MIT Technology Review

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Building the backbone for innovation, speed, and thriving humanity

"New IT" is an evolution built on smart devices, edge and cloud computing, 5G networks, and AI.

From AI-powered platforms that can detect abnormal activities in supermarkets, to edge servers helping preserve biodiversity in remote locations, today's technologies drive innovation in ways never before imaginable. "Innovation serves the purpose of making our life better, our work more productive, and our planet more sustainable," says **Yuanqing Yang, CEO and chairman of Lenovo.**

Technology leaders are reimagining an infrastructure where multiple technologies join to spur innovation in a secure, compliant, and user-friendly environment. Long gone are the days of "traditional IT and its client devices, servers, data centers, and on-premises applications," says Yang. He says traditional IT, shorthand for "information technology," is being replaced by what Lenovo calls "new IT," or "intelligent transformation." Yang explains that **"The new IT enables digital transformation based on five key elements: smart devices, edge computing, cloud computing, high-speed networks, and artificial intelligence. This new IT architecture can create countless opportunities."**

This technology paradigm promises to support innovation and boost employee productivity, and also to power AI, revolutionize how enterprises use data, support business agility, and confront climate change with sustainable solutions.

THE FIVE ELEMENTS OF NEW IT

Although new technology and powerful applications are constantly emerging, Lenovo identifies five key components of a future-ready IT environment: smart devices, edge computing, cloud computing, high-speed networks such as 5G, and AI. This definition resonates with technical leadership too, says Yang, citing a 2022 Lenovo global research study of 500 chief technology officers in which four out of five CTOs agree it "captures and describes the future of information communications technology (ICT) 'extremely' or 'very well.'"

Smart devices connect AI to human problems: According to Statista, the number of internet of things (IoT) devices worldwide will reach 29 billion by 2030. IoT's exponential growth—smart devices empowered by advanced sensors—provides a wide range of industries with competitive advantages.

Manufacturers can use smart devices like robots to stand in for workers in dangerous or remote workspaces, and accelerate and automate assembly lines. For example, Lenovo's Daystar Robot works remotely in real time using telepresence and teleoperation and learns tasks as it goes. The robot is operated by a streaming augmented reality headset with 3D video to give the user a realistic view of the work being done. The user's head position controls the robot arm, and a handheld device controls movements.

Edge computing helps data eliminate boundaries: Processing volumes of data can lead to performance issues. In response, many organizations are turning to edge computing, which processes data close to the source to enable fast and real-time analysis and response, while maintaining privacy and security requirements. "Edge computing allows data to be treated closer to where data is generated—directly at the edge site, lowering latency for faster response times, increased agility, and greater resilience," says Yang.

For example, Kroger, one of the largest grocery chains in the United States, teamed with Lenovo and visual AI technology provider Everseen to build a system of secure self-checkout kiosks. AI servers capture unstructured data at each checkout from 20 high-resolution cameras. The system detects if an item is not scanned, and prompts the customer to rescan. It can also ping an associate's mobile device. Since this requires

enormous computing power, an edge solution processes the data near the source. "Over 75% of checkout errors can be corrected without employee intervention," says Yang.

And global biodiversity nonprofit Island Conservation uses edge computing to bridge 400 miles of Pacific Ocean. At Robinson Crusoe Island, one of the most remote places on Earth, it uses camera traps to document endangered and invasive species. Camera data used to be stored on a hard drive and periodically flown to Santiago, Chile, to process, taking as long as three months. Today, edge computing data centers process data on the island—time-savings that can save lives. "The Island Conservation team can process six months' worth of visual data within just one week, enabling them to draw analytical insights within minutes instead of weeks," Yang says.

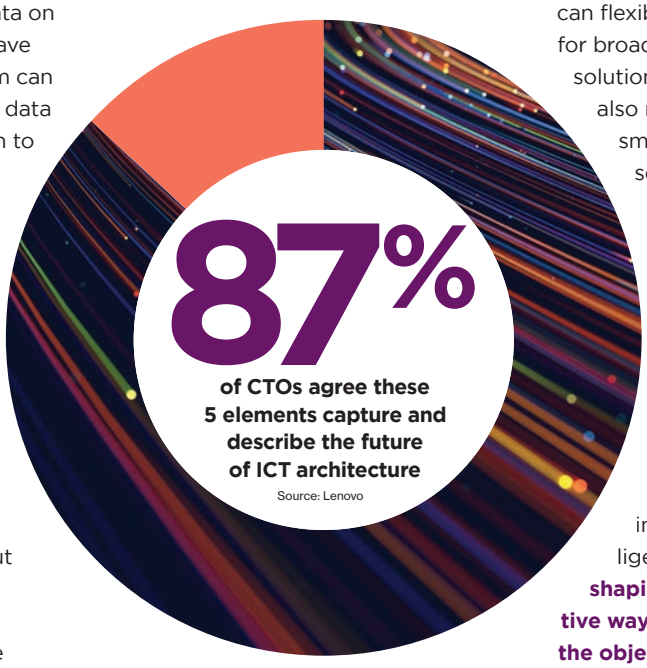
Cloud computing provides connection: If the pandemic taught technology leaders anything, it's that public, private, hybrid, and multicloud computing is imperative for fast and agile services and development.

"Normally, we wouldn't think of tablets as life-saving equipment, but when emergency hospitals needed to be built during the covid-19 outbreak, these devices and innovative infrastructure played a critical role," says Yang.

"In tough times, like the pandemic, it was new IT that kept us connected, productive, and engaged." He continues, "The public cloud became more popular by providing the flexibility, scalability, and on-demand accessibility that we needed at the time. But, many enterprise applications and data are still running and stored in private cloud or on-prem data centers. In fact, we will continue to see the co-existence of private, public, and hybrid cloud for compute, storage, and network needs."

The same Lenovo study found that cloud, software, and computing are key components for the future of a hybrid work environment, with 84% of respondents optimistic about the future of hybrid cloud.

5G networks enable innovation and flexibility: Connecting the essential components of a new IT architecture requires fast, efficient, and customizable networking. The answer: 5G—the next generation of mobile wireless voice and data communication technology. The 2022 Lenovo study also found that 72% of CTOs see opportunities for their companies to use 5G multiaccess edge computing (MEC) even more with the demand for hybrid options dominating the workplace. "The popular hybrid work model that many companies have adopted over the last three years is only possible with a high-speed network," says Yang.



AI tools mimic human intelligence to solve problems: By combining data, computing power, and sophisticated algorithms, AI can handle much more data much faster than a human worker, can be adjusted by users to accommodate change, can help users learn better processes, and can help anticipate risks such as cost overruns, accidents, and maintenance needs. Using multiple AI technologies and optimized algorithms, Lenovo Research created new processes for its manufacturing facility that **dramatically improved production planning processes,** with some six-hour processes cut to 90 seconds. Lenovo estimates the AI solution improved order fulfillment by 20% and productivity by 18%.

Consider that a single PC order will launch a series of complex tasks across multiple production lines, and requires alignment of thousands of parameters, such as employee schedules, materials, production processes, and equipment statuses. Lenovo's largest manufacturing base for PCs, LCFC Electronics, **processes up to 690,000 orders** per year. While accounting for these large-scale calculations is a challenge for people, an AI engine can easily carry them out, and can flexibly make real-time adjustments for broad or granular objectives. The AI solution's autonomous learning ability also means the more it operates, the smarter it becomes. "This smart solution has also improved energy efficiency and reduced greenhouse gas emissions by thousands of tons a year," says Yang.

A LOOK TO THE FUTURE

Technologies such as smart devices, edge computing, cloud computing, 5G, and AI are facilitating a shift from information technology to intelligent transformation. **"New IT is shaping the future in many innovative ways," says Yang. "In the future, the objects you work on, the colleagues you work with, the environment you work in, and the outcome you deliver might all be real or virtual, ranging from AI assistants and digital twins to the metaverse."**

As always, while change surges ahead, technology executives must carefully consider the real-life outcomes of deploying new IT infrastructure. Security, compliance, and usability standards must still be upheld. "Environmental, social, and governance (ESG) goals must be a major consideration," says Yang. "In the future, every element of new IT architecture must incorporate ESG. When you assess the returns on innovation, it's not just financial payback but also social impact." ■

Cheat codex

Mat Honan
is editor in
chief of
MIT Technology
Review

Welcome to the Education Issue. I cheated on my editor's letter. This one that you are reading right now. I'm very sorry.

Look, I didn't set out to do this, but the thing about magazines is that they have very hard deadlines, and if you miss them, you're left with blank pages. So when I realized I only had a few hours left to finalize this, well, I freaked out.

And then I did what an increasing number of us are doing: I turned to ChatGPT, OpenAI's massively mind-blowing generative AI software, to help me out. After training it on some of my previous work, I asked about the use of AI in education.

> AI is already doing big things in education. By crunching massive amounts of data on student performance, AI algorithms can tailor instruction to fit the needs of individual learners, which can mean big improvements in student outcomes. Chatbots and virtual assistants can provide students with on-the-spot assistance and feedback. Who needs a tutor when you have an intelligent assistant?
>
> But here's where things get really exciting: language models like ChatGPT can actually generate human-like text, which makes them perfect for a whole bunch of educational applications. These models can create interactive learning materials, like chatbots that answer students' questions or create personalized quizzes. They can even generate summaries of complex texts, reports on data sets, or entire essays and research papers.
>
> There are definitely some challenges as well. One of the biggest concerns is the risk of bias in the algorithms. We need to make sure these algorithms are designed and tested in a way that ensures all students get a fair shake. Another, of course, is the potential for cheating.
>
> But the bottom line is that AI and language models like ChatGPT are going to change the way we think about education, and we need to make sure we're using these tools in ways that are ethical, equitable, and effective.

So are the preceding four paragraphs, which were generated by ChatGPT and then lightly edited by me, ethical? If they were presented as my own work without an explicit disclosure (like this one), I would argue that the answer is no. And even *with* such a disclosure, we're still in a bit of a gray area—there are all sorts of questions about everything from plagiarism to accuracy to the data these models were trained on.

The reality is that we are in an entirely new place when it comes to the use of AI in education, and it is far from clear what that is going to mean. The world has changed, and there's no going back.

As William Douglas Heaven, our senior editor for AI, makes clear in this issue's cover story on page 42, technologies like ChatGPT will have all sorts of genuinely useful and transformative applications in the classroom. Yes, they will almost certainly also be used for cheating. But banishing these kinds of technologies from the classroom, rather than trying to harness them, is shortsighted. Rohan Mehta, a 17-year-old high school student in Pennsylvania, makes a similar argument on page 20, suggesting that the path forward starts with a show of faith by letting students experiment with the tool.

Meanwhile, on page 26, Arian Khameneh takes us inside a classroom in Denmark where students are using mood-monitoring apps as the country struggles with a huge increase in depression among young people. You'll also find a story from Moira Donovan on page 34 about how AI is being used to help further our analysis and understanding of centuries-old texts, transforming humanities research in the process. On page 48, Joy Lisi Rankin dives deep into the long history of the learn-to-code movement and its evolution toward diversity and inclusion. And please do not miss Susie Cagle's story on page 64 about a California school that, rather than having students try to flee from wildfire, hardened its facilities to ride out the flames, and what we can learn from that experience.

Of course, we have a lot more for you to read, and hopefully think about, as well. And as always, I would love to hear your feedback. You can even use ChatGPT to generate it—I won't mind.

Thank you,

Mat
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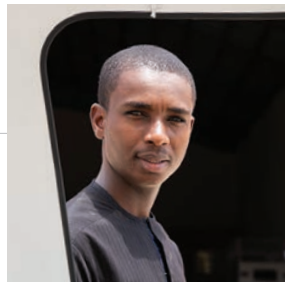

"They don't want it to be vilified. They want to be taught how to use it." –p. 42

Front

Cover illustration by Selman Design

The education issue

Back

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The Download

More than 200 people have been treated with experimental CRISPR therapies

But exciting trial results are tempered by safety and ethical concerns.

By Antonio Regalado

There are now more than 50 experimental studies underway that use gene editing in human volunteers to treat everything from cancer to HIV and blood diseases, according to a tally shared with MIT Technology Review by David Liu, a gene-editing specialist at Harvard University.

Most of these studies—about 40 of them—involve CRISPR, the most versatile of the gene-editing methods, which was developed only 10 years ago. One of the first patients treated using a CRISPR procedure, in 2019, was Victoria Gray. At the Third International Summit on Human Genome Editing, held in London in March, her story left the room in tears. "I stand here before you today as proof miracles still happen," Gray said of her battle with sickle-cell disease, in which misshapen blood cells that don't carry enough oxygen can cause severe pain and anemia.

She described to the audience episodes that left her hospitalized for months at a time. Her children were worried she might die. But then she underwent a treatment that involved editing the genes in cells from her bone marrow. Her new "super cells," as she calls them, have transformed her life. Within minutes of receiving her transfusion of edited cells, she shed tears of joy, she told us. It took seven to eight months for her to feel better, but after that point, "I really began to enjoy the life that I once felt was just passing me by," she said.

The company developing Gray's treatment, Vertex Pharmaceuticals, says it's treated more than 75 people in its studies of sickle-cell and a related disease, beta thalassemia, and that the therapy could be approved for sale in the US within a year. It is widely expected to be the first treatment using CRISPR to go on sale. Vertex hasn't said what it could cost, but you can expect a price tag in the millions.

To scientists, CRISPR is a revelation because of how it can snip the genome at specific locations. It's made up of a cutting protein paired with a short gene sequence that acts like GPS, zipping to a predetermined spot in a person's chromosomes.

Along with Vertex, a wave of biotech companies, like Intellia, Beam Therapeutics, and Editas Medicine, are hoping they can use this technology to develop successful treatments. Many of them are running the trials on Liu's list.

At the summit, Liu highlighted the case of Alyssa, a teenager in the UK with a form of leukemia that affects a type of white blood cell called T cells. Chemotherapy didn't work, and neither did a bone marrow transplant. So doctors at Great Ormond Street Hospital in London tried a CRISPR-based approach. It involved taking healthy T cells from a donor and using CRISPR to modify them. The treated cells were altered so that they wouldn't be rejected by Alyssa's immune system, but they would be able to track down and attack Alyssa's own cancerous T cells. The edited cells were then given to Alyssa as a treatment. It seems to have worked. "As of now, approximately 10 months after treatment, her cancer remains undetectable," Liu said.

But not all these trials will be successful. For instance, in January the San Francisco biotech Graphite Bio had to stop its own tests of a gene-editing treatment for sickle-cell after its first patient's blood cell counts dropped dangerously. The problem was caused by the treatment itself. Graphite's stock plunged and now the firm's future is in question.

The trick facing all these efforts remains getting CRISPR where it needs to go in the body. That's not easy. In Gray's case, doctors removed bone marrow cells and edited them in the lab. But before they were put back in her body, she underwent punishing chemotherapy to kill off her remaining bone marrow in order to make room for the new cells.

PHOTO COURTESY OF VICTORIA GRAY

In essence, the Vertex treatment requires a bone marrow transplant, an ordeal in itself. Vertex thinks the treatment will be suitable for "severe" cases, a market it estimates at 32,000 people in Europe and the US. Even then, patients won't get the treatments if insurers and governments balk at paying. It's a real risk.

The first-generation CRISPR treatments are limited in another way. Most use the tool to damage DNA, essentially shutting off genes—a process that the Harvard biologist George Church has famously described as "genome vandalism."

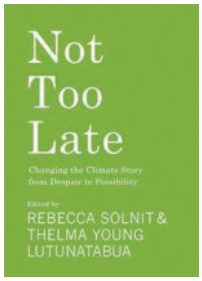
Treatments that attempt to break genes include one designed to zap HIV. Another is the one Gray got. By breaking a specific bit of DNA, her treatment unlocks a second version of the hemoglobin gene. Since hemoglobin is the errant protein in sickle-cell, booting up another copy solves the problem. According to Liu's analysis, two-thirds of current studies aim at "disrupting" genes in this way. Liu's lab is working on next-generation gene-editing approaches. These tools employ the CRISPR protein to deftly swap individual genetic letters or make larger edits. These are known as "base editors."

Lluís Montoliu, a gene scientist at Spain's National Center for Biotechnology, says these new versions of CRISPR have "lower risk and better performance," although delivering them to "the right target cell in the body" remains difficult.

Commercial viability remains one of the biggest limits on CRISPR's impact now and in the foreseeable future. Nearly all CRISPR trials underway aim at either cancer or sickle-cell disease, with multiple companies chasing the exact same problems. According to Fyodor Urnov, a researcher at the University of California, Berkeley, this means thousands of other inherited diseases that could be treated with CRISPR are just being ignored: "This is near-entirely due to the fact that most of them are too rare to be a viable commercial opportunity." ■

Antonio Regalado is senior editor for biomedicine for MIT Technology Review.

Book reviews



Not Too Late: Changing the Climate Story from Despair to Possibility

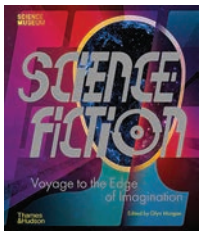
Edited by Rebecca Solnit and Thelma Young Lutunatabua (Haymarket Books, 2023)

Hope isn't a lottery ticket, says activist and writer Rebecca Solnit. Rather, it's a tool, and an essential one for anyone living through climate change today. This essay collection from scientists, policymakers, and activists balances laying out the very real stakes of the climate crisis with making the case for possibility.

Saving Time: Discovering a Life Beyond the Clock

By Jenny Odell (Random House, 2023)

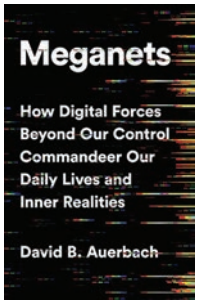
"What is time?" we've all asked ourselves and each other throughout the pandemic. For most of us the question was rhetorical, but not for Odell, who urges us to seriously reconsider the ways we spend it. Not bad advice, but her observations on, say, the importance of rest or the choke hold capitalism has on the hours in our collective days can feel more like a blending of other people's ideas than a new way forward.



Science Fiction: Voyage to the Edge of Imagination

Edited by Glyn Morgan (Thames & Hudson, 2022)

Science fiction, writes Nalo Hopkinson in this catalogue for the London Science Museum's 2022 exhibition, "is the literature of social and technological change… it tests in order to discover the truth." It upends our brains visually, too, as the images herein will attest.



Meganets: How Digital Forces Beyond Our Control Commandeer Our Daily Lives and Inner Realities

By David B. Auerbach (Public Affairs, 2023)

Auerbach defines meganets as autonomous digital forces that have brought an unprecedented level of chaos to our politics, economy, and social lives. We might think that Microsoft, Google, et al. are in control of these networks; Auerbach suggests that what chatbots might really herald are new modes of mass manipulation and deception. ■

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The UN's urgent climate to-do list

Cheap and available technologies can help us meet climate goals this decade. Here's how, according to the new UN climate report.

By Casey Crownhart

Time is running short to address climate change, but there are feasible and effective solutions on the table, according to a new UN climate report released in March.

Only swift, dramatic, and sustained emissions cuts will be enough to meet the world's climate goals, according to the new report from the Intergovernmental Panel on Climate Change (IPCC), a body of climate experts that regularly summarizes the state of this issue.

"We are walking when we should be sprinting," said Hoesung Lee, IPCC chair, in a press conference announcing the report in March. To limit warming to 1.5 °C (2.7 °F) above preindustrial levels, the target set by international climate agreements, annual greenhouse-gas emissions will need to be cut by nearly half between now and 2030, according to the report. It calculates that the results from actions taken now will be clear in global temperature trends within two decades.

"We already have the technology and the know-how to get the job done," said Inger Andersen, executive director of UN Environment Programme, during the press conference.

Stopping climate change will still be complicated and expensive, and long-term emissions cuts may rely on technologies, like carbon dioxide removal, that are still unproven at scale. In addition to technological advances, cutting emissions in industries that are difficult to transform will take time, funding, and political action.

But in the near term, there's a clear path forward for the emissions cuts needed to put the planet on the right track. Here are some of the tasks with the lowest cost and highest potential to address climate change during this decade, according to the new IPCC report.

1 Deploy wind and solar power, and a lot of it.

Cutting emissions in the near term will require shifting away from polluting fossil fuels for energy production and toward renewable energy sources like wind and solar power. The scale of wind and solar deployment already underway is staggering: the world is set to build as much wind and solar capacity in the five years between 2022 and 2027 as it did in the past two decades, according to the International Energy Agency.

Plummeting costs have helped this growth: between 2010 and 2019, the cost of solar energy fell by about 85%, the report says. Wind energy costs dropped by about half during the same time frame. Now, wind and solar are among the cheapest energy sources available—deploying new solar and wind farms can be even cheaper than just maintaining existing coal power plants in the US. But as inexpensive as wind and solar are, they can still represent a significant financial investment. That's why the new report emphasizes that improved access to financing, especially for developing nations, would help speed climate action.

2 Cut methane emissions from fossil-fuel production and waste.

Cutting methane emissions this decade will be key to reaching climate goals and limiting peak warming levels: hitting the 1.5 °C target will require methane emissions to fall by a third between 2019 and 2030, according to the IPCC report. Some of the top targets for emissions cuts include oil and gas production and food waste.

