

The World of YouTube Math Communication

Scott Hershberger

Intriguing patterns emerge when you create a plot in polar coordinates of the points $(r, \theta) = (p, p)$ for prime numbers p . At an intermediate scale, the points seem to fall in 20 spiral arms. Zoom out, and the spirals give way to 280 nearly straight rays arranged mostly in clusters of four. What causes the patterns? That was the hook of a 2019 video by Grant Sanderson, one of the most successful math communicators on the internet.

On his YouTube channel 3Blue1Brown, Sanderson brings non-experts into the world of mathematics through compelling visualizations and clear explanations. The prime spirals video, which amassed 3.7 million views, explored rational approximations of π and Dirichlet's theorem, all with a friendly tone and minimal jargon. Inviting viewers to play with numbers, Sanderson emphasized that "frolicking around in the playground of data visualization" and asking seemingly superficial questions can easily lead to deep mathematical concepts.

With more than 4.5 million subscribers, 3Blue1Brown shows that online videos about math can attract an eager audience beyond the typical boundaries of the mathematics community. And Sanderson is not alone. The past decade has seen the rise of many successful YouTube video creators—or "YouTubers," as they are commonly called—who share the joys of both recreational and research mathematics through imagery, stories, humor, and interviews.

In a sense, math YouTubers are the new Martin Gardner, inspiring the public just as Gardner's "Mathematical Games" column in *Scientific American* once did. In 2021,

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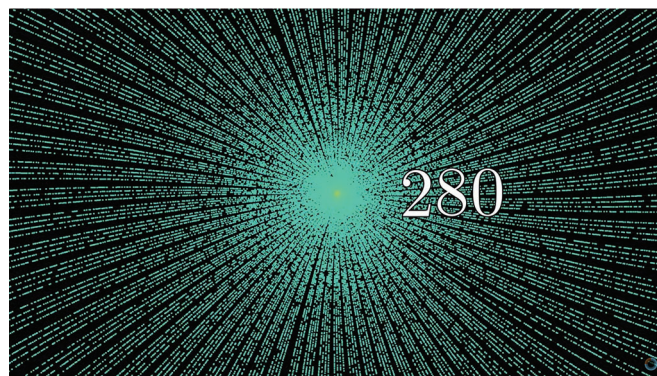


Figure 1. This polar plot, first described in a MathStackExchange post, inspired a 20-minute 3Blue1Brown video. "The whole hook was a single picture that asks a question," Sanderson says. "Don't underestimate how far that can go because so much of [the brain is] visual!"

81% of Americans, including 95% of those ages 18–29, used YouTube [AG19], the most popular social media site in the country. The creators featured in this article hail from the US, Australia, and the United Kingdom, and their reach extends farther: The majority of their viewers reside outside the US, with substantial contingents in India and various European countries.

These YouTubers aren't reaching everyone. Their viewership skews heavily male, a gender disparity that extends to STEM YouTube videos in general [Lan21]. People of all ages watch math videos, but the largest audience segment comprises 18- to 24-year-olds. Even so, "it's probably true to say that more people get attracted to mathematics through YouTube than through anything else at the moment," says Burkard Polster, known on the platform as the Mathologer. "Forget about schools, forget about uni, [...] it just pales into insignificance when you compare it to the impact that [YouTube has]."

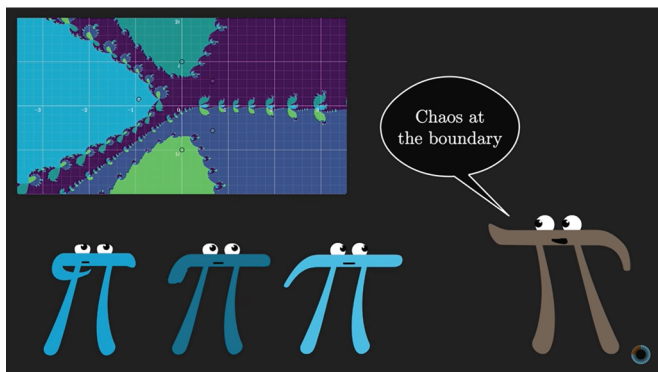


Figure 2. 3Blue1Brown’s anthropomorphized π creatures discuss a fractal related to Newton’s method for finding roots of functions.

Elaborate Animations or Whiteboard Drawings

Many YouTubers begin their channels as side projects. Sanderson started 3Blue1Brown for fun while studying mathematics and computer science at Stanford University. After completing his bachelor’s degree, he spent a year creating online instructional content for Khan Academy before diving into 3Blue1Brown full-time in 2016.

