in a way you're not showing enough empathy because you're excluding the people who don't get it. Some people get a lot of satisfaction out of math, although they might not describe it as beautiful.

I think that's where my kids are. They don't see the beauty of math. But they do get the feeling of satisfaction when the numbers work out, or when they get the right answer. I was the same way as a kid. I wasn't aware that math was beautiful; that didn't occur to me. But it was very satisfying when you could get everything to work.

PH: So, math is beautiful; math is satisfying. What else?

SS: Math is real, in the sense that it describes what's happening in nature.

Math is useful, in that it can help you design and build things.

Math is true. There are many parts of life where you can't be sure, but in math you can be sure: You get the pleasure of having truth. It's good for people to be exposed to the idea that there are certainties, even if there are many uncertainties in real life.

Math is valuable, in the sense that it can help you in your career; it can help you get a good job. This isn't an argument I often make, but it's very important to many people. Math provides an opening to some of the most exciting and profitable careers a person can have.

Math is human. There's a great history of struggle and accomplishment. Anyone who likes history or human achievement or culture would like that part of math.

PH: The human stories of math are sadly absent from most math curricula.

SS: And this is closely tied in with math being creative. Math is a place where human inventiveness shines.

PH: Math is collaborative?

SS: Yeah, math is social. We're on to something good with this list we're making, aren't we? The fact that math is social would come as a surprise to the people who think of it as antisocial.

PH: It might also come as a surprise to some math teachers!

SS: It's extremely social. Mathematicians constantly spend time talking to each other about places where they're stuck. They get insights from each other, new ways of looking at things. Sometimes it's just to commiserate. That is the experience of a professional mathematician: being stuck most of the time. For many people it's an unpleasant aspect of doing math. It's very uncomfortable to be stuck.

PH: It's important for students to understand that being stuck is a natural part of doing math, but it can be hard to communicate that to them.

SS: So much of what we do in school is good citizenship exercises. If you follow this procedure, everything will work out. That's not what it's like to do math at the creative level. Being good and following rules is not enough. You have to have a spark or some inspiration.

PH: So what else is on this list? Social. Human. Creative. True. Fun?

SS: Fun! Of course fun should be there. I don't know how to say what is fun about it, but it is fun. It's fun for all the reasons we just listed.

To read more of this interview, see the *Aftermath* column on page 34 and the *Math Horizons* website *maa.org/publications/periodicals/math-horizons/math-horizons-supplements*. ■

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A conversation with Steven Strogatz (continued)
Patrick Honner

For the rest of the interview with Steven Strogatz see pages 8–11 and 34 of the February 2014 issue of *Math Horizons*.

Patrick Honner: Do you enjoy teaching entry-level calculus?

Steven Strogatz: Teaching calculus can be a little problematic because there's a lot of unlearning that has to happen. Many students have already taken calculus in high school and sometimes haven't done it right, or mislearned it.

On the other hand, with differential equations, it's usually the first time they've seen the material. And the students are sophisticated, but not too sophisticated so as to be jaded. So I find that it's sort of a sweet spot.

PH: What's your impression of today's college students? In what ways are they similar to you and your peers at that age? In what ways are they different?

SS: As in my day, there is still a clear cohort of students who like math and science. They take these advanced math courses because they match their interests and inclinations.

But I think there are also a lot of students who are in these classes who don't want to be there. Maybe it's due to the push for STEM and the talk about how we need so many millions of people with STEM degrees for the workforce.

PH: Maybe those students just think math and science are paths to a good job?

SS: Right. Or their parents think it's a way to make sure they get a good job after college.

PH: It's the new "doctor" or "lawyer" in some sense?

SS: Something like that. Also, other majors are requiring more math than they used to. For example, social sciences now feel that their students should take calculus, and premeds have to take calculus.

PH: Has technology fundamentally changed students?

SS: There are very noticeable changes. For example, the advent of graphing calculators has changed what students know and don't know.

PH: It sounds like you are about to say "for the better and for the worse."

SS: I don't know what I'm about to say: Let's just see what comes out!

Something that is noticeable to me is students' lack of familiarity with curve sketching. If I ask students to draw the graph of a function with a parameter in it, say $1/(x - a)$ for different values of a, many of them are crippled by it. And that's an easy one!

I find that familiarity with the basic shapes of graphs of functions—rational functions, exponentials, sines and cosines, the elementary functions—just isn't there. Students aren't as intimately familiar with them anymore because I think they're used to drawing graphs on their calculators.

There's a feeling that I get when students are trying to step through solving a problem, that each step is laborious, because each step has to be plugged in to a calculator. I think that students are weaker as a result of their reliance on it.

PH: On the other hand, calculators are a pretty fundamental part of mathematics at this point.

SS: In real life, I use calculators and computers all the time, and any applied math student or engineer should know how to do that. But just like you should memorize the multiplication table, I think you need to memorize the shapes of the graphs of simple functions. It's part of our vocabulary. Maybe this is just a question of age, and the next generation won't feel this way.

Like you said, there's better and worse. To me, my students are fantastically good at writing little scripts for handling data. I don't really know how to do that. I'm from a generation where FORTRAN was our computer language. So I can't do anything. And I'm slow at Mathematica. So if they watch me using Mathematica, then I must look pretty…

PH: Every step is laborious.

SS: Yeah. So there is definitely this tradeoff. They have tremendous power because of the technology they have. But it feels like the power is more external to them, and they just know how to tap into it. Whereas I have a lot of power in my head that I know how to tap into, but I'm sort of weak at tapping into the external sources of power.