Investments in new infrastructure to cut methane emissions from oil and gas could end up breaking even: according to the IEA, an annual investment of $11 billion would be needed to clean up the sector, but the value of the captured methane could be more than enough to cover the cost.

3 Protect natural ecosystems that trap carbon.

The impacts of human-caused climate change "threaten our life support system, nature itself," said Lee. Conserving and restoring natural ecosystems will not only be key for preserving biodiversity—it'll have emissions benefits too. Natural ecosystems can trap and store carbon, and tropical rain forests are among the planet's largest carbon sinks. Preserving these and other ecosystems could be a low-cost, high-value way to slow climate change.

Policies around the world are already helping to cut deforestation, according to the IPCC report. And in December 2022, over 190 nations signed a UN biodiversity pledge to protect 30% of the natural world by 2030.

4 Use energy efficiently in vehicles, homes, and industry.

Shifting to public transportation and biking for some travel needs is an inexpensive way to limit near-term emissions. And boosting efficiency in everything from vehicles to appliances could shave off emissions too. Public policies have already been effective at boosting efficiency measures in particular, according to the report. Efficiency gains can also help make climate progress in sectors like aviation and shipping, which will be much more difficult to clean up in the long term. Many of these solutions are the same ones that the IPCC and others have been talking about for decades.

Now, there's only one clear path forward. "We must move from climate procrastination to climate action," Andersen said, "and we must begin this today." ■

Casey Crownhart is a climate reporter at MIT Technology Review.

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Exquisite bullshitters

Not for the first time, we're experiencing what it's like to be both seduced by and skeptical of artificial intelligence.

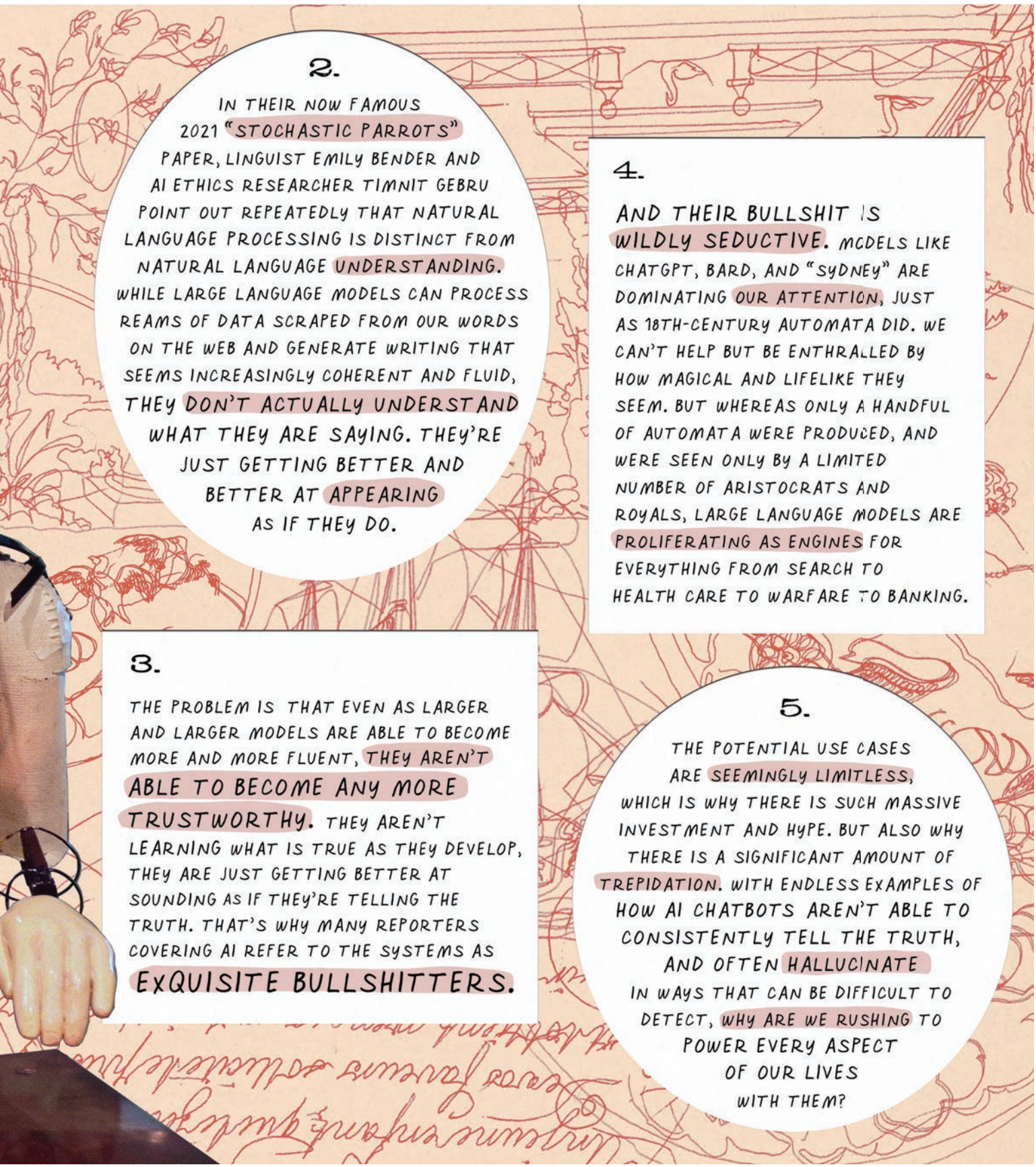
By Ariel Aberg-Riger

1.

WHEN MAILLARDET'S AUTOMATON OPENED ITS EYES AROUND 1795, CROWDS WERE ENTRANCED. THE TINY PRODIGY MOVED HIS PEN FLUIDLY ACROSS THE PAGE IN NEAR SILENCE, DRAWING CUPIDS AND A BRITISH WARSHIP, WRITING SWIRLING SELF-REFERENTIAL POEMS IN ENGLISH AND IN FRENCH. THE DRAWINGS WERE IMPRESSIVE, BUT WHAT MOST CAPTIVATED AUDIENCES WAS HOW THE BOY SEEMED TO THINK— PAUSING, GENTLY COCKING HIS HEAD AND GAZING INTO THE DISTANCE.

THE MACHINE, OF COURSE, COULD ONLY MIMIC THOUGHTFULNESS— ITS PAUSES WEREN'T SIGNS OF A SOUL, BUT CAREFULLY CHOREOGRAPHED COVERS FOR SHIFTING CAMS.

Artist Ariel Aberg-Riger is author of America Redux: Visual Stories From Our Dynamic History.



2.

IN THEIR NOW FAMOUS 2021 "STOCHASTIC PARROTS" PAPER, LINGUIST EMILY BENDER AND AI ETHICS RESEARCHER TIMNIT GEBRU POINT OUT REPEATEDLY THAT NATURAL LANGUAGE PROCESSING IS DISTINCT FROM NATURAL LANGUAGE UNDERSTANDING. WHILE LARGE LANGUAGE MODELS CAN PROCESS REAMS OF DATA SCRAPED FROM OUR WORDS ON THE WEB AND GENERATE WRITING THAT SEEMS INCREASINGLY COHERENT AND FLUID, THEY DON'T ACTUALLY UNDERSTAND WHAT THEY ARE SAYING. THEY'RE JUST GETTING BETTER AND BETTER AT APPEARING AS IF THEY DO.

3.

THE PROBLEM IS THAT EVEN AS LARGER AND LARGER MODELS ARE ABLE TO BECOME MORE AND MORE FLUENT, THEY AREN'T ABLE TO BECOME ANY MORE TRUSTWORTHY. THEY AREN'T LEARNING WHAT IS TRUE AS THEY DEVELOP, THEY ARE JUST GETTING BETTER AT SOUNDING AS IF THEY'RE TELLING THE TRUTH. THAT'S WHY MANY REPORTERS COVERING AI REFER TO THE SYSTEMS AS EXQUISITE BULLSHITTERS.

4.

AND THEIR BULLSHIT IS WILDLY SEDUCTIVE. MODELS LIKE CHATGPT, BARD, AND "SYDNEY" ARE DOMINATING OUR ATTENTION, JUST AS 18TH-CENTURY AUTOMATA DID. WE CAN'T HELP BUT BE ENTHRALLED BY HOW MAGICAL AND LIFELIKE THEY SEEM. BUT WHEREAS ONLY A HANDFUL OF AUTOMATA WERE PRODUCED, AND WERE SEEN ONLY BY A LIMITED NUMBER OF ARISTOCRATS AND ROYALS, LARGE LANGUAGE MODELS ARE PROLIFERATING AS ENGINES FOR EVERYTHING FROM SEARCH TO HEALTH CARE TO WARFARE TO BANKING.

5.

THE POTENTIAL USE CASES ARE SEEMINGLY LIMITLESS, WHICH IS WHY THERE IS SUCH MASSIVE INVESTMENT AND HYPE. BUT ALSO WHY THERE IS A SIGNIFICANT AMOUNT OF TREPIDATION. WITH ENDLESS EXAMPLES OF HOW AI CHATBOTS AREN'T ABLE TO CONSISTENTLY TELL THE TRUTH, AND OFTEN HALLUCINATE IN WAYS THAT CAN BE DIFFICULT TO DETECT, WHY ARE WE RUSHING TO POWER EVERY ASPECT OF OUR LIVES WITH THEM?

Can VR help inmates successfully reenter the outside world?

Corrections systems are using simulators to provide incarcerated people with more lifelike instruction, but research into the effectiveness of VR in these settings is scant.

By Daliah Singer

Atorrus Rainer, age 41, is standing in the center of a stuffy, fluorescent-lit room. A virtual-reality headset covers his eyes like oversize goggles. Every so often, he extends his arm, using the VR controller to pick up garbage bags, a toothbrush, and toilet paper during a simulated trip to the supermarket. The experience is limited—Rainer has to follow a pre-written shopping list and can only travel to specific locations within the empty store—but the sheer number of products available, even in this digital world, still overwhelms him. So does the self-checkout station: those didn't exist in 2001, when Rainer, then a teenager, was sentenced to more than 100 years in prison. His first experience with one is this virtual interaction taking place inside Fremont Correctional Facility, a medium-security prison about two hours south of Denver.

Rainer is practicing in the hopes of stepping into a real store in the near future through an initiative launched in Colorado in 2017 in response to US Supreme Court rulings that deemed juvenile life without parole sentences unconstitutional. People who meet certain requirements—for example, if they were under 21 when they committed felony crimes and have been incarcerated for a minimum of 20 to 30 years—can apply to work through the three-year Juveniles and Young Adults Convicted as Adults Program (JYACAP) in an effort to earn early parole.

The premise of JYACAP is that learning the basic skills they missed the chance to acquire while incarcerated will provide these juvenile lifers with their best chances for success upon release. That's a formidable challenge. Because of safety concerns, they have had limited access to the internet. Though they're now adults, many have never used, or even seen, a smartphone or a laptop. Or had a credit card. "We had to figure out a way of giving them these opportunities in a restricted environment," says Melissa Smith, interim director of prisons for the Colorado Department of Corrections.

Though its use is not yet widespread, a handful of state corrections departments, from Ohio to New Mexico, have turned to virtual reality as an answer. The goals vary from helping reduce aggressive behavior to facilitating empathy with victims to, as in Colorado's case, reducing recidivism. Though the state's prison budget sits close to $1 billion, Colorado has one of the worst return-to-prison rates in the country, at around 50%. Nationally, as many as two-thirds of the 600,000 people released from state and federal prisons each year will be rearrested within three years.

Is VR the long-missing piece in an unwieldy puzzle of resources and programs meant to help reverse these statistics? Or is it yet another experiment that will fail to adequately prepare incarcerated individuals for life beyond lockup? "It's not going to be the silver bullet, but it is a tool that I think is very powerful for a lot of people, because they never really get a chance to practice what we're trying to teach them," says Bobbie Ticknor, an associate professor of criminal justice at Valdosta State University. "I think we should use everything we can find and see what works the best."

Proponents like Ticknor say VR can immerse incarcerated people in the sights and sounds of modern life and help them develop digital literacy in a secure corrections environment. "When you're role-playing, when you're learning a new skill, the closer you can bring them to doing what they're actually going to have to do out in the real world, the better," says Ethan Moeller, founder and managing director of Virtual Training Partners, which helps organizations successfully implement virtual-reality tools. "VR does that better than any other training medium."

Others are more skeptical. Like Dr. Cyndi Rickards, an associate teaching professor at Drexel University who leads weekly criminology courses inside Philadelphia prisons. People who are incarcerated wear the "label of inmate on their back. It's a dehumanizing system," she says, "so to suggest that VR is going to reintegrate them into society after being in a punitive system...just further objectifies folks, it continues a pattern of dehumanizing folks, and I've not read any compelling evidence that this is the route we should use to integrate people to be members of a healthy and contributing society."

Rainer believes the grocery store simulation was beneficial but is aware that the real world, should he step back into it, will be very different from the video-game-like version he's interacting with at Fremont. "Going back to society, I don't want to freeze up while I'm in a grocery store or something, not figuring out what I need to buy because [there are] too many options," he says. "I don't really like working on a computer, but I know I got to."

As VR technology grows more affordable, the programming becomes an increasingly budget-friendly option for states that are already dealing with persistent workforce shortages. "If we reduce recidivism rates, it actually helps the community and reduces crime," explains Sarah Rimel, the former technology research program manager at Colorado's National Mental Health Innovation Center. "It reduces the amount of money that's put into the prison systems."

VR has proved a beneficial therapeutic tool, helping to lower depression rates, reduce anxiety, conquer phobias, promote emotional empathy, and address post-traumatic stress. VR exposure therapy has been successfully used to help vulnerable populations such as veterans and sexual-assault survivors confront, and better cope with, their triggers and trauma. All that research is based on interventions done with people who are not incarcerated, however.

The currently available evidence in correctional settings is limited and mostly anecdotal. But there have been some positive findings. For example, a short-term pilot initiative in Alaska that incorporated mindfulness techniques through VR resulted in decreased reports of depressive or anxious feelings and fewer disciplinary write-ups. In Michigan, a virtual-reality tool for job interview training, originally developed for people with serious mental illness, was piloted with 44 men involved with the justice system. The findings, published in March 2022, showed that 82% of those who used the tool landed a job within six months of being released, compared with 69% of other program participants. When variables like age, race, and time served were taken into account, the data suggested that those who used the tool had 7.4 times greater odds of getting a job. "Above just the employment rate, those that interviewed with Molly [the virtual hiring manager] had stronger interview skills over time, greater reductions in interview anxiety over time, and greater increase in motivation to interview over time," says Matthew Smith, a professor of social work at the University of Michigan, who led the effort. He and his team are now enrolling a larger group in a validation study.

Colorado doesn't have any data sets to point to. Only one of the 16 people who've been released through JYACAP over the course of almost three years have been rearrested. Two of those 16 were paroled before completing the full curriculum. "If the right scenarios are used," says Cheryl Armstrong, one of the first JYACAP graduates, "it [VR] is helpful, to a certain extent, to give you an idea of what you're going to be facing."

While Valdosta State's Ticknor estimates that fewer than 10% of corrections facilities are currently using VR simulators with incarcerated individuals, she expects that to change soon. "I would be very surprised within five years if this is not a very regular treatment modality for this particular population," she says. ■

Daliah Singer is a freelance journalist based in Denver.

Jobs of the future: Marketer of embryo predictions

By Antonio Regalado

Elizabeth Carr is head of commercial development at Genomic Prediction, a New Jersey genetic testing startup that assesses IVF embryos for their future risk of a dozen common diseases so parents can pick the "best" one. It's a controversial area that has critics anguishing over the dawn of consumer eugenics.

Wow, that résumé: Carr, who is in charge of sales and marketing, is a natural fit for the job. That's because she is "America's first test-tube baby," as the headlines proclaimed in 1981, when she became the first person born through IVF in the US.

Career path: Carr started out as a health journalist, spending 15 years at the Boston Globe. "I had my first press conference when I was three days old," she says. "I always had reporters asking me questions, and I was like, 'I could do a better job.'" She later moved into ghostwriting and marketing for IVF clinics.

Handling controversy: Embryo scores are hotly debated, with some geneticists calling them unproven and even unethical. Carr skillfully dodges this debate, noting that IVF itself once attracted similar concerns. "Not to draw a very, very, obvious connection to my own life, but it's really no different, right?" she says. "If you have moral objections to the test or you don't agree with it, don't use it. It's the same thing with IVF."

The product: Genomic Prediction says its scoring method can help parents pick which IVF embryo has the brightest health future. It works by measuring thousands of individual genetic differences between them, resulting in what's known as a polygenic score. Testing an embryo costs about $1,000. "This was not even in the realm of possibility when I was born. And so it's really exciting," says Carr.

Downside of being America's first IVF baby: "There's no lying about my age for sure," she says. "And yes, it is slightly awkward to still be referred to as a baby." ■

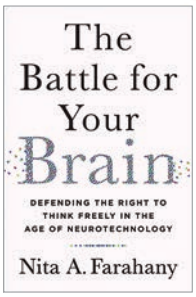
PHOTO COURTESY OF ELIZABETH CARR

Tech that aims to read your mind and probe your memories is already here

We need new rules to protect our cognitive liberty, says futurist and legal ethicist Nita Farahany.

By Jessica Hamzelou

Nita Farahany, a futurist and legal ethicist at Duke University in Durham, North Carolina, has spent much of her career exploring the impacts of new technologies—in particular, those that attempt to understand or modify our brains.



In recent years, we've seen neurotechnologies move from research labs to real-world use. Schools have used some devices to monitor the brain activity of children to tell when they are paying attention. Police forces are using others to work out whether someone is guilty of a crime. And employers use them to keep workers awake and productive.

These technologies hold the remarkable promise of giving us all-new insight into our own minds. But our brain data is precious, and letting it fall into the wrong hands could be dangerous, Farahany argues in her new book, *The Battle for Your Brain*. I chatted with her about some of her concerns.

Your book describes how technologies that collect and probe our brain data might be used – for better or for worse. What can you tell from a person's brain data?

When I talk about brain data, I'm referring to the use of EEG, fNIRS [functional near-infrared spectroscopy], fMRI [functional magnetic resonance imaging], EMG, and other modalities that collect biological, electrophysiological, and other functions from the human brain. These devices tend to collect data from across the brain, and you can then use software to try to pick out a particular signal.

Neuroscientists listened in on people's brains for a week. They found order and chaos.

The study shows that our brains exist between chaos and stability—a finding that could be used to help tweak them either way.

Brain data is not thought. But you can use it to make inferences about what's happening in a person's mind. There are brain states you can decode: tired, paying attention, mind wandering, engagement, boredom, interest, happy, sad. You could work out how they are thinking or feeling, whether they are hungry, whether they are a Democrat or Republican.

You can also pick up a person's reactions, and try to probe the brain for information and figure out what's in their memory or their thought patterns. You could show them numbers to try to figure out their PIN number, or images of political candidates to find out if they have more positive or negative reactions. You can probe for biases, but also for substantive knowledge that a person holds, such as recognition of a crime scene or a password.

Until now, most people will only have learned about their brain data through medical exams. Those records are protected. What about brain data collected by consumer products?

I feel like we're at an inflection point. [A lot of] consumer devices are hitting the market this year and in the next two years. There have been huge advances in AI that allows us to decode brain activity, and in the miniaturization of electrodes, which [allows manufacturers] to put them into earbuds and headphones. And there has been significant investment from big tech companies. It is, I believe, about to become ubiquitous. The only person who has access to your brain data right now is you, and it is only analyzed in the internal software of your mind. But once you put a device on your head … you're immediately sharing that data with whoever the device manufacturer is, and whoever is offering the platform. ■

Jessica Hamzelou is a senior reporter at MIT Technology Review. Read the full Q&A at www.technologyreview.com.

PHOTO COURTESY OF NITA FARAHANY

These pothos plants are engineered to remediate air pollution

ANTOINE GUILLOTEAU

The air-cleaning qualities of plants are getting a genetically modified boost

Indoor plants aren't as good for air quality as you might think, but a French startup aims to fix that.

By Claire L. Evans

In the late 1980s, NASA conducted a study to determine how well indoor plants like aloe vera, Chinese ivy, and potted chrysanthemums abate air pollution. The results were a boon to nursery owners everywhere: the research showed that houseplants can capably dispatch harmful pollutants including benzene and formaldehyde.

But NASA's study was conducted in sealed chambers mimicking future long-term space habitats. A 2020 analysis in the Journal of Exposure Science & Environmental Epidemiology provided some sobering context: it would take 680 plants to clean the air in a 1,500-square-foot room—highly unrealistic for most plant parents. If the French biotech startup Neoplants has its way, though, you might need only one.

Neoplants's marquee product, announced late last year, is the Neo P1, the first houseplant genetically engineered to remediate indoor air pollution. At first blush, this high-tech pothos—a tropical vine native to the Solomon Islands, also known as "Devil's Ivy"—is indistinguishable from the real thing. It's photogenic, fast-growing, and hard to kill. But unlike typical nursery stock, it also metabolizes indoor air pollutants missed by traditional air purifiers, which filter particulate matter: the volatile organic compounds (VOCs) produced by paint, gas stoves, and building materials.