3Blue1Brown video topics range from puzzles like computing π using colliding blocks and solving Wordle using information theory to major areas of mathematics like Fourier series and linear algebra. In all cases, Sanderson sees his work as complementary and supplementary to traditional math education. “[The channel is] not meant to substitute for any actual class that someone’s taking,” he says. “The usual aim is that it helps more people self-identify as loving math, whether [...] they already kind of do and it fans those flames, or if it can spark that interest in some way.”

As he writes a script for a video, Sanderson makes sure to lead with concrete examples before moving into abstract concepts—a structure that entices viewers’ curiosity and guides them toward true understanding. He typically recruits a friend or two for a sample lesson to gauge the effectiveness of explanations and calibrate the right level of detail. In his delivery, Sanderson avoids the rapid-fire, almost breathless pace of many viral videos. He instead speaks slowly and deliberately, giving viewers plenty of opportunities to “pause and ponder.”

3Blue1Brown videos feature intricate animations of diagrams and equations, often interspersed with the reactions of anthropomorphized π creatures. Sanderson uses his own custom Python library to generate the animations programmatically. While this unique approach yields an eye-catching and polished visual style, he points out that visuals don’t need to be fancy to be effective.

Mithuna Yoganathan is one YouTuber who embraces a simpler style, filling the screen with colorful diagrams

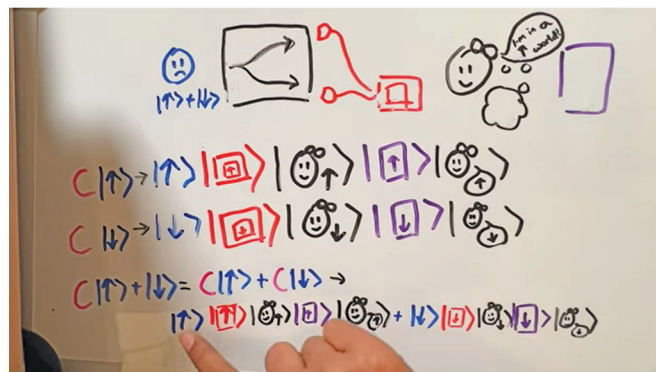


Figure 3. A Looking Glass Universe video about the many-worlds interpretation of quantum mechanics.

and equations hand-drawn on a whiteboard. Her channel, Looking Glass Universe, originated as a place for her to solidify her learning of quantum mechanics concepts by explaining them. She cites fellow video creator Vi Hart, a winner of the 2018 Joint Policy Board for Mathematics Communications Award, as a major influence on her early videos.

Yoganathan posted occasional videos throughout her PhD in quantum computing, finding an audience of hobbyists eager to learn alongside her. “They don’t necessarily already know quantum mechanics, but they’re pretty comfortable with doing maths and comfortable with watching longer videos,” she says. Yoganathan keeps her explanations less technical than a typical lecture—for example, she might disregard the normalization constants in wave functions or omit the entries of matrices. Still, she finds that her viewers want more details than are included in hand-wavy popularizations elsewhere.

In fact, one of the most popular Looking Glass Universe videos is a guide to self-studying quantum mechanics, which inspired viewers ranging from high school students to a retired biochemist. In other videos, Yoganathan speaks candidly about the nature of mathematics research and the winding path of her PhD work at Cambridge University. She shifted to making YouTube videos full-time after earning her doctorate in early 2021. Now, Yoganathan is producing a series of videos demonstrating how to do “Quantum Experiments at Home.”

“I find it a very enriching experience to be on YouTube,” she says. “I’m making very niche videos about quite technical topics in quantum mechanics, and I can still get a decent audience for that, which is only possible because of the scale of YouTube.”

Inspiring Students to Pursue Math

Sanderson and Yoganathan each write, record, and edit most of their videos single-handedly. By contrast, Numberphile, one of the longest-running YouTube channels

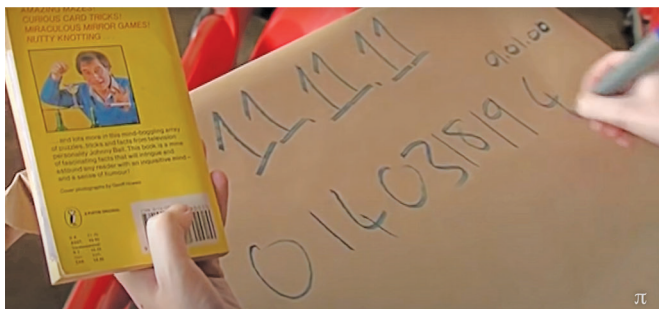


Figure 4. The first Numberphile video used the date 11/11/2011 as an entry point to discuss the error-correcting code used in the ISBN system. The brown paper “shows up better on film [...] than white paper,” says Haran. “It’s unique to the channel as opposed to the cliché of the whiteboard. [...] It’s like a brand.”

about math, has found success with a rotating and ever-expanding cast of guest mathematicians. According to video journalist Brady Haran, who films and produces Numberphile, well over 100 mathematicians have starred in his videos since the channel’s 2011 debut.