PH: *The Calculus of Friendship* is a revealing, emotional story [about Strogatz's 30-year correspondence with his high school calculus teacher, Don Joffray]. Did you find it difficult to open yourself up like that?

SS: It was emotional for me. There were times when I was writing it that I cried, and even to this day when I read parts of it, it makes me cry.

It was meant to be raw, yet understated. I didn't want to be blubbering on the page, but there was a lot at stake emotionally. It's a very intimate story. I've never had any particular trouble being direct or open about myself or my feelings, so that was not hard.

In fact my kids always tease me about TMI—too much information. It's in my nature to be frank and open about things; I'm not shy about that.

PH: The book is both emotional and understated. It's not blubbering at all.

SS: I always thought it was just a collection of problems that might be interesting to some calculus teachers. It was my wife, Carole, who said maybe there's something else going on there: "You must know each other so well." It's the story I tell in the book.

PH: Was writing the book cathartic for you?

SS: I think it was a bit. It was an easy book to write, the easiest of all my books. It felt like that story had to come out, like it wanted to come out. I don't normally feel that. I usually feel like I have to squeeze material out of the tube. Whereas with this, each morning I would just sit down and write for a few hours and just surprise myself with what came out.

My friend Alan Alda told me that in writing this kind of a story, to not think about it. Don't outline it too much, or plan it. Just write.

The Calculus of Friendship wasn't like [*The Joy of x*]; there's a lot in there that isn't teaching. That was a new experience for me; it was storytelling. I wanted it to have some poignancy; I wanted to have a story that would keep the reader turning the pages.

PH: But as it turns out, there's a good deal of teaching in there too.

SS: There's a lot of teaching. There's quite a bit of teaching about calculus in there, although I don't teach the basics of calculus. You can't follow it unless you know the basics.

PH: It's not a textbook.

SS: It's certainly not a textbook. And then there are sections where I try to do a little bit of poetry, the poetry of calculus—calculus as a metaphor for the story. Calculus is the mathematics of change, and this story is about a relationship that changes.

I tried to play on those connections, by thinking about evolution and time, which is what differential equations is all about. Can we think about how this relationship evolves in time and how limited calculus is at understanding the kinds of change that occurs between two people over the course of their lives?

So, it's a little about the strength of calculus and the weakness of calculus; the strength of a mathematical outlook on the world, and the naiveté of the mathematical outlook in trying to think about human affairs.

PH: Do you have former students who communicate with you about math problems now?

SS: Nothing like what Mr. Joffray and I did.

PH: I guess the bond between a high school teacher and a student is kind of unique.

SS: And also people don't write handwritten letters to each other in the way that we used to. There's email, of course, and I certainly keep in touch with my former students, but not really about math.

Aftermath
Steven Strogatz on mathematics education

Patrick Honner: What are your thoughts about the state of math education right now?

Steven Strogatz: My thoughts are mostly based on my own instincts as a teacher and what I've seen of teachers I admire. I don't know much about the constraints that practicing teachers face in high schools right now, so my opinions are fairly uninformed. But I do worry about math communication and teaching in general.

Can I give you my "I have a dream" speech?

PH: By all means!

SS: In my dream world, everyone would have the chance to be a teacher the way Mr. Joffray [Strogatz's high school calculus teacher, and the subject of his book *The Calculus of Friendship*] was a teacher. His job was to teach us calculus, but he had his own vision of how to teach it and he followed that vision. He was creative, and he put his personal stamp on the course for us. He trusted his judgment and the school trusted him. He could teach us the way he wanted to teach us, and he was a great teacher.

This is a profession that should be revered. What's more important than teaching? Why not let teachers teach creatively and inventively? So that's my dream: a world in which teachers are given the freedom to teach the subject they're supposed to teach, the way that makes sense to them.

PH: You have two daughters in school right now. Do you think they are being exposed to math in a positive way?

SS: No, I don't. I worry that my kids are not falling in love with math because it's being presented as lots of procedures that they need to learn.

It's too fast. My eighth grade daughter is taking algebra, and one day she's doing word problems, like find three consecutive odd numbers that add up to 123, and the next day she was doing something I'd never heard of—literal equations.

It just struck me as unbelievable that we're doing word problems in one night's homework. Students should spend at least 2–3 weeks on word problems. They're hard! Every old-fashioned word problem is being thrown at her in one night.

PH: And then it's off to literal equations the next day.

SS: I can't imagine what any kid is doing who doesn't have a math professor as a parent. The whole thing looks crazy to me. I'm sure even my daughter's teacher doesn't want to do it this way. Something is really messed up.

PH: Should math be a mandatory subject for kids?

SS: I'm conflicted about it—I don't know what to think. There are a lot of students out there who would love math but don't know that. So they have to be exposed, or maybe even forced, to take math to realize they like it. But after a certain amount of that, it becomes clear to a student that they don't want to take more math. We as a profession should think about this again.

PH. What math do you think all people should know?

SS: Some amount of number sense is essential—for example, to know what it means when the store says certain items are 20% off. If you don't know what that means, to me, you're not educated. I feel comfortable saying that every person should understand fractions. But after that, what? Does a person need to know what a polynomial is? That's not clear to me.

What should a person learn, *if anything*, after arithmetic? That seems like a pretty interesting pedagogical question and I don't believe our current curriculum is the optimal answer. Algebra I and II are good subjects, but so is network theory. It would be nice if people could understand how Google works, for example; it's not that hard.

There's a lot of fun in math. Do we really have to teach such dead material? If we could get a cadre of people who love math and who get it the way you get it or the way I get it—people who know what math is about—you don't need to tell them how to teach. You just leave them alone and it'll be okay.