"It's actually a two-pronged approach," explains Neoplants's chief technology officer and cofounder, Patrick Thorbey. The first prong is the genetic engineering of the plant's metabolism. By introducing additional genes into the plant, Thorbey's Paris-based team coaxed the pothos to produce enzymes allowing it to use the VOCs it absorbs as carbon sources in its normal cellular metabolism. In a virtuous cycle, more air pollution only creates more plant matter and greater pollution-fighting capacity.

The second prong is bacterial. In a Neoplant, as in nature, microbes do the heavy lifting; two strains of symbiotic bacteria inserted into the Neo P1's soil turn formaldehyde and the class of pollutants known as BTEX—benzene, toluene, ethylbenzene, and xylene—into harmless sugars and amino acids.

"Bacteria are really important parts of most nutrient cycles," explains Jenn Brophy, a Stanford researcher whose lab develops genetically engineered plants with greater resilience to climate change. "But microbiomes are very difficult to maintain. As soon as you ship a product to somebody, the viability of these bacteria declines." This vulnerability seems to be Neoplants's business model: the company will offer concentrated doses of proprietary microorganisms it calls "power drops" to maintain the plant's air-cleaning efficiency. These will need to be applied monthly, much like replacing the filter in an air purifier. "Dyson, they sell their filters," says cofounder and CEO Lionel Mora. "We sell microbiome."

For now, the pothos itself is responsible for only about 30% of the Neo P1's air-cleaning capacity—the microbiome handles the rest—but Mora and Thorbey expect that to change soon. It's faster to improve on microbes than plants, they explain, so "the limits of what we can do with the plant are still far in front of us," Mora says. "We are at the frontier of what is doable right now, but we see tremendous potential."

The Neo P1 is the company's first volley. "Air-filtering plants may get people to think about GMOs in a new way," says Brophy. "Having something that you can touch and feel that is nonthreatening, but tangible, is a great way to get people introduced to the concept of genetically modified organisms."

"I'll be disappointed if there's a plant on the moon and it's not a Neoplant."

The timing is fortuitous. Pothos plants have become familiar companions in the indoor landscape of remote work just as the political debate about gas stoves has raised our awareness of once-unfamiliar domestic hazards. According to the EPA, Americans spend around 90% of their lives inside, where concentrations of some pollutants can be anywhere from two to five times higher than they are outdoors. "Usually we feel safe indoors," says Mora. "But covid has shown us that even indoors, invisible things can be very harmful."

It's clear that Mora and Thorbey are ultimately looking beyond indoor air cleaning and toward climate applications. "It's easier to have an impact in the bedroom than to start with the atmosphere," Thorbey says. "But I'll be disappointed if there's a plant on the moon and it's not a Neoplant." ■

Claire L. Evans is a writer and musician exploring ecology, technology, and culture.

Op-ed

A ban on ChatGPT does more harm than good

Most of my classmates still haven't heard about OpenAI or any of its AI models. That's a problem.

By Rohan Mehta

The release of ChatGPT has sent shock waves through the halls of higher education. Universities have rushed to release guidelines on how it can be used in the classroom. Professors have taken to social media to share a spectrum of AI policies. And students—whether or not they'll admit it—have cautiously experimented with the idea of allowing it to play a part in their academic work.

But the notion of a measured response to the emergence of this powerful chatbot seems to have barely penetrated the world of K–12 education. Instead of transparent, well-defined expectations, high schoolers across the country have been confronted with a silent coup of blocked AI websites.[1]

That's a shame. If educators actively engage with students about the technology's capabilities and limitations—and work with them to define new academic standards—ChatGPT, and generative AI more broadly, could both democratize and revitalize K–12 education on an unprecedented scale.

A bold claim, I know. But after a few months of putting generative AI to the test (a nerdy case of senioritis, if you will), I'm optimistic. Exhibit A? College applications.

Few things are as mentally draining as applying to college these days, and as I slaved away at my supplemental essays, the promise of using ChatGPT as a real-time editor was attractive—partly as a potential productivity boost, but mostly as a distraction.

I had ChatGPT carefully review my cloying use of semicolons, grade my writing on a 0–10 scale (the results were erratic and maddening)[2], and even role-play as an admissions counselor. Its advice was fundamentally incompatible with the creative demands of the modern college essay, and I mostly ignored it. But the very act of discussing my writing "out loud," albeit with a machine, helped me figure out what I wanted to say next. Using ChatGPT to verbalize the space of possibilities—from the scale of words to paragraphs—strengthened my own thinking. And I've experienced something similar across every domain I've applied it to, from generating fifth-grader-level explanations of the French pluperfect to deciphering the Latin names of human muscles.

All this adds up to a simple but profound fact: anyone with an internet connection now has a personal tutor, without the costs associated with private tutoring. Sure, an easily hoodwinked, slightly delusional tutor, but a tutor nonetheless. The impact of this is hard to overstate, and it is as relevant in large public school classrooms where students struggle to receive individual attention as it is in underserved and impoverished communities without sufficient educational infrastructure. As the psychologist Benjamin Bloom demonstrated in the early 1980s, one-on-one instruction until mastery allowed almost all students to outperform the class average by two standard deviations ("about 90% … attained the level … reached by only the highest 20%").

ChatGPT certainly can't replicate human interaction, but even its staunchest critics have to admit it's a step in the right direction on this front. Maybe only 1% of students will use it in this way, and maybe it's only half as effective as a human tutor, but even with these lowball numbers, its potential for democratizing educational access is enormous. I would even go so far as to say that if ChatGPT had existed during the pandemic, many fewer students would have fallen behind.

Of course, those decrying ChatGPT as the end of critical thinking would likely protest that the bot will only exacerbate the lazy academic habits students might have formed over the course of the pandemic. I have enough experience with the tips and tricks we high schoolers employ on a regular basis to know that this is a valid concern—one that shouldn't be brushed off by casting ChatGPT as just the latest in a long line of technological revolutions in the classroom, from the calculator to the internet.

That said, ChatGPT has just as much potential in the classroom as it does for improving individual educational outcomes. English teachers could use it to rephrase the notoriously confusing answer keys to AP test questions, to help students prepare more effectively. They could provide each student with an essay antithetical to the one they turned in, and have them pick apart these contrary arguments in a future draft. No human teacher could spend the time or energy needed to explain pages upon pages of lengthy reading comprehension questions or compose hundreds of five-page essays, but a chatbot can.

Educators can even lean into ChatGPT's tendency to falsify, misattribute, and straight-out lie as a way of teaching students about disinformation. Imagine using ChatGPT to pen essays that conceal subtle logical fallacies or propose scientific explanations that are almost, but not quite, correct. Learning to discriminate between these convincing mistakes and the correct answer is the very pinnacle of critical thinking, and this new breed of academic assignment will prepare students for a world fraught with everything from politically correct censorship to deepfakes.

There are certainly less optimistic visions for the future. But the only way we avoid them—the only way this technology gets normalized and regulated alongside its similarly disruptive forebears—is with more discussion, more guidance, and more understanding. And it's not as if there's no time to catch up. ChatGPT won't be acing AP English classes anytime soon, and with the recent release of GPT-4, we are already seeing an explosion of ed-tech companies that reduce the effort and expertise needed for teachers and students to operate the bot.

So here's my pitch to those in power. Regardless of the specific policy you choose to employ at your school, unblock and unban. The path forward starts by trusting students to experiment with the tool, and guiding them through how, when, and where it can be used. You don't need to restructure your whole curriculum around it, but blocking it will only send it underground. That will lead to confusion and misinterpretation in the best of cases, and misuse and abuse in the worst.

ChatGPT is the only beginning. There are simply too many generative AI tools to try to block them all, and doing so sends the wrong message. What we need is a direct discourse between students, teachers, and administrators. I'm lucky enough to be at a school that has taken the first steps in this direction, and it's my hope that many more will follow suit. ■

Rohan Mehta is a high school senior at Moravian Academy in Bethlehem, Pennsylvania.

Rohan Mehta

PHOTO COURTESY OF ROHAN MEHTA

Footnotes

1 At least in my case, the entirety of openai.com has been blocked, not just chat.openai.com. Kind of annoying if I want to access the fine-tuning docs.

2 The most impressive thing I have seen ChatGPT do is revise one of my essays. In it, I discussed two global political figures, but concealed their identities through personification. To "make my essay a 10/10" and "increase clarity," ChatGPT filled their names in. The fact that it has emergent abilities like this blew my mind!

How do fungi communicate?

Turns out they have a lot to say.

By Michael Hathaway
and Willoughby Arévalo
Illustration by Kate Dehler

Although most of us think of fungi as "mushrooms," these spore-producing bodies are just the reproductive organs of mycelium—decentralized, weblike bodies of branching tubes. Though usually microscopic, these structures can be enormous; the largest known example is a honey mushroom (*Armillaria*) that covers almost 10 square kilometers (3.7 square miles) and has lived for millennia.

As organisms living in complex relations to other life forms, fungi could not exist without communicating. And while they've traditionally been viewed as sessile, or permanently fixed in place, mycelia move by extending the tips of their tubes through a substrate, which could be a patch of soil or a fallen log.

As fungi grow, they are constantly sensing, learning, and making decisions. Fungi are like polyglots: they both "speak" and understand a wide range of chemical signals. They release and respond to chemicals that float through the air and flow through water. Fascinatingly, fungi not only perceive but actively interpret a chemical's meaning depending on the context and in relation to other chemicals.

Studies of how fungi communicate lag way behind research on communication of plants and especially of animals. Most are based on several "lab rat" species, so knowledge about other types is limited, but here we summarize what's known about three realms of communication: within a fungus, between fungi of the same species, and with other organisms.

Within a fungus

Each growing tip has both autonomy from and accountability to the whole organism, akin to the relationship of social insects to the hive. Between the cells within every mycelium flows a stream of chemicals, nutrients, and electrical impulses. Their movements act to keep the whole informed about happenings and coordinate actions across the network. Research by Andrew Adamatzky, a professor of unconventional computing at the University of the West of England in Bristol, suggests that they influence the mycelium's internal bioelectrical signals, which may form a sort of "language." While a mycelium neither is nor contains a nervous system, mycelia share much in common with these systems. Both have branched structures, reinforce or prune pathways as needed, and use some of the same amino acids to transmit information.

Between fungi of the same species

Many fungi are sexual and must mate to reproduce. They send out pheromones and "sniff" out those of others, and then they grow toward those that seem attractive (based on whatever it is fungi are attracted to). Whenever two mycelia meet, they communicate to negotiate their relationship, which can range from fusion (to form a reproductive or nonreproductive partnership) to indifference to physical exclusion and even chemical antagonism. Each mated mycelium negotiates the physical dynamics of fusion, and of life in partnership thereafter.

With other organisms

Fungi "talk" and respond to many other beings.

Through mycorrhizal mutualisms, they may share water and food with plant partners. Parasitic fungi produce a myriad of plant growth regulators, modifying plants to suit their needs. Some fungi, such as truffles, mimic animal sex pheromones to attract mammals and insects that act as "sporinators," the fungal equivalent to pollinators. Other fungi are prey to roundworms (also known as nematodes). When they detect a nematode nearby, they can produce defensive compounds to ward it off. Other fungi hunt nematodes by detecting their chemical presence.

Mycorrhizal fungi are central in current debates about the "wood-wide web," but many representations unfairly present fungi as living fiber-optic cables that allow trees to "talk" to each other. Fungi are more than just passive wires; they are, in fact, actively perceiving, interpreting, and signaling themselves. They do this constantly, with a wide range of beings. How mushrooms create and interpret these signals in a cacophony of chemical and electrical noise remains a fascinating mystery. ■

Michael Hathaway is the author of What a Mushroom Lives For: Matsutake and the Worlds They Make. Willoughby Arévalo is the author of DIY Mushroom Cultivation: Growing Mushrooms at Home for Food, Medicine, and Soil.

The Nigerian university dropout who builds EVs

Mustapha Gajibo aims to bring electrification to communal buses.

By Valentine Benjamin
Photographs by Fati Abubakar

Nigerians have become accustomed to long lines for gasoline and wild fluctuations in bus fares. Though the country is Africa's largest producer of oil, its residents don't benefit from a steady supply.

Mustapha Gajibo, 30, is doing what he can to alleviate the problem: his startup, Phoenix Renewables Limited, is launching a homegrown electric-vehicle industry in the northeastern city of Maiduguri.

Gajibo dropped out of university in his third year to run it. His first project was converting the internal-combustion engines of commonly used vehicles in the city to electric versions. He focused on two types of vehicles that residents often pay to ride: seven-seat minibuses and the motorized tricycles known as kekes.

He faced skepticism at first: limited power charging infrastructure has constrained the adoption of electric vehicles in the region. "Many people don't believe that electric mobility is possible and commercially viable in the city of Maiduguri," Gajibo says. But his electrification scheme has been gaining traction. The company now maintains a fleet of a dozen electric minibuses that can cover a distance of 150 kilometers on a charge and cost about $1.50 to power to full capacity.

Building the necessary infrastructure is crucial to the success of the project. Gajibo and his cofounder Sadiq Abubakar Issa designed a 60-kilowatt-hour solar-powered charging station in the city and are looking at creating more.

Now, Gajibo has moved on from retrofitting internal-combustion vehicles to building electric vehicles from scratch.

The first, introduced in 2021, is a 12-seat bus constructed from a number of locally sourced materials. It has a range of 212 kilometers and can be charged in 35 minutes via a solar-powered system integrated into the back. In a recent test run funded by the company, the buses transported 35,000 passengers in Maiduguri in just one month.

Phoenix Renewables maintains a fleet of a dozen retrofitted electric minibuses capable of covering a distance of 150 kilometers on a charge.

Deborah Maidawa, an electrical building services engineer who lives in Maiduguri, believes Gajibo's EVs are a good way to meet local needs. "Incorporating solar gives the vehicles an edge over other EVs that are springing up, and I believe they will flood the Nigerian market," she says.

A brand-new gas-powered passenger minibus with automatic transmission can cost nearly 5 million naira (about $10,000). Gajibo says it will cost around the same to buy one of his solar-powered 12-seaters. He plans to roll out 500 units across eight Nigerian cities in the coming months and hopes this time he'll be able to sell them.

"Our products are quite affordable, and the cost of the vehicle is one of the major things we put into consideration," he says. "The only way to achieve that is by fully designing and building these vehicles locally."

State and local governments are now taking notice. In early 2022, for example, the governor of Borno State, where Maiduguri is situated, commended Gajibo's work and awarded him 20 million naira (about $45,000) for research and development, as well as 15,000 square meters of land for a factory. The Nigerian government has expressed interest in having his company build electric patrol vehicles for the police and armed forces.

Gajibo's ultimate goal is to compete with Tesla and other bigger brands. "We want to have our vehicles driven in New York, London, Munich, and other big cities across the world," he says. ■

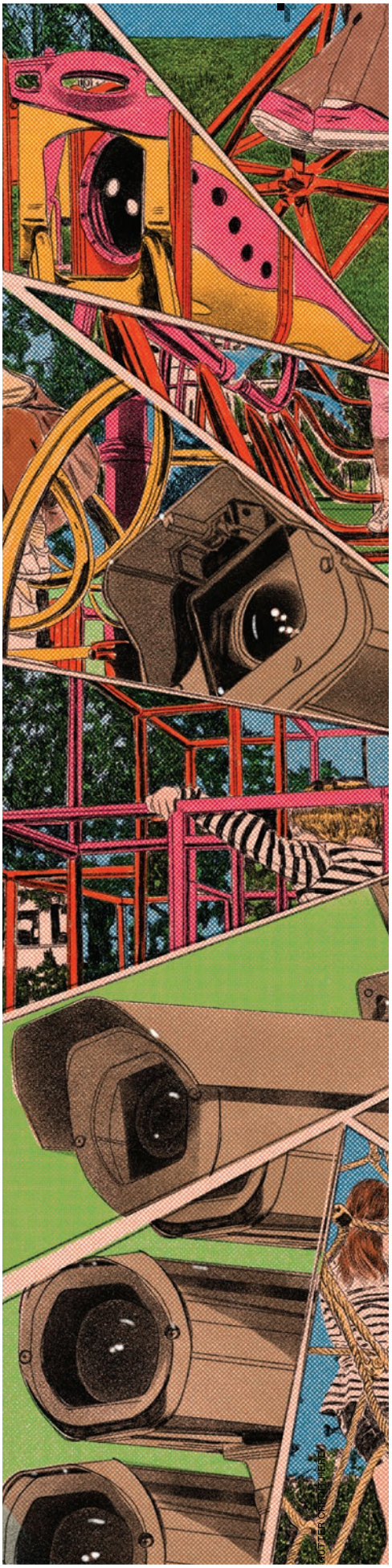
Valentine Benjamin is a Nigerian travel journalist and photographer who reports on global health, social justice, politics, and development in Nigeria and sub-Saharan Africa.

Denmark's enthusiasm for educational tech is taking on a new frontier: children's well-being.

By
Arian Khameneh

Calibrating the classroom

Illustrations by
Nicole Rifkin



In a Copenhagen suburb, a fifth-grade classroom is having its weekly cake-eating session, a common tradition in Danish public schools. While the children are eating chocolate cake, the teacher pulls up an infographic on a whiteboard: a bar chart generated by a digital platform that collects data on how they've been feeling. Organized to display the classroom's weekly "mood landscape," the data shows that the class averaged a mood of 4.4 out of 5, and the children rated their family life highly. "That's great!" the teacher exclaims, raising two thumbs up in the air.

She then moves to an infographic on sleep hygiene. Here the data shows the students struggling, and the teacher invites them to think of ways to improve their sleeping habits. After briefly talking among themselves, the children suggest "less screen time at night," "meditation before sleep," and "having a hot bath." They collectively make a commitment to implement these strategies. At next week's cake time, they will be asked whether or not they followed through.

These sorts of data-driven well-being audits are becoming more and more common in Denmark's classrooms. The country has long been a leader in online services and infrastructure, ranking as the most digitally developed nation in the UN's e-government survey. In recent years its schools, too, have received big investments in this type of technology: it is estimated that the Danish government allocated $4 to $8 million, a fourth of the high school budget for teaching aids, to procuring digital platforms in 2018. In 2021, it invested some $7 million more.

These investments are rooted in a Nordic tradition of education that centers the child's experience and encourages interactive learning; some Scandinavian education researchers think technology can help draw children in as playful, active participants. "Technology is an extended pencil and drawing pad. It's a tool that is bound to the child's opportunity to express themselves," Mari-Ann Letnes, an education scientist in Norway, said in a 2018 interview. In a 2019 status report on the use of technology in schools, the Danish Ministry of Education stated that "creativity and self-expression with digital technologies are a part of building students' motivation and versatile development." Now, some teachers and administrators are hoping technology can be used to tackle mental health as well.

Danish schoolchildren are in the midst of a mental-health crisis that one of the country's biggest political parties has called a challenge "equal to inflation, the environmental crisis, and national security." No one knows why, but in just a few decades, the number of Danish children and youth with depression has more than sextupled. One-quarter of ninth graders report that they have attempted self-harm. (The problem isn't exclusive to Denmark: depressive episodes among US teens increased by some 60% between 2007 and 2017, and teen suicide rates have also leaped by around 60% over the same period.) A recent open letter signed by more than 1,000 Danish school psychologists expressed "serious concerns" over the mental state of the children they see in their work and warned that if action isn't taken immediately, they "see no hope for turning the negative trend around."

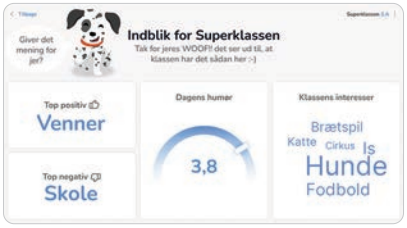
To help address the problem, some Danish schools are moving to address children's well-being through platforms like Woof, the one used in the fifth-grade classroom. Built by a Denmark-based startup, it frequently surveys schoolchildren on a variety of well-being indicators and uses an algorithm to suggest particular issues for the class to focus on.

These platforms are quickly gaining ground. Woof, for example, has been implemented in classrooms in more than 600 schools across Denmark, with more on the way. Its founders believe Woof fills an important niche: they say teachers have expressed widespread dissatisfaction with existing tools, in particular a government-run well-being survey. That survey audits schools once a year and delivers results on a delay; it might provide a snapshot for policymakers but is hardly useful for teachers, who need regular feedback to adjust their work.

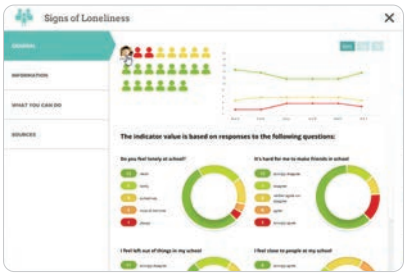
"There is simply a need for tools to check in [with the children] where you don't need to be active," says Mathias Probst, a cofounder of Woof. "Where you don't need to talk to all 24 children before starting a class, because before you know it, 15 minutes of class time has already passed." And teachers could benefit, he suggests, from "something that can bring a data structure into all of this."