Since 2013, the Mathematical Sciences Research Institute (MSRI) has sponsored Numberphile, and Haran frequently travels to Berkeley to interview the mathematicians who visit MSRI. When preparing to film with a new presenter, “We just sit down over a cup of tea and talk about it. The key is that the person feels relaxed,” he says. “Most mathematicians are better at explaining their work than people give them credit for—the bigger challenge is easing the nerves that a camera can generate. That’s often about creating trust and a rapport.”

Haran has worked on more than a dozen YouTube channels throughout his career, including still-active channels on chemistry, physics, and astronomy. Compared to those other projects, the biggest challenge for Numberphile is the lack of something “spectacular” to display on camera, he says. “Astronomers can show me pretty galaxies, chemists can perform explosive experiments, but mathematicians are often limited to a pen and paper.”

Yet a thick pen and a large roll of brown paper, the visual hallmark of Numberphile videos, turn out to be plenty to capture the imaginations of viewers. Numberphile is by far the most successful of Haran’s projects, with a cumulative 650 million views as of April 2022. Teachers around the world show Numberphile videos in their classrooms. When students in one class met frequent Numberphile presenter James Grimes at school, they said it was “like meeting a rock star.”¹

YouTube was launched in 2005, making it the same age as today’s high school seniors—so the newest wave of math YouTubers can testify firsthand that the platform

¹<https://twitter.com/Fellermaths/status/375317712336994305>.



Figure 5. Toby Hendy explains logarithms in the style of Bob Ross. For many viewers, Hendy’s videos create “new associations between math and positive emotions,” she says.

galvanizes students to pursue STEM. “Watching the very early YouTubers [...] really did inspire me in high school to [...] look into science in the first place,” says Toby Hendy. Hendy went on to major in physics and mathematics at the University of Canterbury in New Zealand, then began a PhD program in biophysics. All the while, she made YouTube videos for a growing audience. Less than a year into her PhD, Hendy realized that her passion lay in science communication rather than science research. She left academia to create videos full-time on her channel Tibeas.

With a calm, soothing demeanor, Hendy analyzes math exams from around the globe and shows documents from the lives of famous mathematicians and physicists. When some commenters described her as “the Bob Ross of math,” she leaned into the comparison to the host of *The Joy of Painting*. On a windy day, she lugged a chalkboard, easel, camera, and tripod to the top of a scenic hill. There, she explained logarithms “Bob Ross style,” complete with drawings of trees and logs. Other videos in the series—filmed at an overlook, in a forest, or by a lake—explore Euler’s identity, parabolas, and sine waves.

Hendy continued bending genres with her most ambitious project to date, “Finding X.” Narrated as a poem and featuring animations made from felt, the allegorical short film tells the story of x ’s search for their mathematical—and human—value. Like Hendy’s Bob Ross-style videos, “Finding X” struck a chord with viewers who previously associated math with stressful experiences.

“If this had been mandatory viewing when I was around 10 years old - I wouldn’t have dreaded mathematics existentially, fearing continuous failure and wrong solutions,” wrote one commenter. “Thank you so very much for this beautiful new narrative [of] what mathematics is actually about: creative exploring of all the patterns and relations we can think of!”

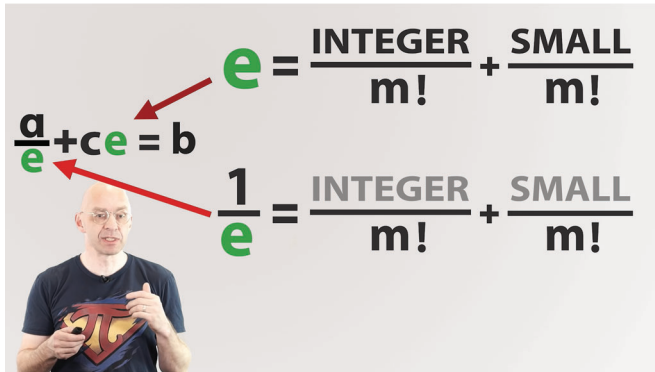


Figure 6. In one of the most ambitious Mathologer videos to date, Burkard Polster presented the proofs that π and e are transcendental.