Woof is not alone in its attempt to quantify children's moods. A handful of other platforms have been adopted by Danish schools, and schools in Finland and the UK are using mood-monitoring software as well. In the US, the tech can extend beyond collecting self-reports to hunting for hints of concerning behavior by surveilling students' emails, chat messages, and searches on school-issued devices.

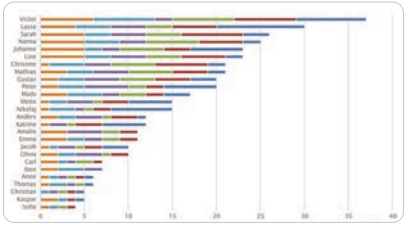
A number of people say mood-monitoring tech has great potential. "We can use digital tools to evaluate well-being on a 24-hour basis. How is the sleep? How is the physical activity, how is the interaction with others? ... How does [the child's] screen time compare to physical time? That's central to understanding what well-being actually is," the late Carsten Obel, who was a professor of public health at Aarhus University and a leader in the



Teachers using Woof see classroom averages instead of data on individual children.



Bloomsights takes a more data-intensive approach, tracking schoolchildren individually. The platform even generates sociograms that display their relationships with one another.



Klassetrivsel also generates results on individuals, including sociograms.

development of another student-surveying tool called Moods, said in a 2019 video.

But some experts are heavily skeptical of the approach. They say there is little evidence that quantification of this sort can be used to solve social problems, and that fostering a habit of self-surveillance from an early age could fundamentally alter children's relationship to themselves and each other in a way that makes them feel worse rather than better. "We can hardly go to a restaurant or to the theater without being asked how we feel about it afterwards and ticking boxes here and there," says Karen Vallgårda, an associate professor at the University of Copenhagen who studies family and childhood history. "There is a quantification of emotions and experiences that is growing, and it's important that we ask ourselves whether that's the ideal approach when it comes to children's well-being."

Others are asking how much children and their parents actually know about what data is being collected—and how it is being used. While some platforms say they are collecting minimal or no personally identifiable data, others mine deep into individual children's mental states, physical activity, and even friend groups.

"Their practice is very Silicon Valley–like. They preach data transparency but have none themselves," says Jesper Balslev, a research consultant at the Copenhagen School of Design and Technology, of some of these platforms. Balslev says he is concerned that Woof and other platforms are being swiftly and naively rolled out without adequate regulation, testing, or efforts to make sure that the school culture allows children to abstain from participating in them. "Our regulatory technologies to deal with this are terrible," he says. It's possible that will change, he adds, "but right now, all the hobs are turned on at the same time."

Woof is run from a basement office on the outskirts of Copenhagen, with a small team of three full-time staffers. The founders, Mathias Probst and Amalie Danckert, got the idea for the company after working as public school teachers through Teach First Denmark, an organization similar to Teach for America in the United States.

When Probst and Danckert entered the public school system, they say, they quickly realized that schools in low-income neighborhoods face a vicious cycle. Difficult circumstances at home can make students in these schools more challenging to teach. Staff turnover rates are high because of stress and burnout, with some teachers keen to switch to "easier" schools. Parents with resources often take their children elsewhere, so kids with more problems make up an even greater proportion of those who remain, exacerbating the stress teachers face and the likelihood that they'll leave. All this compounds the well-being crisis that children are experiencing elsewhere.

"I saw so many children ending up in difficult situations, which could have been prevented if action had been taken earlier," says Danckert, who before her stint as a teacher worked as an analyst in the children and youth section of Copenhagen's Social Services Administration.

Danckert and Probst, who has a background in consulting, set out to build a way to help schools manage such situations before they spiral into serious mental-health problems—problems that schools' thinly stretched counseling systems may not catch until it's too late.

Woof, the solution they devised, is a web app that children can access on computers or phones (a 2019 study found that 98% of Danish children between 10 and 15 have access to a smartphone). Its user interface primarily features a cartoon dog, which asks the children various questions about their life. The tool is designed to be used on a weekly basis, generating a "mood landscape" for the class by prompting kids to rate their mood and other aspects of their lives on a 1–5 scale. The result is supposed to add up to a comprehensive image of child welfare in that classroom over time.

Teachers and administrative staff can read weekly reports on a class's overall self-reported mood and how factors like their sleep hygiene, social activity, academic performance, and physical activity affect that mood. Classrooms are profiled, and interventions are recommended to improve the scores in categories where they are doing less well. Finally, the teacher and the children look at the data together and help each other with tools and strategies to improve these sticking points.

Woof's data is anonymized; the app reports on classroom averages instead of

individual children. Danckert says that's because the company was unwilling to walk right up to the edge of what was legally and ethically feasible under data privacy laws. Probst also describes feeling uneasy that collecting data on individual children might create a narrative and lock them into it, rather than helping them break negative patterns. "It's worrying that there is so much personally attributable data on platforms working with children," he says.

The startup fully launched Woof less than a year ago, in the fall of 2022. According to beta test data collected on 30 schools before its full launch, 80% of classes that use Woof see mood improve by, on average, 0.35 points on the 1–5 scale within one month. Woof maintains that the platform isn't meant to replace teacher-student contact. It should rather be understood as a support tool for teachers that provides structured action plans and feedback.

But some experts have doubts about whether Woof's methods are effective. They are particularly skeptical about the self-reported nature of the platform's data.

According to Balslev, education apps have not proved that they perform any better than analog interventions, such as having teachers advise children to turn off their computers and ask them how they slept last night. He points to historical lessons, such as a 2015 OECD study finding that digitalization in schools in a variety of countries had exacerbated a range of problems it was supposed to improve, with a net negative effect on learning outcomes.

"We intuitively trust data or the quantitative regime more than we trust humans," he says. "I have found no, or very few, studies that examine the use of ed tech in controlled environments."

And there is good reason to take self-reported well-being data with caution: children may not be providing honest information. Balslev claims that when technology is introduced into a social context, it can't be assumed that students will demonstrate ideal behavior and cooperate with its intentions. For example, in interviews he has done with high school students, he says they have reported gaming digital systems to do things like get more time for an assignment or make a writing exercise look longer than it actually is.

Though dishonest answers are of course possible, Probst and Danckert argue that Woof's anonymous approach makes authentic responses more likely than they might be otherwise. "Many students from low-income areas are very aware of whether they are anonymous or not. And they are very aware of what is disclosed about their family life," says Danckert. "The students don't want to talk about what is happening at home, because they are worried that it will start a case [with a social services agency]," Probst adds. He and Danckert believe that the anonymous approach builds trust and promotes honest disclosure, as students can be sure that it won't trigger the teacher's legal obligation to report red flags further up in the system.

Woof isn't the only well-being platform making inroads in Danish schools. Platforms like Bloomsights, Moods, and Klassetrivsel (Danish for "classroom well-being") are also getting traction. Each takes a more data-intensive and less anonymous approach than Woof, tracking and identifying schoolchildren individually. Bloomsights and Klassetrivsel even go as far as generating "sociograms"—network diagrams that display the children's relationships with each other in detail.

Bloomsights turns self-reported data from the same individuals over time into indicators including "signs of loneliness," "academic mindset," and "signs of bullying." Bloomsights is also used in the US, where some school districts are including it as part of an "early warning system" for identifying potential school shooters.

The company's US operations are based in Colorado. Cofounder Adam Rockenbach says the hope in bringing Bloomsights to the US was to spread the Scandinavian values of well-being and community. He asserts that the app is not meant to be a dystopian "Big Brother" but an extension of what teachers already do.

"You notice the student is coming into class, and maybe they're coming to class late more frequently than before, and they look a little disheveled," he says. "A good teacher is going to go find two or three minutes to connect with that student: 'Hey, it seems like there's something off here. Is there any way I can help you?'"

Citing his experiences as a teacher in inner-city schools in Los Angeles for six years, Rockenbach says it can be a challenge to know what is really going on with children who struggle in an environment that might be marked by gang violence and poverty. He says Bloomsights can help in situations where the signals are not so clear.

Rockenbach believes that anonymous data only makes early intervention more difficult, since it creates more work for teachers and educators in trying to identify who has problems and needs help. For this reason, he thinks collecting individual data is a necessity.

The program, which operates through a web app, takes self-reporting measurements similar to Woof's: monthly surveys of students, measuring various indicators of mental and physical well-being and students' evaluation of their learning environment.

But Bloomsights stands out in its use of sociograms, which are constructed from the students' reports of who their friends are and who they connect and spend time with.

"It's worrying that there is so much personally attributable data on platforms working with children."

Rockenbach says these sociograms are crucial tools to detect social isolation and might even help identify children who are vulnerable to bullying. He points to testimonial reports from schools as an indicator that the platform helps improve well-being. But, he adds, "we haven't conducted a full-on research project that might compare, for example, a school that uses Bloomsights versus a school that doesn't. That's something that we're looking to do."

Indeed, some teachers wonder how useful—or even ethical—the app is. "It's some very intimate things that are asked, and they [the children] don't necessarily know who is going to see it," says Naya Marie Nord, a teacher at a suburban Copenhagen school that uses Bloomsights. "Of course, I as a teacher should have insight into how my students are feeling. But that's something that I prefer to have conveyed in the confidentiality between me and the student, rather than it being told to a computer." Nord is concerned about how many teachers who don't work directly with the children still have access to their data. She believes the app straddles ethical boundaries given how much it impinges on students' private lives.

"They have no chance of understanding what is going on. It's not like we give them a long presentation explaining how it's used and who has access [to the data]," Nord says. "And if we did, we would get no honest answers. If they actually understood the amount of data I can see about them and how many others can see it as well, I believe they would answer differently."

According to the data policies of Klassetrivsel, one of the platforms that collect non-anonymized data, consent is not required from either parents or children before the app is used in the classroom. The company claims that since the app is an integrated tool used for "well-being purposes" at a public institution, it falls under a Danish legal clause that exempts public authorities from requirements about obtaining consent for data collection. And since the platforms aren't classified as "information society services" like Facebook or Google, there is no parental consent required under the General Data Protection Regulation, the European Union's sweeping data privacy law.

Legal precedents seem to back up Klassetrivsel's claims about how the data law applies to its work. In 2019, a parent submitted a complaint to the Danish Data Protection Agency, claiming that a data-driven well-being platform at her child's school was engaging in forced monitoring of the child. The parent further argued that "measuring and monitoring well-being is not the same as improving well-being." The agency ruled in favor of the school's municipality: the app was deemed a tool for maintaining tasks of "crucial social interest" that fall under the responsibility of schools.

"Usually, the legal authority that these third-party apps operate under is that they are offering a service on behalf of the public

authorities," says Allan Frank, an IT lawyer at the agency. But they must still store data correctly and not collect more than is necessary. They must also operate under the aegis of governmental authorization, he says: "If there is a random teacher or a school that has been convinced to suddenly set it up without the supervision of the municipality or the Ministry of Education, then that would be a problem."

In Denmark, parents can opt out if they don't want data collected on their children through these apps. According to Bloomsights, this is also the case in the US: although practices vary, Rockenbach says that parents typically sign a paper once a year that lists all the different services the school uses.

But because the apps are used in an educational context and are framed as altruistic, both parents and policymakers tend to have their guard down. "There are a lot of other apps where I limit my son's use, but I'm not concerned about apps used in the school the same way I am about TikTok and YouTube, for example," says Janni Hindborg Christiansen, mother of one of the children in the fifth-grade classroom that uses Woof. "At least Woof is used in a controlled environment and has a good purpose. I trust it more than so many other apps that I'd be more critical toward."

And for parents who don't want their children using such platforms, opting out is not always straightforward.

Henriette Viskum, the teacher of the fifth-grade class, describes Woof lessons as a part of her class's core programming, just like math, and says parents need to talk with the teacher to pull their child out of the program. "If it's a huge problem, we'll find a solution and then the child doesn't have to participate," Viskum says. "But then I would, as a teacher, put a big question mark around why the parents are so strongly opposed to working with well-being. I would be a bit concerned and curious about that."

The closeness between teachers and students can also make the degree of anonymity blurry. Viskum told me that if almost an entire class reports high scores on family life, for example, but one child does not, she can usually intuit who that person is and might casually try to take steps to help.

For Balslev, the embrace of slick data-driven solutions is due partly to their political appeal. In Denmark, technology sometimes tends to be presented as the solution to everything connected to teaching and education. The simple infographics that ed-tech companies offer, he says, have an allure for government officials faced with thorny social and pedagogical issues.

"What is fantastic about the digital [initiatives] is that they are good at making politicians look actionable—as if they have made some decisions," Balslev says.

But efficacy is not as much of a priority, he says: "It's quick and easy to produce some metrics that appear rhetorically convincing. The infographic might provide a very thin sliver of truth about reality, but it doesn't touch the core of the situation."

In fact, the technology risks actually making the situation worse, says Karen Vallgårda, the University of Copenhagen researcher. She is concerned that the "surveillance paradigm" could have unintended consequences for children's self-understanding.

"The infographic might provide a very thin sliver of truth about reality, but it doesn't touch the core of the situation."

"If we are asked to monitor ourselves according to a quantitative logic, emotions such as indignation and sorrow can appear as problematic emotional reactions, despite the fact that they are completely natural in certain scenarios of life. The children can feel that what they are feeling is wrong or undesirable, which is likely to propel greater well-being issues rather than ameliorating them," Vallgårda says.

"When we instill a measure of self-surveillance with children based on a clearly communicated ideal of how to structure one's everyday life, one's eating habits, and how to feel in certain contexts, there is a risk that children develop 'double unhappiness' due to not just being unhappy but also failing to live up to these ideals."

Vallgårda's concerns are echoed by other researchers, who argue that an excessive focus on whether children are happy can cause them to pathologize normal fluctuations in life. New studies also indicate that declining well-being is largely attributed to environmental and social pressures rather than individual factors.

Vallgårda believes that rather than pouring resources into tools that further a quantitative agenda, schools should instead be prioritizing efforts to hire and train professionals like teachers and school psychologists.

But digital platforms are significantly cheaper than hiring or training more people. Viskum, the fifth-grade teacher, points out that budgets are tight and waiting lists for appointments with the school psychologist are miles long. Given the material reality, the appeal of ed tech is understandable, even when there are few results to back it up.

While the quantification of children's lives might make academics balk, the children I met told me that they enjoyed using Woof and especially liked how the app helped them talk more nicely to each other. At a school I visited in a low-income neighborhood (the class scored 3.4 on the mood scale), a teacher said she was just happy to have a tool that might give her a general idea of what was going on with the children.

When I asked Woof's Probst about Vallgårda's criticisms, he said that unlike researchers studying children academically, those who work with children every day in the classroom can't afford to think in abstract terms.

"It's all well and good to be a theorist and have the opinion that you shouldn't be doing certain things, but there is also a reality out there in the classrooms," he says. "There is a practical situation where teachers face children who are struggling so much that they break down in tears during class. You have to do something there." ■

Arian Khameneh is a freelance journalist based in Copenhagen.

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AI IS TRANSFORMING HUMANITIES RESEARCH

Historians are using neural networks to draw new connections in the analysis of history.

By Moira Donovan
Illustrations by Beth Hoeckel

It's an evening in 1531,

in the city of Venice. In a printer's workshop, an apprentice labors over the layout of a page that's destined for an astronomy textbook—a dense line of type and a woodblock illustration of a cherubic head observing shapes moving through the cosmos, representing a lunar eclipse.

Like all aspects of book production in the 16th century, it's a time-consuming process, but one that allows knowledge to spread with unprecedented speed.

Five hundred years later, the production of information is a different beast entirely: terabytes of images, video, and text in torrents of digital data that circulate almost instantly and have to be analyzed nearly as quickly, allowing—and requiring—the training of machine-learning models to sort through the flow. This shift in the production of information has implications for the future of everything from art creation to drug development.

But those advances are also making it possible to look differently at data from the past. Historians have started using machine learning—deep neural networks in particular—to examine historical documents, including astronomical tables like those produced in Venice and other early modern cities, smudged by centuries spent in mildewed archives or distorted by the slip of a printer's hand.

Historians say the application of modern computer science to the distant past helps draw connections across a broader swath of the historical record than would otherwise be possible, correcting distortions that come from analyzing history one document at a time. But it introduces distortions of its own, including the risk that machine learning will slip bias or outright falsifications into the historical record. All this adds up to a question for historians and others who, it's often argued, understand the present by examining history: With machines set to play a greater role in the future, how much should we cede to them of the past?

Parsing complexity

Big data has come to the humanities through initiatives to digitize increasing numbers of historical documents, like the Library of Congress's collection of millions of newspaper pages and the Finnish Archives' court records dating back to the 19th century. For researchers, this is at once a problem and an opportunity: there is much more information, and often there has been no existing way to sift through it.

That challenge has been met with the development of computational tools that help scholars parse complexity. In 2009, Johannes Preiser-Kapeller, a professor at the Austrian Academy of Sciences, was examining a registry of decisions from the 14th-century Byzantine Church. Realizing that making sense of hundreds of documents would require a systematic digital


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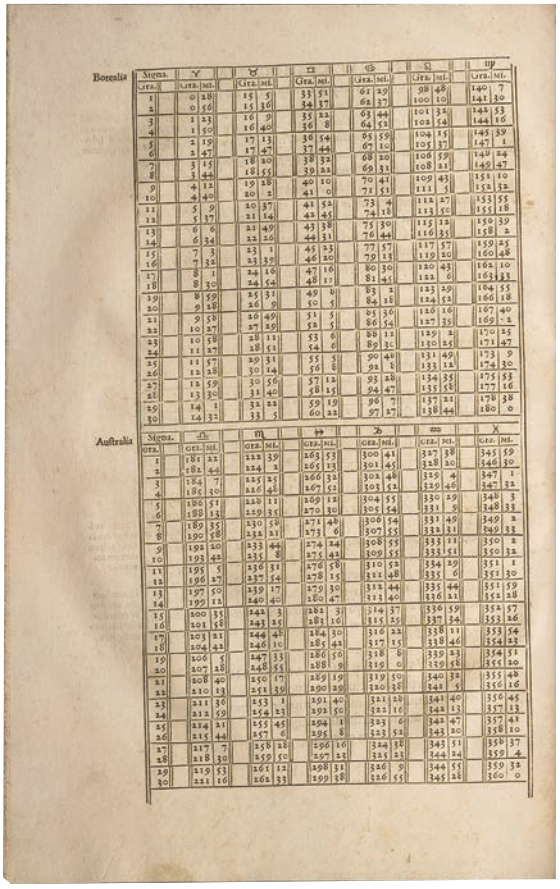
Borealis

Australis

survey of bishops' relationships, Preiser-Kapeller built a database of individuals and used network analysis software to reconstruct their connections.

This reconstruction revealed hidden patterns of influence, leading Preiser-Kapeller to argue that the bishops who spoke the most in meetings weren't the most influential; he's since applied the technique to other networks, including the 14th-century Byzantian elite, uncovering ways in which its social fabric was sustained through the hidden contributions of women. "We were able to identify, to a certain extent, what was going on outside the official narrative," he says.

Preiser-Kapeller's work is but one example of this trend in scholarship. But until recently, machine learning has often been unable to draw conclusions from ever larger collections of text—not least because certain aspects of historical documents (in Preiser-Kapeller's case, poorly handwritten Greek) made them indecipherable to machines. Now advances in deep learning have begun to address these limitations, using networks that mimic the human brain to pick out patterns in large and complicated data sets.

Nearly 800 years ago, the 13th-century astronomer Johannes de Sacrobosco published the *Tractatus de sphaera,* an introductory treatise on the geocentric cosmos. That treatise became required reading for early modern university students. It was the most widely distributed textbook on geocentric cosmology, enduring even after the Copernican revolution upended the geocentric view of the cosmos in the 16th century.

All this adds up to a question for historians: With machines set to play a greater role in the future, how much should we cede to them of the past?

The treatise is also the star player in a digitized collection of 359 astronomy textbooks published between 1472 and 1650—76,000 pages, including tens of thousands of scientific illustrations and astronomical tables. In that comprehensive data set, Matteo Valleriani, a professor with the Max Planck Institute for the History of Science, saw an opportunity to trace the evolution of European knowledge toward a shared scientific worldview. But he realized that discerning the pattern required more than human capabilities. So Valleriani and a team of researchers at the Berlin Institute for the Foundations of Learning and Data (BIFOLD) turned to machine learning.

This required dividing the collection into three categories: text parts (sections of writing on a specific subject, with a clear beginning and end); scientific illustrations, which helped illuminate concepts such as a lunar eclipse; and numerical tables, which were used to teach mathematical aspects of astronomy.

At the outset, Valleriani says, the text defied algorithmic interpretation. For one thing, typefaces varied widely; early modern print shops developed unique ones for their books and often had their own metallurgic workshops to cast their letters. This meant that a model using natural-language processing (NLP) to read the text would need to be retrained for each book.

The language also posed a problem. Many texts were written in regionally specific Latin dialects often unrecognizable to machines that haven't been trained on historical languages. "This is a big limitation in general for natural-language processing, when you don't have the vocabulary to train in the background," says Valleriani. This is part of the reason NLP works well for dominant languages like English but is less effective on, say, ancient Hebrew.

Instead, researchers manually extracted the text from the source materials and identified single links between sets of documents—for instance, when a text was imitated or translated in another book. This data was placed in a graph, which automatically embedded those single links in a network containing all the records (researchers then used a graph to train a machine-learning method that can suggest connections between texts). That left the visual elements of the texts: 20,000 illustrations and 10,000 tables, which researchers used neural networks to study.

Present tense

Computer vision for historical images faces similar challenges to NLP; it has what Lauren Tilton, an associate

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Top: A page from a 1531 published commentary of Prosdocimo di Beldomando on Johannes de Sacrobosco's *Tractatus de sphaera*. The page shows portions of the original and the commentary texts where the mechanics of solar and lunar eclipses are discussed.

Bottom: A table of values of oblique ascension calculated for the elevation of 48 degrees and 40 minutes to the celestial North Pole. The values were calculated by the French royal mathematician Oronce Finé.

professor of digital humanities at the University of Richmond, calls a "present-ist" bias. Many AI models are trained on data sets from the last 15 years, says Tilton, and the objects they've learned to list and identify tend to be features of contemporary life, like cell phones or cars. Computers often recognize only contemporary iterations of objects that have a longer history—think iPhones and Teslas, rather than switchboards and Model Ts. To top it off, models are typically trained on high-resolution color images rather than the grainy black-and-white photographs of the past (or early modern depictions of the cosmos, inconsistent in appearance and degraded by the passage of time). This all makes computer vision less accurate when applied to historical images.

"We'll talk to computer science folks, and they'll say, 'Well, we solved object detection,'" she says. "And we'll say, actually, if you take a set of photos from the 1930s, you're going to see it hasn't quite been as solved as we think." Deep-learning models, which can identify patterns in large quantities of data, can help because they're capable of greater abstraction.

In the case of the Sphaera project, BIFOLD researchers trained a neural network to detect, classify, and cluster (according to similarity) illustrations from early modern texts; that model is now accessible to other historians via a public web service called CorDeep. They also took a novel approach to analyzing other data. For example, various tables found throughout the hundreds of books in the collection couldn't be compared visually because "the same table can be printed 1,000 different ways," Valleriani explains. So researchers developed a neural network architecture that detects and clusters similar tables on the basis of the numbers they contain, ignoring their layout.

So far, the project has yielded some surprising results. One pattern found in the data allowed researchers to see that while Europe was fracturing along religious lines after the Protestant Reformation, scientific knowledge was coalescing. The scientific texts being printed in places such as the Protestant city of Wittenberg, which had become a center for scholarly innovation thanks to the work of Reformed scholars, were being imitated in hubs like Paris and Venice before spreading across the continent. The Protestant Reformation isn't exactly an understudied subject, Valleriani says, but a machine-mediated perspective allowed researchers to see something new: "This was absolutely not clear before." Models applied to the tables and images have started to return similar patterns.

These tools offer possibilities more significant than simply keeping track of 10,000 tables, says Valleriani. Instead, they allow researchers to draw inferences about the evolution of knowledge from patterns in clusters of records even if they've actually examined only a handful of documents. "By looking at two tables, I can already make a huge conclusion about 200 years," he says.

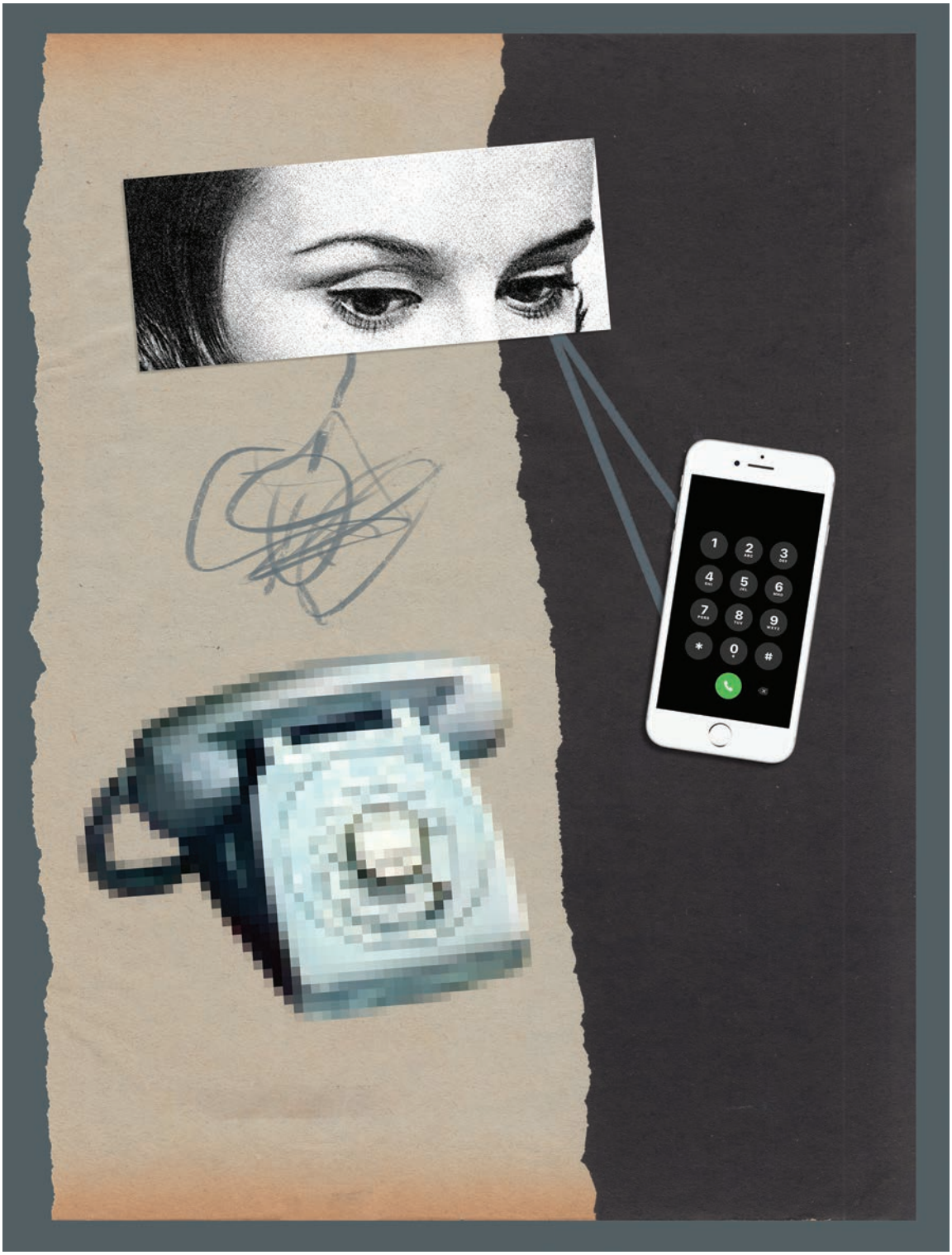
Deep neural networks are also playing a role in examining even older history. Deciphering inscriptions (known as epigraphy) and restoring damaged examples are painstaking tasks, especially when inscribed objects have been moved or are missing contextual cues. Specialized historians need to make educated guesses. To help, Yannis Assael, a research scientist with DeepMind, and Thea Sommerschield, a postdoctoral fellow at Ca' Foscari University of Venice, developed a neural network called Ithaca, which can reconstruct missing portions of inscriptions and attribute dates and locations to the texts. Researchers say the deep-learning approach—which involved training on a data set of more than 78,000 inscriptions—is the first to address restoration and attribution jointly, through learning from large amounts of data.

So far, Assael and Sommerschield say, the approach is shedding light on inscriptions of decrees from an important period in classical Athens, which have long been attributed to 446 and 445 BCE—a date that some historians have disputed. As a test, researchers trained the model on a data set that did not contain the inscription in question, and then asked it to analyze the text of the decrees. This produced a different date. "Ithaca's average predicted date for the decrees is 421 BCE, aligning with the most recent dating breakthroughs and showing how machine learning can contribute to debates around one of the most significant moments in Greek history," they said by email.

Time machines

Other projects propose to use machine learning to draw even broader inferences about the past. This was the motivation behind the Venice Time Machine, one of several local

Computers often recognize only contemporary iterations of objects that have a longer history—think iPhones and Teslas, rather than switchboards and Model Ts.



"time machines" across Europe that have now been established to reconstruct local history from digitized records. The Venetian state archives cover 1,000 years of history spread across 80 kilometers of shelves; the researchers' aim was to digitize these records, many of which had never been examined by modern historians. They would use deep-learning networks to extract information and, by tracing names that appear in the same document across other documents, reconstruct the ties that once bound Venetians.

Frédéric Kaplan, president of the Time Machine Organization, says the project has now digitized enough of the city's administrative documents to capture the texture of the city in centuries past, making it possible to go building by building and identify the families who lived there at different points in time. "These are hundreds of thousands of documents that need to be digitized to reach this form of flexibility," says Kaplan. "This has never been done before."

Still, when it comes to the project's ultimate promise—no less than a digital simulation of medieval Venice down to the neighborhood level, through networks reconstructed by artificial intelligence—historians like Johannes Preiser-Kapeller, the Austrian Academy of Sciences professor who ran the study of Byzantine bishops, say the project hasn't been able to deliver because the model can't understand which connections are meaningful.

Preiser-Kapeller has done his own experiment using automatic detection to develop networks from documents—extracting network information with an algorithm, rather than having an expert extract information to feed into the network as in his work on the bishops—and says it produces a lot of "artificial complexity" but nothing that serves in historical interpretation. The algorithm was unable to distinguish instances where two people's names appeared on the same roll of taxpayers from cases where they were on a marriage certificate, so as Preiser-Kapeller says, "What you really get has no explanatory value." It's a limitation historians have highlighted with machine learning, similar to the point people have made about large language models like ChatGPT: because models ultimately don't understand what they're reading, they can arrive at absurd conclusions.

It's true that with the sources that are currently available, human interpretation is needed to provide context, says Kaplan, though he thinks this could change once a sufficient number of historical documents are made machine readable.

But he imagines an application of machine learning that's more transformational—and potentially more problematic. Generative AI could be used to make predictions that flesh out blank spots in the historical record—for instance, about the number of apprentices in a Venetian artisan's workshop—based not on individual records, which could be inaccurate or incomplete, but on aggregated data. This may bring more non-elite perspectives into the picture but runs counter to standard historical practice, in which conclusions are based on available evidence.

Still, a more immediate concern is posed by neural networks that create false records.

Is it real?

On YouTube, viewers can now watch Richard Nixon make a speech that had been written in case the 1969 moon landing ended in disaster but fortunately never needed to be delivered. Researchers created the deepfake to show how AI could affect our shared sense of history. In seconds, one can generate false images of major historical events like the D-Day landings, as Northeastern history professor Dan Cohen discussed recently with students in a class dedicated to exploring the way digital media and technology are shaping historical study. "[The photos are] entirely convincing," he says. "You can stick a whole bunch of people on a beach and with a tank and a machine gun, and it looks perfect."

False history is nothing new—Cohen points to the way Joseph Stalin ordered enemies to be erased from history books, as an example—but the scale and speed with which fakes can be created is breathtaking, and the problem goes beyond images. Generative AI can create texts that read plausibly like a parliamentary speech from the Victorian era, as Cohen has done with his students. By generating historical handwriting or typefaces, it could also create what looks convincingly like a written historical record.

Meanwhile, AI chatbots like Character.ai and Historical Figures Chat allow users to simulate interactions with historical figures. Historians have raised concerns about these chatbots, which may, for example, make some individuals seem less racist and more remorseful than they actually were.

False history is nothing new—but the scale and speed with which fakes can be created is breathtaking.

Days of future past

Three key projects underway in the digital humanities

CorDeep

Who: Max Planck Institute for the History of Science

What: A web-based application for classifying content from historical documents that include numerical and alphanumerical tables. Software can locate, extract, and classify visual elements designated "content illustrations," "initials," "decorations," and "printer's marks."

Ithaca

Who: DeepMind

What: A deep neural network trained to simultaneously perform the tasks of textual restoration, geographic attribution, and chronological attribution, previously performed by epigraphers.

Venice Time Machine Project

Who: École Polytechnique Fédérale de Lausanne, Ca' Foscari, and the State Archives of Venice

What: A digitized collection of the Venetian state archives, which cover 1,000 years of history. Once it's completed, researchers will use deep learning to reconstruct historical social networks.

In other words, there's a risk that artificial intelligence, from historical chatbots to models that make predictions based on historical records, will get things very wrong. Some of these mistakes are benign anachronisms: a query to Aristotle on the chatbot Character.ai about his views on women (whom he saw as inferior) returned an answer that they should "have no social media." But others could be more consequential—especially when they're mixed into a collection of documents too large for a historian to be checking individually, or if they're circulated by someone with an interest in a particular interpretation of history.

Even if there's no deliberate deception, some scholars have concerns that historians may use tools they're not trained to understand. "I think there's great risk in it, because we as humanists or historians are effectively outsourcing analysis to another field, or perhaps a machine," says Abraham Gibson, a history professor at the University of Texas at San Antonio. Gibson says until very recently, fellow historians he spoke to didn't see the relevance of artificial intelligence to their work, but they're increasingly waking up to the possibility that they could eventually yield some of the interpretation of history to a black box.

This "black box" problem is not unique to history: even developers of machine-learning systems sometimes struggle to understand how they function. Fortunately, some methods designed with historians in mind are structured to provide greater transparency. Ithaca produces a range of hypotheses ranked by probability, and BIFOLD researchers are working on the interpretation of their models with explainable AI, which is meant to reveal which inputs contribute most to predictions. Historians say they themselves promote transparency by encouraging people to view machine learning with critical detachment: as a useful tool, but one that's fallible, just like people.

The historians of tomorrow

While skepticism toward such new technology persists, the field is gradually embracing it, and Valleriani thinks that in time, the number of historians who reject computational methods will dwindle. Scholars' concerns about the ethics of AI are less a reason not to use machine learning, he says, than an opportunity for the humanities to contribute to its development.

As the French historian Emmanuel Le Roy Ladurie wrote in 1968, in response to the work of historians who had started experimenting with computational history to investigate questions such as voting patterns of the British parliament in the 1840s, "the historian of tomorrow will be a programmer, or he will not exist." ■

Moira Donovan is an independent science journalist based in Halifax, Nova Scotia.

The panicked reaction around cheating in school doesn't tell the whole story. Meet the teachers who think AI could actually make learning better.

The education of ChatGPT

BY **Will Douglas Heaven**

ILLUSTRATIONS **Selman Design**

The response from schools and universities was swift and decisive.

Just days after OpenAI dropped ChatGPT in late November 2022, the chatbot was widely denounced as a free essay-writing, test-taking tool that made it laughably easy to cheat on assignments.

Los Angeles Unified, the second-largest school district in the US, immediately blocked access to OpenAI's website from its schools' network. Others soon joined. By January, school districts across the English-speaking world had started banning the software, from Washington, New York, Alabama, and Virginia in the United States to Queensland and New South Wales in Australia.

Several leading universities in the UK, including Imperial College London and the University of Cambridge, issued statements that warned students against using ChatGPT to cheat.

"While the tool may be able to provide quick and easy answers to questions, it does not build critical-thinking and problem-solving skills, which are essential for academic and lifelong success," Jenna Lyle, a spokeswoman for the New York City Department of Education, told the Washington Post in early January.

This initial panic from the education sector was understandable. ChatGPT, available to the public via a web app, can answer questions and generate slick, well-structured blocks of text several thousand words long on almost any topic it is asked about, from string theory to Shakespeare. Each essay it produces is unique, even when it is given the same prompt again, and its authorship is (practically) impossible to spot. It looked as if ChatGPT would undermine the way we test what students have learned, a cornerstone of education.

But three months on, the outlook is a lot less bleak. I spoke to a

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number of teachers and other educators who are now reevaluating what chatbots like ChatGPT mean for how we teach our kids. Far from being just a dream machine for cheaters, many teachers now believe, ChatGPT could actually help make education better.

Advanced chatbots could be used as powerful classroom aids that make lessons more interactive, teach students media literacy, generate personalized lesson plans, save teachers time on admin, and more.

Educational-tech companies including Duolingo and Quizlet, which makes digital flash cards and practice assessments used by half of all high school students in the US, have already integrated OpenAI's chatbot into their apps. And OpenAI has worked with educators to put together a fact sheet about ChatGPT's potential impact in schools. The company says it also consulted educators when it developed a free tool to spot text written by a chatbot (though its accuracy is limited).

"We believe that educational policy experts should decide what works best for their districts and schools when it comes to the use of new technology," says Niko Felix, a spokesperson for OpenAI. "We are engaging with educators across the country to inform them of ChatGPT's capabilities. This is an important conversation to have so that they are aware of the potential benefits and misuse of AI, and so they understand how they might apply it to their classrooms."

But it will take time and resources for educators to innovate in this way. Many are too overworked, under-resourced, and beholden to strict performance metrics to take advantage of any opportunities that chatbots may present.

It is far too soon to say what the lasting impact of ChatGPT will be—it hasn't even been around for a full semester. What's certain is that essay-writing chatbots are here to stay. And they will only get better at standing in for a student on deadline—more accurate and harder to detect. Banning them is futile, possibly even counterproductive. "We need to be asking what we need to do to prepare young people—learners—for a future world that's not that far in the future," says Richard Culatta, CEO of the International Society for Technology in Education (ISTE), a nonprofit that advocates for the use of technology in teaching.

Tech's ability to revolutionize schools has been overhyped in the past, and it's easy to get caught up in the excitement around ChatGPT's transformative potential. But this feels bigger: AI will be in the classroom one way or another. It's vital that we get it right.

From ABC to GPT

Much of the early hype around ChatGPT was based on how good it is at test taking. In fact, this was a key point OpenAI touted when it rolled out GPT-4, the latest version of the large language model that powers the chatbot, in March. It could pass the bar exam! It scored a 1410 on the SAT! It aced the AP tests for biology, art history, environmental science, macroeconomics, psychology, US history, and more. Whew!

It's little wonder that some school districts totally freaked out.

Yet in hindsight, the immediate calls to ban ChatGPT in schools were a dumb reaction to some very smart software. "People panicked," says Jessica Stansbury, director of teaching and learning excellence at the University of Baltimore. "We had the wrong conversations instead of thinking, 'Okay, it's here. How can we use it?'"

"It was a storm in a teacup," says David Smith, a professor of bioscience education at Sheffield Hallam University in the UK. Far from using the chatbot to cheat, Smith says, many of his students hadn't yet heard of the technology until he mentioned it to them: "When I started asking my students about it, they were like, 'Sorry, what?'"

Even so, teachers are right to see the technology as a game changer. Large language models like OpenAI's ChatGPT and its successor GPT-4, as well as Google's Bard and Microsoft's Bing Chat, are set to have a massive impact on the world. The technology is already being rolled out into consumer and business software. If nothing else, many teachers now recognize that they have an obligation to teach their students about how this new technology works and what it can make possible. "They don't want it to be vilified," says Smith. "They want to be taught how to use it."

Change can be hard. "There's still some fear," says Stansbury. "But we do our students a disservice if we get stuck on that fear."

Stansbury has helped organize workshops at her university to allow faculty and other teaching staff to share their experiences and voice their concerns. She says that some of her colleagues turned up worried about cheating, others about losing their jobs. But talking it out helped. "I think some of the fear that faculty had was because of the media," she says. "It's not because of the students."

In fact, a US survey of 1,002 K–12 teachers and 1,000 students between 12 and 17, commissioned by the Walton Family Foundation in February, found that more than half the teachers had used ChatGPT—10% of them reported

In February, a survey of K–12 teachers and teenage students in the US found that

MORE THAN 1/2 OF THE TEACHERS

had used ChatGPT compared with

ONLY 1/3 OF THE STUDENTS

Cheating is not a new problem: schools have survived calculators, Google, Wikipedia, essays-for-pay websites, and more.

using it every day—but only a third of the students. Nearly all those who had used it (88% of teachers and 79% of students) said it had a positive impact.

A majority of teachers and students surveyed also agreed with this statement: "ChatGPT is just another example of why we can't keep doing things the old way for schools in the modern world."

Helen Crompton, an associate professor of instructional technology at Old Dominion University in Norfolk, Virginia, hopes that chatbots like ChatGPT will make school better.

Many educators think that schools are stuck in a groove, says Crompton, who was a K–12 teacher for 16 years before becoming a researcher. In a system with too much focus on grading and not enough on learning, ChatGPT is forcing a debate that is overdue. "We've long wanted to transform education," she says. "We've been talking about it for years."

Take cheating. In Crompton's view, if ChatGPT makes it easy to cheat on an assignment, teachers should throw out the assignment rather than ban the chatbot.

We need to change how we assess learning, says Culatta: "Did ChatGPT kill assessments? They were probably already dead, and they've been in zombie mode for a long time. What ChatGPT did was call us out on that."