Funding the Creative Process and Building Community

Writing, filming, editing, promoting—releasing high-quality videos on a regular basis is a time-consuming endeavor. To turn their passion into a profession, creators typically depend on funding sources beyond ad revenue. Many math YouTubers accept sponsorships from educational organizations or crowdfund their work on a platform such as Patreon. Both Yoganathan and Hendy won grants from Screen Australia and Google Australia to carry out their latest projects.

But not all successful math YouTubers create videos full-time. In addition to running his YouTube channel Stand-up Maths, Matt Parker gives public talks, performs stand-up comedy, and writes popular books about math. Burkard Polster creates Mathologer videos between research and teaching as an associate professor at Monash University—a juxtaposition of pursuits made possible by the support of his colleagues and institution.

Mathologer videos do not shy away from mathematical detail, so typical viewers hold at least a bachelor's degree in mathematics or engineering. Polster frequently engages with his audience by proposing challenges related to his videos. For example, an invitation for viewers to code interactive apps for modular multiplication circle diagrams yielded at least three dozen submissions. "I think the world is a richer place now that people can just go there and play with these apps," Polster says.

Some viewers' contributions may shine, but other remarks dampen the glow. Like other social media sites, YouTube struggles with abusive behavior, especially toward female creators [AA21]. Negative comments "can be very personal in nature, attacking my appearance or personality," Hendy says. "My job has required me [to form] a 'thick skin' with regards to hateful comments and [do] what I can to protect my privacy." In the comments of a

Mathologer video about why $0.9999\dots = 1$, Polster even received death threats.

For Hendy, positive interactions far outweigh the negative ones. Yoganathan similarly prioritizes community-building on her channel, often posting videos that directly respond to viewers' conceptual questions. She says that this give-and-take fosters collaborative learning and even enhances her own understanding of quantum mechanics.

Math Communicators Rise and Unsolved Problems Fall

Following the path pioneered by Numberphile, 3Blue1Brown, and others, creative and skilled communicators continue stepping up to fill the public's appetite for engaging video content about mathematics. In 2021, Sanderson of 3Blue1Brown held a "Summer of Math Exposition"² to encourage people to explain math online. He received a staggering 1,200 submissions, most of them videos. Undergraduates, graduate students, educators, researchers, engineers, and even video game developers took part.

Sanderson coordinated a peer review process to evaluate submissions, and then he assessed the top 100. "One of the coolest outcomes of it was that even before I announced the ones that I [...] chose as winners, many of them had actually picked up a lot of traction on YouTube," he says. The winning videos explicated on Bézier curves, lock patterns on smartphones, Pick's theorem in geometry, and the envelopes of light in coffee mugs. At press time for this article, a second Summer of Math Exposition was underway.

In at least one instance, a series of YouTube videos for a broad audience directly led to new mathematics research. A 2015 Numberphile video explored the conjecture that all positive integers (except those with remainder 4 or 5 when divided by 9) can be expressed as the sum of three cubes of positive or negative integers. At the time, such expressions were known for all numbers below 100 except for 33, 42, and 74. Viewer Sander Huisman, a physicist, was inspired to write a computer program to search for solutions—and he succeeded for 74 [Hui16].

The follow-up Numberphile video, "74 is cracked," spurred another researcher to develop new algorithms that identified a solution for 33 [Boo19]. Finally, the expanding group of collaborators found a way to write 42 as the sum of three cubes in 2019 [Mil19]. "We started with this one video and just released it out into the wild and said, 'Look at this interesting thing,'" Haran says. "As a result of it, [...] all these amateur [and] professional mathematicians—people who may never have met—have been working on papers together."

²<https://www.3blue1brown.com/blog/some1-results>.

The original conjecture remains unproven. But if and when a proof is found, Haran will record a video about it. “I would love it if someone who watched the Numberphile videos is the person who proves it.”

As with any craft, there is no single best approach to math communication. Polster used to improvise his explanations based on an outline, but he now follows scripts that he writes; meanwhile, Sanderson is moving away from full scripts in favor of outlines. Similarly, a YouTuber must decide with each project whether they hope to create “the perfect video” for a small audience or “a pretty good video” for a larger audience, Sanderson says.

Research mathematicians who want to join the ecosystem of math communication on YouTube don’t have to start a new channel from scratch. An appearance on Numberphile is one possible point of entry. Sanderson invites researchers to connect with him as well. “More active collaboration with mathematicians is something I would greatly welcome,” he says.

Hendy concurs: “Having partnerships between research mathematicians and us YouTube science communicators, I think, makes the platform better for everyone.”

A list of links to the YouTube channels and videos mentioned in this article is available at <https://www.ams.org/about-us/scotthershberger>.

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