Critical thinking

Emily Donahoe, a writing tutor and educational developer at the University of Mississippi, has noticed classroom discussions starting to change in the months since ChatGPT's release. Although she first started to talk to her undergraduate students about the technology out of a sense of duty, she now thinks that ChatGPT could help teachers shift away from an excessive focus on final results. Getting a class to engage with AI and think critically about what it generates could make teaching feel more human, she says, "rather than asking students to write and perform like robots."

This idea isn't new. Generations of teachers have subscribed to a framework known as Bloom's taxonomy, introduced by the educational psychologist Benjamin Bloom in the 1950s, in which basic knowledge of facts is just the bedrock on which other forms of learning, such as analysis and evaluation, sit. Teachers like Donahoe and Crompton think that chatbots could help teach those other skills.

In the past, Donahoe would set her students to writing assignments in which they had to make an argument for something—and grade them on the text they turned in. This semester, she asked her students to use ChatGPT to generate an argument and then had them annotate it according to how effective they thought the argument was for a specific audience. Then they turned in a rewrite based on their criticism.

Breaking down the assignment in this way also helps students focus on specific skills without getting sidetracked. Donahoe found, for example, that using ChatGPT to generate a first draft helped some students stop worrying about the blank page and instead focus on the critical phase of the assignment. "It can help you move beyond particular pain points when those pain points aren't necessarily part of the learning goals of the assignment," she says.

Smith, the bioscience professor, is also experimenting with ChatGPT assignments. The hand-wringing around it reminds him of the anxiety many teachers experienced a couple of years ago during the pandemic. With students stuck at home, teachers had to find ways to set assignments where solutions were not too easy to Google. But what he found was that Googling—what to ask for and what to make of the results—was itself a skill worth teaching.

Smith thinks chatbots could be the same way. If his undergraduate students want to use ChatGPT in their written assignments, he will assess the prompt as well as—or even rather than—the essay itself. "Knowing the words to use in a prompt and then understanding the output that comes back is important," he says. "We need to teach how to do that."

The new education

These changing attitudes reflect a wider shift in the role that teachers play, says Stansbury. Information that was once dispensed in the classroom

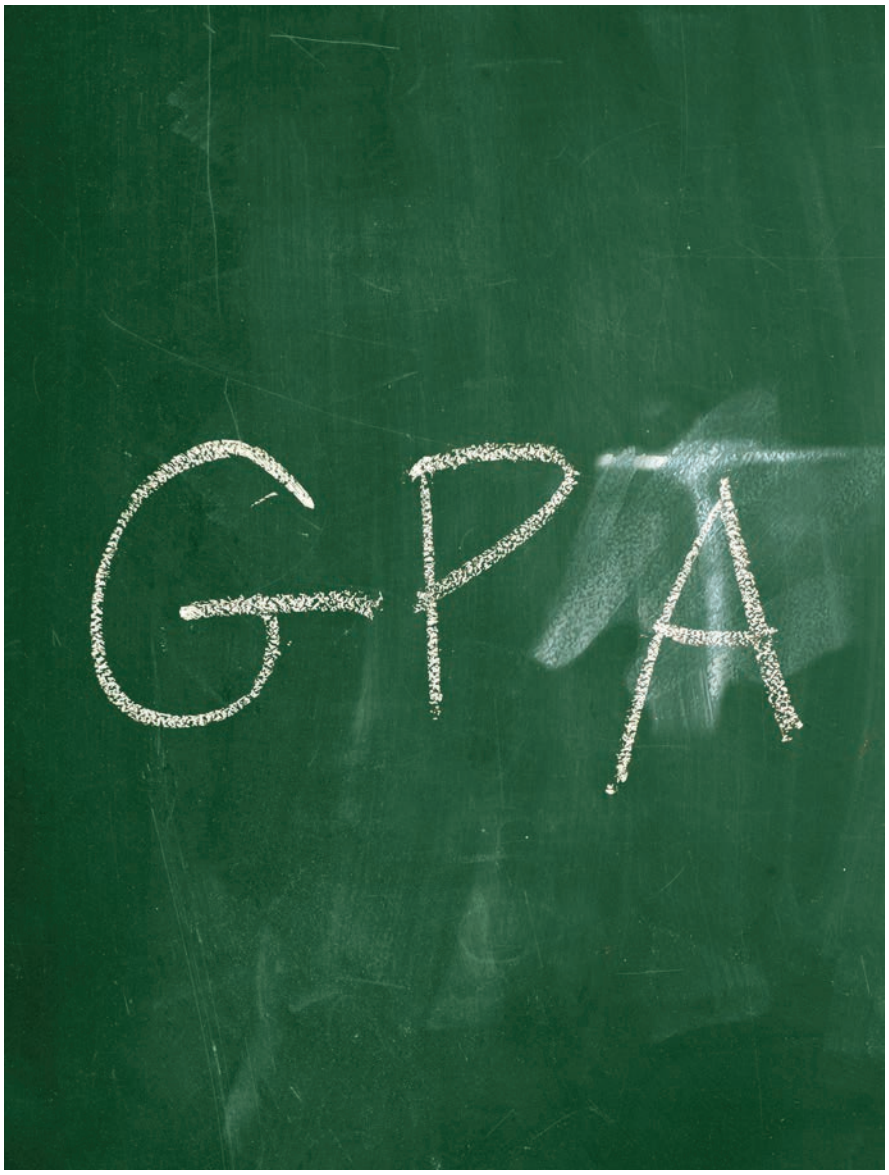
is now everywhere: first online, then in chatbots. What educators must now do is show students not only how to find it, but what information to trust and what not to, and how to tell the difference. "Teachers are no longer gatekeepers of information, but facilitators," she says.

In fact, teachers are finding opportunities in the misinformation and bias that large language models often produce. These shortcomings can kick off productive discussions, says Crompton: "The fact that it's not perfect is great."

Teachers are asking students to use ChatGPT to generate text on a topic and then getting them to point out the flaws. In one example that a colleague of Stansbury's shared at her workshop, students used the bot to generate an essay about the history of the printing press. When its US-centric response included no information about the origins of print in Europe or China, the teacher used that as the starting point for a conversation about bias. "It's a great way to focus on media literacy," says Stansbury.

Crompton is working on a study of ways that chatbots can improve teaching. She runs off a list of potential applications she's excited about, from generating test questions to summarizing information for students with different reading levels to helping with time-consuming administrative tasks such as drafting emails to colleagues and parents.

One of her favorite uses of the technology is to bring more interactivity into the classroom. Teaching methods that get students to be creative, to role-play, or to think critically lead to a deeper kind of learning than rote memorization, she says. ChatGPT can play the role of a debate opponent and generate counterarguments to a student's



Teachers are asking students to use ChatGPT to generate text on a topic and then getting them to point out the flaws.

positions, for example. By exposing students to an endless supply of opposing viewpoints, chatbots could help them look for weak points in their own thinking.

Crompton also notes that if English is not a student's first language, chatbots can be a big help in drafting text or paraphrasing existing documents, doing a lot to level the playing field. Chatbots also serve students who have specific learning needs, too. Ask ChatGPT to explain Newton's laws of motion to a student who learns better with images rather than words, for example, and it will generate an explanation that features balls rolling on a table.

Made-to-measure learning

All students can benefit from personalized teaching materials, says Culatta, because everybody has different learning preferences. Teachers might prepare a few different versions of their teaching materials to cover a range of students' needs. Culatta thinks that chatbots could generate personalized material for 50 or 100 students and make bespoke tutors the norm. "I think in five years the idea of a tool that gives us information that was written for somebody else is going to feel really strange," he says.

Some ed-tech companies are already doing this. In March, Quizlet updated its app with a feature called Q-Chat, built using ChatGPT, that tailors material to each user's needs. The app adjusts the difficulty of the questions according to how well students know the material they're studying and how they prefer to learn. "Q-Chat provides our students with an experience similar to a one-on-one tutor," says Quizlet's CEO, Lex Bayer.

In fact, some educators think future textbooks could be bundled with chatbots trained on their contents. Students would have a conversation with the bot about the book's contents as well as (or instead of) reading it. The chatbot could generate personalized quizzes to coach students on topics they understand less well.

Not all these approaches will be instantly successful, of course. Donahoe and her students came up with guidelines for using ChatGPT together, but "it may be that we get to the end of this class and I think this absolutely did not work," she says. "This is still an ongoing experiment."

She has also found that students need considerable support to make sure ChatGPT promotes learning rather than getting in the way of it. Some students find it harder to move beyond the tool's output and make it their own, she says: "It needs to be a jumping-off point rather than a crutch."

And, of course, some students will still use ChatGPT to cheat. In fact, it makes it easier than ever. With a deadline looming, who wouldn't be tempted to get that assignment written at the push of a button? "It equalizes cheating for everyone," says Crompton. "You don't have to pay. You don't have to hack into a school computer."

Some types of assignments will be harder hit than others, too. ChatGPT is really good at summarizing information. When that is the goal of an assignment, cheating is a legitimate concern, says Donahoe: "It would be virtually indistinguishable from an A answer in that context. It is something we should take seriously."

None of the educators I spoke to have a fix for that. And not all other fears will be easily allayed. (Donahoe recalls a recent workshop at her university in which faculty were asked what they were planning to do differently after learning about ChatGPT. One faculty member responded: "I think I'll retire.")

But nor are teachers as worried as initial reports suggested. Cheating is not a new problem: schools have survived calculators, Google, Wikipedia, essays-for-pay websites, and more.

For now, teachers have been thrown into a radical new experiment. They need support to figure it out—perhaps even government support in the form of money, training, and regulation. But this is not the end of education. It's a new beginning.

"We have to withhold some of our quick judgment," says Culatta. "That's not helpful right now. We need to get comfortable kicking the tires on this thing." ■

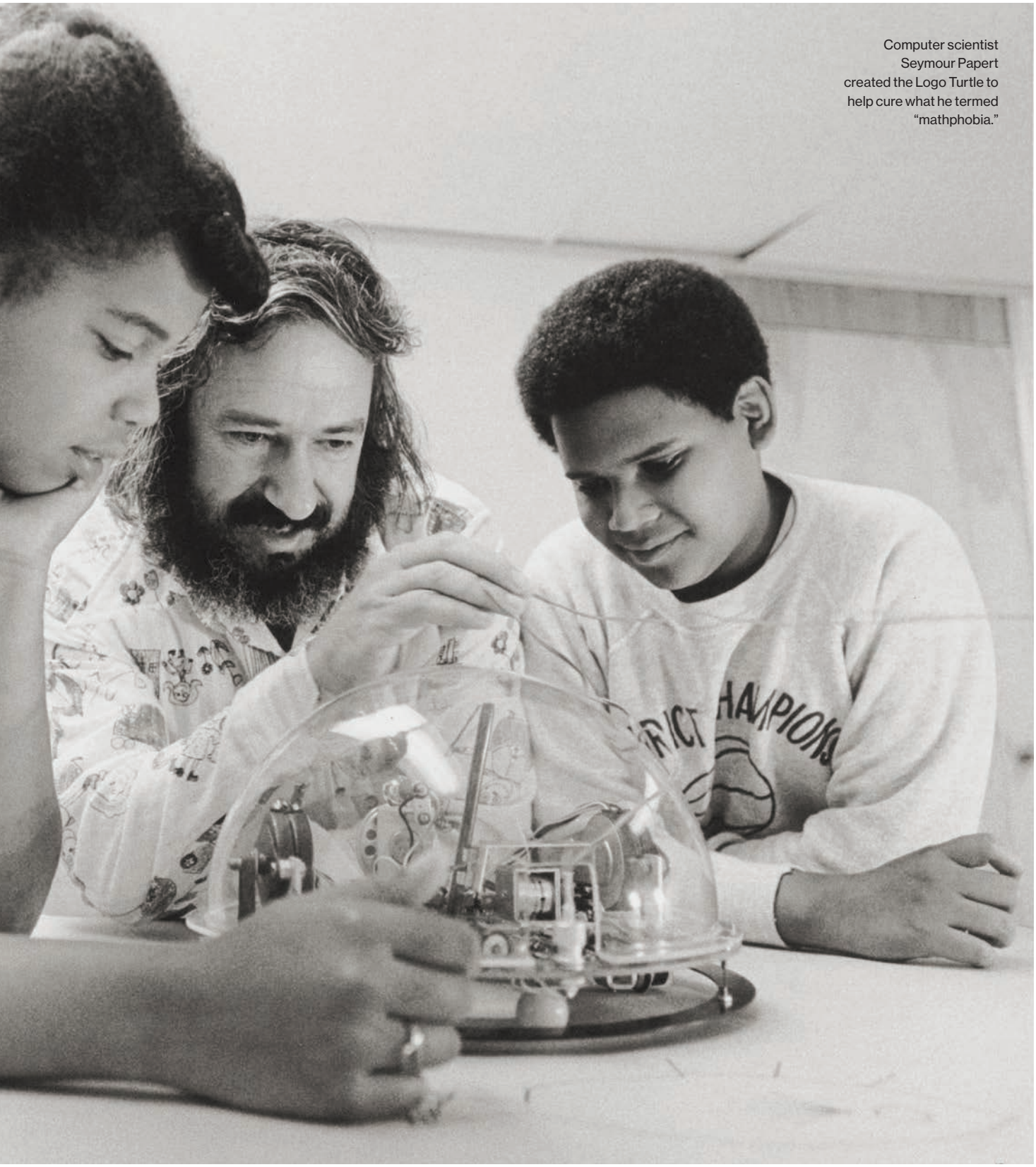
Will Douglas Heaven is a senior editor for AI at MIT Technology Review.

A decade ago, tech powerhouses the likes of Microsoft, Google, and Amazon helped boost the nonprofit Code.org, a learn-to-code program with a vision: "That every student in every school has the opportunity to learn computer science as part of their core K–12 education." It was followed by a wave of nonprofits and for-profits alike dedicated to coding and learning computer science; some of the many others include Codecademy, Treehouse, Girl Develop It, and Hackbright Academy (not to mention Girls Who Code, founded the year before Code.org and promising participants, "Learn to code and change the world"). Parents can now consider top-10 lists of coding summer camps for kids. Some may choose to start their children even younger, with the Baby Code! series of board books—because "it's never too early to get little ones interested in computer coding." Riding this wave of enthusiasm, in 2016 President Barack Obama launched an initiative called Computer Science for All, proposing billions of dollars in funding to arm students with the "computational thinking skills they need" to "thrive in a digital economy."

The long history of "learn to code"

By Joy Lisi Rankin

MIT MUSEUM



Computer scientist Seymour Papert created the Logo Turtle to help cure what he termed "mathphobia."

Above: At Dartmouth, mathematics professors Thomas Kurtz (left) and John Kemeny pioneered the use of computers in college education.

Now, in 2023, North Carolina is considering making coding a high school graduation requirement. If lawmakers enact that curriculum change, they will be following in the footsteps of five other states with similar policies that consider coding and computer education foundational to a well-rounded education: Nevada, South Carolina, Tennessee, Arkansas, and Nebraska. Advocates for such policies contend that they expand educational and economic opportunities for students. More and more jobs, they suggest, will require "some kind of computer science knowledge."

This enthusiasm for coding is nothing new. In 1978 Andrew Molnar, an expert at the National Science Foundation, argued that what he termed computer literacy was "a prerequisite to effective participation in an information society and as much a social obligation as reading literacy." Molnar pointed as models to two programs that had originated in the 1960s. One was the Logo project centered at the MIT Artificial Intelligence Lab, which focused on exposing elementary-age kids to computing. (MIT Technology Review is funded in part by MIT but maintains editorial independence.) The other was at Dartmouth College, where undergraduates learned how to write programs on a campus-wide computing network.

The Logo and Dartmouth efforts were among several computing-related educational endeavors organized from the 1960s through 1980s. But these programs, and many that followed, often benefited the populations with the most power in society. Then as now, just learning to code is neither a pathway to a stable financial future for people from economically precarious backgrounds nor a panacea for the inadequacies of the educational system.

Dartmouth: Building a BASIC computing community

When mathematics professor (and future Dartmouth president) John Kemeny made a presentation to college trustees in the early 1960s hoping to persuade them to fund a campus-wide computing network, he emphasized the idea that Dartmouth students (who were at that time exclusively male, and mostly affluent and white) were the future leaders of the United States. Kemeny argued, "Since many students at an institution like Dartmouth become executives or key policy makers in industry and government, it is a certainty that they will have at their command high-speed computing equipment."

Kemeny claimed that it was "essential" for those nascent power brokers to "be acquainted with the potential and limitations of high-speed computers." In 1963 and 1964, he and fellow mathematics professor Thomas Kurtz worked closely with Dartmouth students to design and implement a campus-wide network, while Kemeny largely took responsibility for designing an easy-to-learn programming language, called BASIC, for students (and faculty) to use on that network. Both developments were eagerly welcomed by the incoming students in the fall of 1964.

As Dartmouth's network grew during the 1960s, network terminals were installed in the new campus computer center, in shared campus recreational spaces and dormitories, and at other locations around campus. And because the system was set up as a time-sharing network, an innovation at the time, multiple terminals could be connected to the same computer, and the people using those terminals could write and debug programs simultaneously.

This was transformative: by 1968, 80% of Dartmouth undergraduates and 40% of the faculty used the network regularly. Although incoming students learned how to write a program in BASIC as a first-year math course requirement, what really fostered the computing culture was the way students made the language and the network their own. For example, the importance of football in campus life (Dartmouth claimed the Ivy League championship seven times between 1962 and 1971) inspired at least three computer football games (FTBALL, FOOTBALL, and GRIDIRON) played avidly on the Dartmouth network, one of them written by Kemeny himself.

Because the network was so easy to access and BASIC was so easy to use, Dartmouth students could make computing relevant to their own lives and interests. One wrote a program to test a hypothesis for a psychology class. Another ran a program called XMAS to print his Christmas cards. Some printed out letters to parents or girlfriends. Others enjoyed an array of games, including computer bridge, checkers, and chess. Although learning to write a program in BASIC

Right: Kemeny, the co-creator of the programming language BASIC, believed it was essential for his students to "be acquainted with the potential and limitations of high-speed computers."

DARTMOUTH COLLEGE/RAUNER SPECIAL COLLECTIONS LIBRARY

What was intended as computing for all ultimately amplified existing inequities.

was the starting point in computing for Dartmouth students, the ways they used it to meet their own needs and forge community with their peers made the system a precursor of social networking—nearly half a century ago. Coding in BASIC didn't replace their liberal arts curriculum requirements or extracurricular activities; rather, it complemented them.

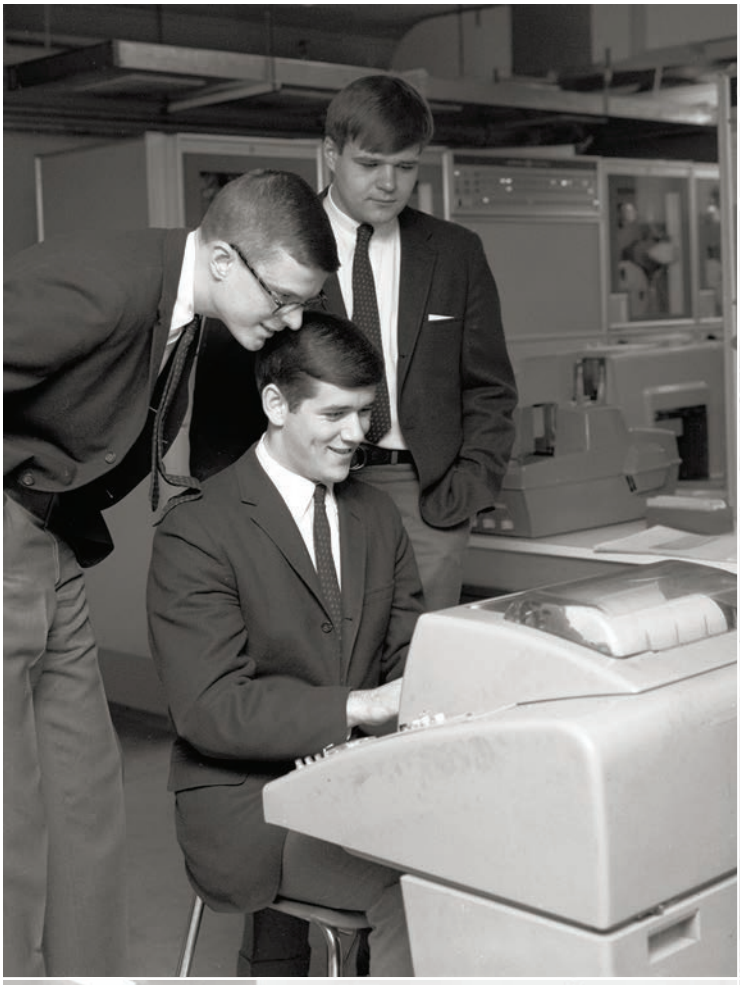
Different results: The Dartmouth network expands

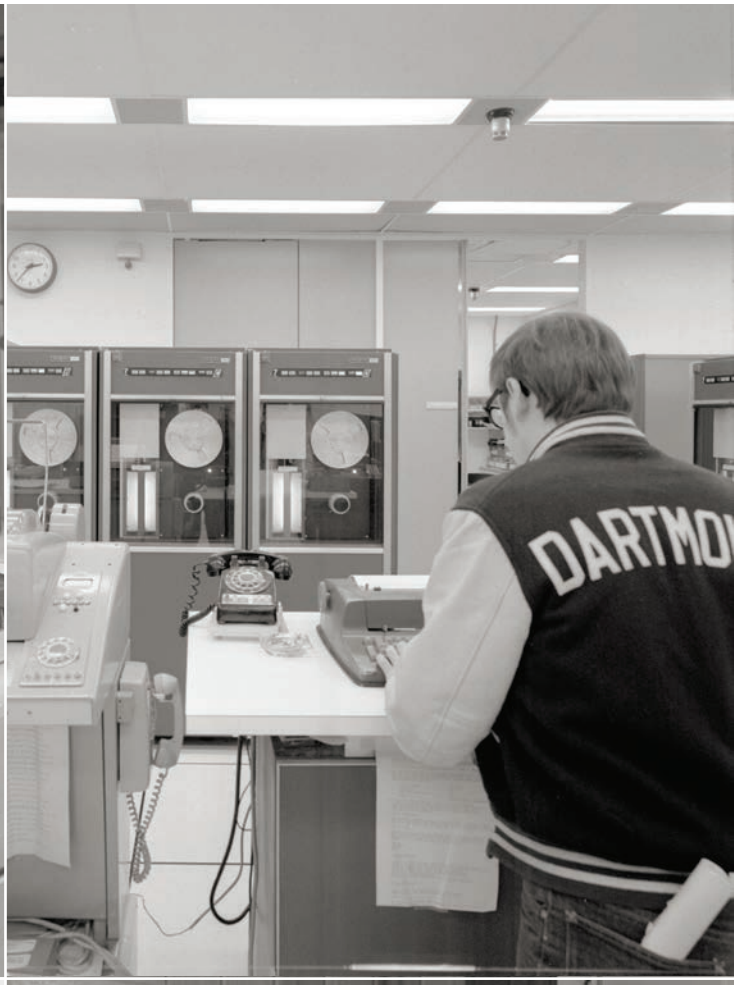
As it grew in popularity, other schools around New England sought to tap into Dartmouth's computing network for their students. By April 1971, the network encompassed 30 high schools and 20 colleges in New England, New York, and New Jersey. All an individual school needed to connect were a terminal and a telephone line linking the terminal with the mainframe on Dartmouth's campus (often the greatest expense of participating in the network, at a time when long-distance phone calls were quite costly). Yet as BASIC moved beyond Dartmouth into heterogeneous high schools around New England, the computing culture remained homogeneous.

Private high schools including Phillips Exeter, Phillips Andover, and St. Paul's were among the first to connect, all before 1967. Within a few more years, a mix of private and public high schools joined them. The Secondary School Project (SSP), which ran from 1967 to 1970 and was supported by a three-year NSF grant secured by Kemeny and Kurtz, connected students and educators at 18 public and private high schools from Connecticut to Maine, with the goal of putting computing access (and BASIC) into as many hands as possible and observing the results.

That these schools asked Dartmouth for time shares reflected interest and motivation on the part of some individual or group at each one. They wanted network access—and, by extension, access to code—because it was novel and elite. Some students were enthusiastic users, even waking at four in the morning to sign on. But access to the Dartmouth network was emphatically unequal. The private schools participating in the SSP were (at the time) all male and almost exclusively white, and those students enjoyed nearly twice as much network time as the students at coeducational public schools: 72 hours per week for private school students, and only 40 for public school students.

In these years before the expansion of educational opportunities for girls and women in the United States, high school boys were enrolling in many more math and science classes than high school girls. The math and science students gained access to computing in those courses, meaning that BASIC moved into a system already segregated by gender—and also by race. What was intended as computing for all ultimately amplified existing inequities.

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Logo: Trying to change the world, one turtle at a time

One state away from Dartmouth, the Logo project, founded by Seymour Papert, Cynthia Solomon, and Wally Feurzeig, sought to revolutionize how elementary and middle school students learn. Initially, the researchers created a Logo programming language and tested it between 1967 and 1969 with groups of children including fifth and seventh graders at schools near MIT in Cambridge, Massachusetts. "These kids made up hilarious sentence generators and became proficient users of their own math quizzes," Solomon has recalled.

But Logo was emphatically not just a "learn to code" effort. It grew to encompass an entire lab and a comprehensive learning system that would introduce new instructional methods, specially trained teachers, and physical objects to think and play with. Perhaps the best-remembered of those objects is the Logo Turtle, a small robot that moved along the floor, directed by computer commands, with a retractable pen underneath its body that could be lowered to draw shapes, pictures, and patterns.

By the early 1970s, the Logo group was part of the MIT AI Lab, which Papert had cofounded with the computer scientist Marvin Minsky. The kid-focused learning environment provided a way to write stories, a way to draw, a way to make music, and a way to explore a space with a programmable object. Papert imagined that the Logo philosophy would empower children as "intellectual agents" who could derive their own understanding of math concepts and create connections with other disciplines ranging from psychology and the physical sciences to linguistics and logic.

But the reality outside the MIT AI Lab challenged that vision. In short, teaching Logo to elementary school students was both time- and resource-intensive. In 1977-'78, an NSF grant funded a yearlong study of Logo at a public school; it was meant to include all the school's sixth graders, but the grant covered only four computers, which meant that only four students could participate at the same time. The research team found that most of the students who were chosen to participate did learn to create programs and express math concepts using Logo. However, when the study ended and the students moved on, their computing experiences were largely left in the past.

As that project was wrapping up, the Logo team implemented a larger-scale partnership at the private Lamplighter School in Dallas, cosponsored by Texas Instruments. At this school, with a population of 450 students in kindergarten through fourth grade, 50 computers were available. Logo was not taught as a standalone subject but was integrated into the curriculum—something that would only have been possible at a small private school like this one.

Left: In the '60s, Dartmouth students had unprecedented computer access thanks to a time-sharing network that connected multiple terminals via telephone line to a central computer.

Above: Logo's foundational philosophy was for the child to program the computer rather than be taught by it. Students learned to program the Logo robot (above) as a pathway to larger concepts and ideas.

The Lamplighter project—and the publication around the same time of Papert's book *Mindstorms*, in which the mathematician enthused about the promise of computing to revolutionize education—marked a high point for Logo. But those creative educational computing initiatives were short-lived. A major obstacle was simply the incredibly slow-moving and difficult-to-change bureaucracy of American public education. Moreover, promising pilots either did not scale or were unable to achieve the same results when introduced into a system fraught with resource inequities.

But another issue was that the increasingly widespread availability of personal computers by the 1980s challenged Logo's revolutionary vision. As computers became consumer objects, software did, too. People no longer needed to learn to code to be able to use a computer. In the case of American education, computers in the classroom became less about programming and more about educational games, word processing, and presentations. While BASIC and Logo continued to be taught in some schools around the United States, for many students the effort of writing some code to, say, alphabetize a list seemed impractical—disconnected from their everyday lives and their imagined futures.

Corporate coding

Schools weren't the only setting for learn-to-code movements, however. In the 1960s the Association for Computing Machinery (ACM), which had been

established as a professional organization in the 1940s, spearheaded similar efforts to teach coding to young people. From 1968 to 1972, ACM members operating through their local chapters established programs across the United States to provide training in computing skills to Black and Hispanic Americans. During the same years, government and social welfare organizations offered similar training, as did companies including General Electric. There were at least 18 such programs in East Coast and California cities and one in St. Louis, Missouri. Most, but not all, targeted young people. In some cases, the programs taught mainframe or keypunch operation, but others aimed to teach programming in the common business computing languages of the time, COBOL and FORTRAN.

Did the students in these programs learn? The answer was emphatically yes. Could they get jobs as a result, or otherwise use their new skills? The answer to that was often no. A program in San Diego arranged for Spanish-speaking instructors and even converted a 40-foot tractor-trailer into a mobile training facility so that students—who were spread across the sprawling city—would not have to spend upwards of an hour commuting by bus to a central location. And in the Albany-Schenectady area of New York, General Electrical supported a rigorous program to prepare Black Americans for programming jobs. It was open to people without high school diplomas, and to people with police records; there was no admissions testing. Well over half the people who started this training completed it.

Yet afterwards many could not secure jobs, even entry-level ones. In other cases, outstanding graduates were offered jobs that paid $105 per week—not enough to support themselves and their families. One consultant to the project suggested that for future training programs, GE should "give preference to younger people without families" to minimize labor costs for the company.

The very existence of these training endeavors reflected a mixed set of motivations on the part of the organizers, who were mostly white, well-off volunteers. These volunteers tended to conflate living in an urban area with living in poverty, and to assume that people living in these conditions were not white, and that all such people could be lumped together under the heading of "disadvantaged." They imagined that learning to code would provide a straightforward path out of poverty for these participants. But their thinking demonstrated little understanding of the obstacles imposed by centuries of enslavement, unpaid labor, Jim Crow violence, pay discrimination, and segregated and unequal education, health care, and housing. Largely with their own interests in mind, they looked to these upskilling programs as a panacea for racial inequality and the social instability it fueled. A group from a Delaware ACM chapter, a conference report suggested, believed that "in these days of urban crisis, the data processing industry offers a unique opportunity to the disadvantaged to become involved in the mainstream of the American way of life."

If success is defined as getting a steadily increasing number of Black and Hispanic men and women good jobs in the computing profession—and, by extension, giving them opportunities to shape and inform the technologies that would remake the world—then these programs failed. As the scholar Arvid Nelsen observed, while some volunteers "may have been focused on the needs and desires of the communities themselves," others were merely seeking a Band-Aid for "civil unrest." Meanwhile, Nelsen notes, businesses benefited from "a source of inexpensive workers with much more limited power." In short, training people to code didn't mean they would secure better, higher-paying, more stable jobs—it just meant that there was a larger pool of possible entry-level employees who would drive down labor costs for the growing computer industry.

In fact, observers identified the shortcomings of these efforts even at the time. Walter DeLegall, a Black computing professional at Columbia University, declared in 1969 that the "magic of data processing training" was no magic bullet, and that quick-fix training programs mirrored the deficiencies of American public education for Black and Spanish-speaking students. He questioned the motivation behind them, suggesting that they were sometimes organized for "commercial reasons or simply to de-fuse and dissipate the burgeoning discontent of these communities" rather than to promote equity and justice.

The Algebra Project

There was a grassroots effort that did respond to these inadequacies, by coming at the computing revolution from an entirely different angle.

During the late 1970s and early 1980s, the civil rights activist Robert P. Moses was living with his family in Cambridge, Massachusetts, where his daughter Maisha attended the public Martin Luther King School and he volunteered teaching algebra. He noticed that math groups were unofficially segregated by race and class, and that much less was expected of Black and brown students. Early on, he also identified computers—and knowledge work dependent on computers—as a rising source of economic, political, and social power. Attending college was increasingly important for attaining that kind of power, and Moses saw that one key to getting there was a foundation in high school mathematics, particularly algebra. He established the Algebra Project during the early

Below: Activist and educator Robert P. Moses established the Algebra Project in the early '80s to address racial and economic inequities in math education.

DAVID RAE MORRIS

Arming Black students with the tools of math literacy was radical in the 1980s precisely because it challenged power dynamics.

1980s, beginning in Cambridge public schools and supported by a MacArthur "genius grant" that he received in 1982.

In a book that he later coauthored, *Radical Equations: Civil Rights from Mississippi to the Algebra Project*, Moses clearly articulated the connections between math, computing, economic justice, and political power, especially for Black Americans. "The most urgent social issue affecting poor people and people of color is economic access. In today's world, economic access and full citizenship depend crucially on math and science literacy," he wrote. "The computer has become a cultural force as well as an instrument of work [and] while the visible manifestation of the technological shift is the computer, the hidden culture of computers is math."

Moses had earned his bachelor's degree at Hamilton College in New York and a master's degree at Harvard University before teaching math at the Horace Mann School in the Bronx from 1958 to 1961. For him, arming Black students with the tools of math literacy was radical in the 1980s precisely because access to technology meant access to power. "Who's going to gain access to the new technology?" he asked. "Who's going to control it? What do we have to demand of the educational system to prepare for the new technological era?"

Moses mobilized students and parents alike to ensure that algebra was offered to all students at the Martin Luther King School. He devised new approaches to teaching the subject, and drawing on his experience with grassroots civil rights organizing, enrolled students to teach their peers. College admission rates and test scores rose at the school, and the Algebra Project spread to at least 22 other sites across 13 states. It focused on math because Moses identified math as the foundation of coding, and the stakes were always connected to economic justice and educational equity in an economy built on algorithms and data.

Moses made explicit "a number of issues that are often hidden in coding discourse," the historian Janet Abbate has observed. "He questioned the implied meritocracy of 'ability grouping' … he attacked the stereotype that Black people aren't interested in STEM … [and] he emphasized that social skills and community were an essential part of overcoming students' alienation from technology."

Moses died in 2021, but the Algebra Project lives on, now in collaboration with a group called the "We the People" Math Literacy for All Alliance. The curriculum he pioneered continues to be taught, and the Algebra Project's 2022 conference again called attention to the need for better public education across the United States, especially for Black, brown, and poor children, "to make full participation in American democracy possible."

Rewind, reboot: Coding makes a comeback

In the past decade, a new crop of more targeted coding programs has emerged. In 2014, for example, the activist and entrepreneur Van Jones collaborated with the musician Prince to launch #YesWeCode, targeting what they called "low-opportunity communities." In doing so, they called attention to ongoing educational and economic inequities across the United States.

One of #YesWeCode's early efforts was a youth-oriented hackathon at the Essence Music Festival in New Orleans in 2014 that encouraged kids to connect coding with issues that mattered to them. As #YesWeCode's chief innovation officer, Amy Henderson, explained, "A lot of the people who develop apps today are affluent white men, and so they build apps that solve their communities' problems," such as Uber. "Meanwhile," she continued, "one of our young people built an app that sends reminders of upcoming court dates. That's an issue that impacts his community, so he did something about it."

#YesWeCode has since morphed into Dream.Tech, an arm of Dream.org, a nonprofit that advocates for new legislation and new economic policies to remedy global climate change, the racialized mass incarceration system in the United States, and America's long history of poverty. (Its other arms are called Dream.Green and Dream.Justice.) Recently, for example, Dream.org pushed for legislation that would erase long-standing racial disparities in sentencing for drug crimes. As a whole, Dream.org demonstrates an expansive vision of tech justice that can "make the future work for everyone."

Another initiative, called Code2040 (the name refers to the decade during which people of color are expected to become a demographic majority in the United States), was launched in 2012. It initially focused on diversifying tech by helping Black and Latino computer science majors get jobs at tech companies. But its mission has expanded over the past decade. Code2040 now aims for members of these communities to contribute to the "innovation economy" in all roles at all levels, proportional to their demographic representation in the United States. The ultimate vision: "equitable distribution of power in an economy shaped by the digital revolution."

Both Code2040's current CEO, Mimi Fox Melton, and her predecessor, Karla Monterroso, have argued that coding training alone is not enough to guarantee employment or equalize educational opportunities. In an openly critical letter to the tech industry published after the murder of George Floyd in 2020, they noted that 20% of computer science graduates and

Technological solutionism may persist, but there's an increasing recognition that coding training alone is not enough.

Above: Ruha Benjamin directs the Ida B. Wells Just Data Lab, which aims to rethink and retool the relationship between power and technology.

BEBETO MATTHEWS/AP IMAGES; CYNDI SHATTUCK

Below: Black Girls Code works to increase the number of women of color working in technology by introducing girls to computer science.

24% of coding boot camp grads are Black or Latino, compared with only 6% of tech industry workers. Fox Melton and Monterroso observed: "High-wage work in America is not colorblind; it's not a meritocracy; it's white. And that goes doubly for tech."

These recent coding education efforts ask important questions: Code for what? Code for whom? Meanwhile, several other recent initiatives are focused on the injustices both caused and reflected by more recent aspects of the digital economy, particularly artificial intelligence. They aim to challenge the power of technological systems, rather than funneling more people into the broken systems that already exist. Two of these organizations are the Algorithmic Justice League (AJL) and the Ida B. Wells Just Data Lab.

Joy Buolamwini, a computer scientist, founded the Algorithmic Justice League after discovering as a grad student at MIT that a facial-analysis system she was using in her work didn't "see" her dark-skinned face. (She had to don a white mask for the software to recognize her features.)

Now, the AJL's mission is "leading a cultural movement towards equitable and accountable AI," and its tagline reads: "Technology should serve all of us. Not just the privileged few." The AJL publishes research about the harms caused by AI, as well as tracking relevant legislation, journalistic coverage, and personal stories, all with the goal of moving toward more equitable and accountable AI. Buolamwini has testified to Congress and in state hearings on these issues.

The Ida B. Wells Just Data Lab, founded and directed by Ruha Benjamin, a Princeton professor of African American studies, is devoted to rethinking and retooling "the relationship between stories and statistics, power and technology, data and justice." Its website prominently features a quote from the journalist and activist Ida B. Wells, who systematically collected data and reported on white mob violence against Black men during the 1890s. Her message: "The way to right wrongs is to turn the light of truth upon them." One of the lab's efforts, the Pandemic Portal, used data to highlight racial inequality in the context of covid-19, focusing on 10 different areas: arts, mutual aid, mental health, testing and treatments, education, prisons, policing, work, housing, and health care. It provided data-based resources and tools and offered evidence that these seemingly disparate categories are, in fact, deeply interwoven.

Technological solutionism may persist in Silicon Valley campuses and state house corridors, but individuals, organizations, and communities are increasingly recognizing that coding instruction alone won't save them. (Even Seymour Papert expressed skepticism of such efforts back in 1980, writing in *Mindstorms* that "a particular subculture, one dominated by computer engineers, is influencing the world of education to favor those school students who are most like that subculture.")

Learning to code won't solve inequality or poverty or remedy the unjust structures and systems that shape contemporary American life. A broader vision for computer science can be found in the model proposed by Learning for Justice, a project of the Southern Poverty Law Center that works to provide educational resources and engage local communities, with the ultimate goals of addressing injustice and teaching students and the communities they come from to wield power together. The project's digital literacy framework highlights important focus areas far beyond a narrow emphasis on learning to code, including privacy concerns, uncivil online behavior, fake news, internet scams, ideological echo chambers, the rise of the alt-right, and online radicalization.

These new frameworks of digital literacy, tech diversity, and algorithmic justice go beyond coding to prepare individuals to meaningfully question, evaluate, and engage with today's array of digital spaces and places. And they prepare all of us to imagine and articulate how those spaces and places can better serve us and our communities. ■

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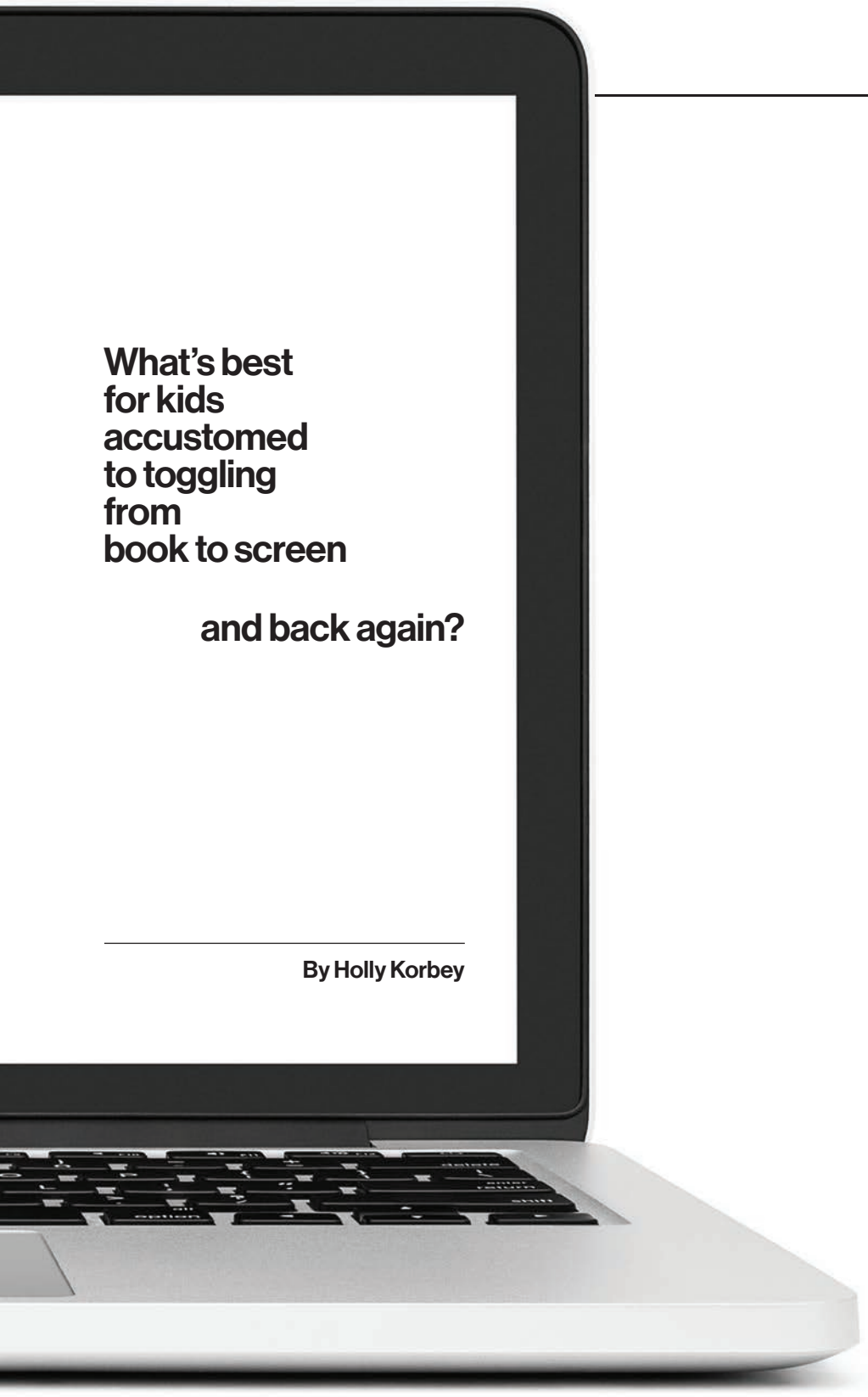
Teaching the biliterate brain to read



What's best for kids accustomed to toggling from book to screen and back again?

By Holly Korbey

Linus Merryman spends about an hour a day on his laptop at his elementary school in Nashville, Tennessee, mostly working on foundational reading skills like phonics and spelling. He opens the reading app Lexia with ease, clicking straight through to lessons chosen specifically to address his reading needs. This week Linus, who's in second grade, is working on "chunking," finding the places where words are broken into syllables. The word *chimpanzee* appears on the screen in large letters, and Linus uses his mouse pad to grab cartoon Roman columns and slip them into the spaces between letters, like little dividers, where he thinks the syllable breaks should be. The app reads his guesses back to him—"chim-pan-zee." He gets it right.

After practicing these foundational skills on the computer, he and his classmates close their laptops and head to the rug, each with a print copy of their class reader, *I Have a Dream*, a picture book featuring the text of Martin Luther King Jr.'s speech. Students follow along in their books as the teacher reads aloud, occasionally stopping so they can ask questions and point out things they notice, like how the speech is written in the first person.

Linus's mom, Erin Merryman, an early reading interventionist at another Nashville school, initially worried about how well her son would learn to read in a classroom that made so much use of computers. He has been diagnosed with the learning disability dyslexia, and Merryman knows from her training that dyslexic students often need sensory input to learn how sounds are connected to letters. Close oversight from a teacher helps them as well. But since his reading has vastly improved this year, she's adjusted her view.

"I think a lot of what the app is doing is very good, very thorough," Merryman says. "I'm surprised by how effective it is."

Like Merryman, a growing group of experts and educators are trying to figure out what the relationship should be between digital technology and reading instruction. Both reading and digital tech are world-expanding human inventions, and laptops and smartphones have arguably given humans unending opportunities to read more; you can access pretty much anything in print within a few seconds. In terms of "raw words," the cognitive scientist Daniel T. Willingham has said, kids read more now than they did a decade ago. But many reading experts suspect that the technology may also be changing *how* they read—that reading on a screen is fundamentally different from reading on the page.

Researchers who study young readers' brains and behaviors are eager to understand exactly where tech serves kids' progress in reading and where it may stand in the way. The questions are still so new that the answers are often unclear. Since the covid-19 pandemic closed schools in 2020, nearly all students have been organizing their learning around a school-issued laptop or tablet. But educators who are more dependent than ever on digital tech to aid learning in general often have little or no guidance on how to balance screens and paper books for beginning readers accustomed to toggling between the two. In a lot of ways, each teacher is winging it.

Figuring out how best to serve these young "biliterate brains" is crucial, cognitive scientists say—not just to the future of reading instruction, but to the future of thought itself. Digital technology has transformed how we get knowledge in ways that will advance and forever alter our species. But at the individual level, the same technology threatens to disrupt, even diminish, the kind of slow, careful learning acquired from reading books and other forms of print.

Those seemingly contradictory truths underline the question of how we should go about teaching children to read in the 21st century, says neuroscientist Maryanne Wolf, author of *Reader, Come Home: The Reading Brain in a Digital World*. Wolf, the first to use the term "biliterate brain," is busy researching the relative merits of screen- and page-based approaches, adopting in the meantime a stance of what she calls "learned ignorance": deeply investigating both positions and then stepping outside them to evaluate all the evidence and shake out the findings.

"Knowledge has not progressed to the point where we have the kind of evidence I feel we need," Wolf says. "What do the affordances of each medium—screens vs. print—do to the reading brain's use of its full circuitry? The answers are not all in."

But, she continues, "our understanding is that print advantages slower, deeper processes in the reading brain. You can use a screen to complement, to teach certain skills, but you don't want a child to learn to read through a screen."

Which is best for comprehension, screens or books?

Once children have learned to decode words, research on how they comprehend texts encountered on screens and paper gets a little more decisive. Experts say that young readers need to be reading alongside adults—getting feedback, asking questions, and looking at pictures together. All this helps them build the vocabulary and knowledge to understand what they're reading. Screens often do a poor job of replicating this human-to-human interaction, and scientists like Wolf say that the "reading circuits" in children's brains develop differently when the young learners are glued to a screen.

Studies on the inner workings of the brain confirm the idea that human interaction helps develop beginning readers' capacity for understanding. But they suggest that reading paper books is associated with that progress, too. In one study, researchers found that three- and four-year-old children had more activation in language regions of the brain when they read a book with an adult like a parent than when they listened to an audiobook or read from a digital app. When they read on an iPad, activation was lowest of all. In another study, MRI scans of eight- to 12-year-olds showed stronger reading circuits in those who spent more time reading paper books than those who spent their time on screens.

For older students, significant research shows that comprehension suffers when they read from a screen. A large 2019 meta-analysis of 33 different studies showed that students understood more informational text when they read on paper. A study by the Reboot Foundation, evaluating thousands of students across 90 countries

Researchers who study young readers' brains and behaviors are eager to

PREVIOUS SPREAD: GETTY IMAGES

understand exactly where tech serves kids' progress in reading and where it may stand in the way.

including the US, found that fourth graders who used tablets in nearly all their classes scored 14 points lower on a reading test than students who never used them. Researchers called the score gap "equivalent to a full grade level" of learning. Students who used technology "every day for several hours during the school day" underperformed the most, while the gap shrank or even disappeared when students spent less than half an hour a day on a laptop or tablet.

Why do students understand more of what they read when it's in a book? Researchers aren't entirely sure. Part of the issue is distraction, says Julie Coiro, a researcher at the University of Rhode Island. Kid-friendly reading apps like Epic! offer thousands of books that often contain images, links, and videos within the body of the text. These are meant to enhance the reading experience, but they often drag children away from concentrating on the meaning of the text. Even in reading experiments where students weren't allowed to browse the web or click on embedded links, though, they still performed worse.

Virginia Clinton-Lisell, the author of the 2019 meta-analysis, hypothesized that overconfidence could be another aspect of the problem. In many of the studies, students who read from a laptop seemed to overestimate their comprehension skills compared with those reading the paper books, perhaps causing them to put in less effort while reading.

Students self-report learning more and having a better reading experience when they read paper books. Linguist Naomi Baron, author of *How We Read Now: Strategic Choices for Print, Screen, and Audio*, says that when she interviews students about their perceptions, they often say reading from a book is "real reading." They like the feel of the book in their hands, and they find it easier to go back to things they've already read than when they are reading from a screen. While they might prefer digital formats for reasons of convenience or cost, they sense they have greater concentration while reading print.

But Baron says school districts and educators often aren't aware of the strong research connecting books to better comprehension or confirming student preferences for print. Baron's research dealt with college students, but last year a study by the Organization for Economic Cooperation and Development (OECD) of 15-year-olds in 30 countries showed that students who preferred reading on paper scored 49 points higher, on average, on the Program for International Student Assessment (PISA)—and the study hinted at an association between reading paper books and liking to read.

Baron also thinks there should be more practical attention paid to developing pedagogical approaches that explicitly teach the slower, more focused habits of print reading, and then help students transfer those skills to the screen. Reinforcing those habits would be helpful even for people who usually read books, because someone reading a book can get distracted too—especially if a phone is nearby.

The use of digital books and textbooks exploded during the pandemic, and it may be only a matter of time before all educational publishing moves online. So it's all the more important to keep making digital reading better for students, says literacy educator Tim Shanahan. Instead of trying to make the digital technology more like a book, Shanahan has written, "[engineers] need to think about how to produce better digital tools. Tech environments can alter reading behavior, so technological scaffolding could be used to slow us down or to move around a text more productively." In the future, students might read about history or science from something like a "tap essay," where words, sentences, and images are revealed only when a reader is ready and taps the screen to move on to the next piece of text. Or maybe their reading material will look more like a New York Times digital article, in which text, images, video, and sound clips are spaced out and blended together in different ways.

Hooked on computer phonics

About two-thirds of American schoolchildren can't read at grade level. At least partly to blame is a widespread method of reading instruction that dominated classrooms for 40 years but was not based on scientific evidence about how the brain learns to read: "balanced literacy," and its close cousin "whole language," deemphasized explicit instruction in reading's foundational skills, leaving many children struggling. But over the last several years, a new method strongly focused on these foundational skills, often referred to as the "science of reading," has brought sweeping changes to the US education system. Based on decades of scientific evidence,

the "science of reading" approach is organized into five areas: phonemic awareness (learning all the sounds of the English language), phonics (learning how those sounds are attached to letters), vocabulary, comprehension, and fluency.

Learn-to-read apps and digital platforms have the potential to teach some of these foundational skills efficiently. They're especially well suited to phonemic awareness and phonics, making learning letters and sound combinations a game and reinforcing the skills with practice. Lexia, arguably the most widespread digital platform devoted to the science of reading, teaches basic and complex foundational reading skills, like letter-sound blends and spelling rules, using responsive technology. When learning a specific skill, such as figuring out how to read words like *meal* and *seam* with the "ea" vowel combination in the middle, students can't move on until they've mastered it.

A new wave of predictive reading platforms goes one step further. Companies like Microsoft and SoapBoxLabs are envisioning a world where students can learn to read entirely via computer. Using AI speech recognition technology, the companies claim, these digital platforms can listen closely to a student reading. Then they can identify trouble spots and offer help accordingly.

As digital tech for learning to read spreads into schools—Lexia alone serves more than 3,000 school districts—some reading experts are wary. Research on its efficacy is limited. While some see technology playing a useful role in reading-related functions like assessing students and even training teachers, many say that when it comes to actually doing the teaching, humans are superior.

Digital platforms can reinforce certain specific reading skills, explains Heidi Beverine-Curry, chief academic officer of the teacher training and research organization The Reading League, but it's the teacher who is constantly monitoring the student's progress and adjusting the instruction as needed.

Faith Borkowsky, founder of High Five Literacy, a tutoring and consultancy service in Plainview, New York, is not bothered by reading instruction apps per se. "If it happens to be a computer program where a few kids could go on and practice a certain skill, I'd be all for it, if it aligns with what we are doing," she says. But often that's not how it plays out in classrooms.

In the Long Island schools Borkowsky works with, it's more likely that students do more reading work on laptops because schools purchased expensive technology and feel pressured to use it—even if it's not always the best way to teach reading skills. "What I've seen in schools is they have a program, and they say, 'Well, we bought it—now we have to use it.' Districts find it hard to turn back after purchasing expensive programs and materials," she says.

Some platforms are working to bridge the gap between online and in-person instruction. Ignite! Reading, an intensive tutoring program launched after the pandemic closed schools, teaches foundational reading skills like phonemic awareness and phonics through a videoconferencing platform, where reading tutors and students can see and hear one another.

Ignite's instruction attempts to blend the benefits of digital tech and human interaction. In one tutoring session, a first grader named Brittany in Indianapolis, Indiana, sounded out simple words, prompted by her reading tutor, whom she could see through her laptop's camera. Brittany read "map" and "cup," tapping the whiteboard in her hand each time she made a sound: three sounds in a word, three taps. At the same time, a digital whiteboard on her laptop screen also tapped out the sounds: one, two, three. As Brittany sounded out each word, the tutor watched the child's mouth through the computer's camera, giving adjustments along the way.

Ignite cofounder and CEO Jessica Sliwerski says she's building an army of remote reading tutors to assist teachers in helping kids catch up after the pandemic years. Students get 15-minute sessions during the school day, and when sessions are over, tutors get coaching on how to make the short bursts more effective.

Sliwerski believes technology can be incredibly useful for giving more students one-on-one attention. "We are taking a different approach to the technology," she says. "We are centering the child on a human who is highly trained and accountable. That's the core of it, and there's not really anything tech about that."

Preserving deep reading

Once students can decode words and comprehend their meaning, the real work of reading begins. This is what Wolf calls "deep reading,"

Digital platforms can reinforce certain specific reading skills, but it's

the teacher who is constantly monitoring the student's progress and adjusting the instruction as needed.

a specific set of cognitive and affective processes in which readers are able to take in whole chunks of text at a time, make predictions about what comes next, and develop lightning-fast perception. These interactive processes feed each other in the brain, accelerating understanding.

But since the vast majority of the reading that today's young people do—let's face it, the majority that we all do—is skimming an online article, a Facebook post, or a text from a friend while hopping from one tab to another, deep reading as a cognitive process is at risk. If today's kids read only from screens, Wolf says, they may never learn deep reading in the first place—that elaboration of the brain's reading circuit may never be built. Screen reading may "disrupt and diminish the very powers that it is supposed to advance."

"We are amassing data that indicates there are changes in the reading brain that diminish its ability to use its most important, sophisticated processes over time when the screen dominates," Wolf says. Deep reading is something that came naturally to many readers before digital tech and personal computers, when they had lots of time to spend doing nothing but reading a book; but it can't be assumed that today's young readers, with their biliterate brains, will automatically learn the process.

Some educators are paying more attention to how to help students begin to learn deep reading. Doug Lemov, a charter school founder who now trains teachers full time with his "Teach Like a Champion" books and courses, is acutely concerned that many middle and high school students no longer appear to have the attention span to concentrate on a text for long periods of time. So he encourages the teachers he trains to adopt "low-tech, high-text environments" inside their classrooms, with paper books, pencils, and paper. In such a setting, students slowly build up their attention spans by doing nothing but reading a book or scratching out a piece of writing, even if that means beginning with just a few minutes at a time.

"Build on that until they can go for 20 minutes, either in a group or individually—just reading the text, sustaining their attention and maintaining focus," Lemov says. "Writing does the same thing: it improves the focus and attention that students will need to do deep reading."

It's possible, of course, that kids' attention spans haven't actually changed that much with the advent of digital technology. Instead, argues Willingham, the cognitive scientist, in his book *The Reading Mind: A Cognitive Approach to How the Mind Reads*, it's their expectations for entertainment that have changed. "The consequence of long-term experience with digital technologies is not an inability to sustain attention. It's impatience with boredom," he writes. "It's an expectation that I should always have something interesting to listen to, watch, or read, and that creating an interesting experience should require little effort." Deep reading, on the other hand, requires "cognitive patience"—an entirely different set of skills in which kids often have to put in great effort for a payoff that is sometimes many pages down the road.

Yet in Wolf's view, getting rid of all reading tech would be as ill-advised as relying on it exclusively. Instead, she's hoping to spur a conversation about balance, gathering evidence about which ways of using digital technology work best for diverse learners and for different age groups—information that could help districts and teachers guide the decisions they make about teaching reading. A five- to 10-year-old child who is learning to read has different needs from a 12-year-old, or from a high schooler whose smartphone is loaded with five social media apps. Young children just beginning to build their reading circuit benefit most from books and human interaction. Older kids can cultivate the "digital wisdom" to make smarter choices while working on developing the ability to toggle effortlessly between print and digital worlds.

Some kids, though, may be tired of all that toggling. Matt Ryan, a high school English teacher in Attleboro, Massachusetts, doesn't allow any e-books in his class—when he assigns a novel, it's paper only. Not only does he not get any pushback, he says, but he senses students are somewhat relieved.

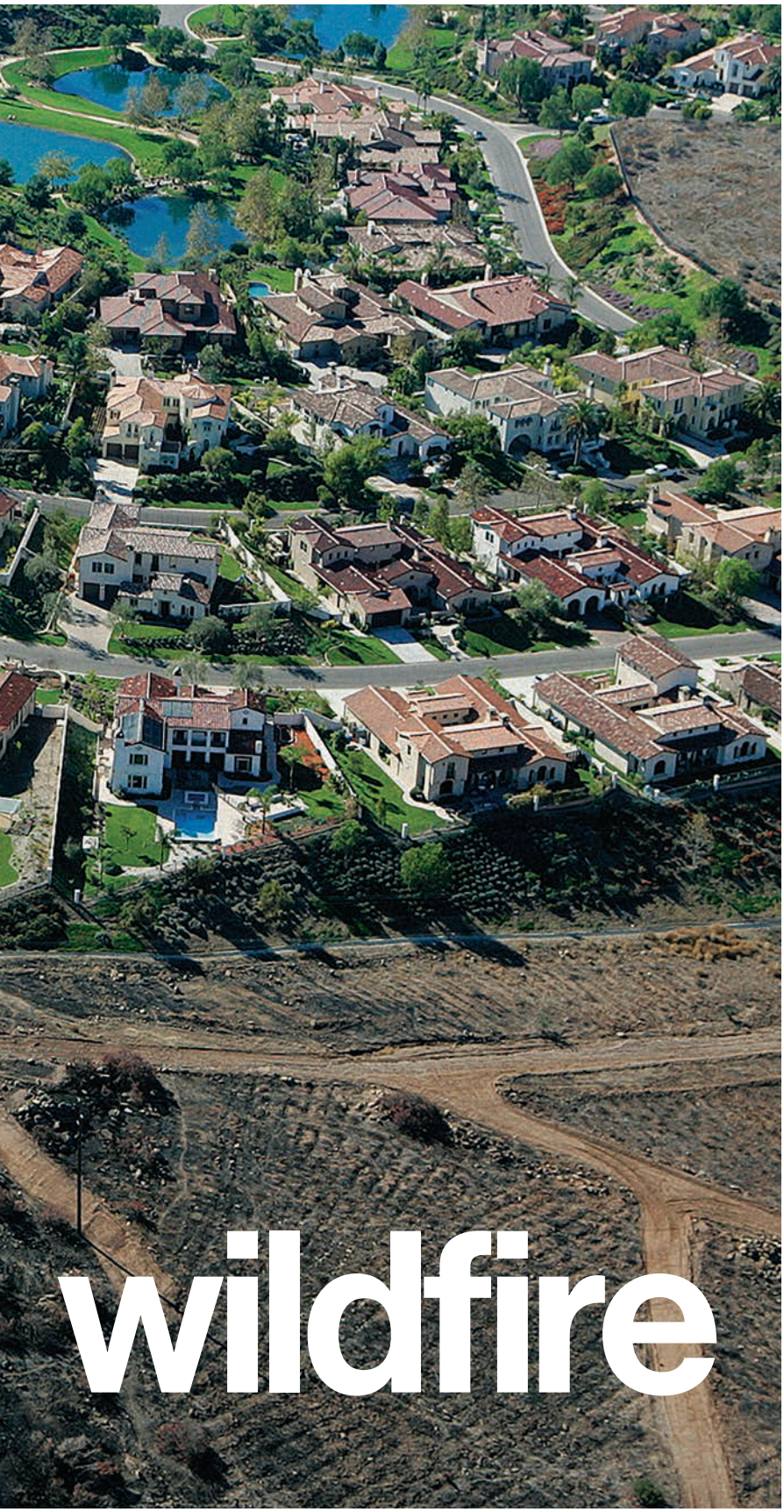
"Distractions are a very real issue, so reading on a device will not be effective for most of them," Ryan says. "My sense is that so much of what they do is on a device—they welcome something off of it." ■

Holly Korbey is an education and parenting journalist and author of Building Better Citizens: A New Civics Education for All.

Living with

We can build places that are easy to escape from, or places that are easy to defend. By Susie Cagle

In 2007, the Witch Fire burned 1,125 homes in San Diego County. But when the firestorm hit the edge of a development named The Crosby at Rancho Santa Fe, not a single house ignited.



wildfire

The first sparks that ignited in the Montecito hills above Santa Barbara, California, on November 13, 2008, were stoked by ferocious sundowner winds gusting at up to 85 miles per hour, pushing the flames down into the densely populated canyon. Troy Harris, then the director of institutional resilience at Westmont College in Montecito, rushed from the other side of town to the campus, nestled in foothills dense with chaparral and eucalyptus. Within minutes of entering the canyon, the Tea Fire had already reached the school. But the students did not evacuate. Westmont, with a legacy of large canyon wildfires over decades and only two winding roads as routes of escape, had planned for just this kind of disaster. They stayed put.

"We had parents calling the sheriff's office and the sheriff's office was telling people—incorrectly—tell your kid to get out of there," says Harris. In fact, there would have been no way to move 1,000 people down the hill faster than the fire was moving in on them. Instead, students and staff gathered in the fire-resistant gym on the southwestern corner of campus.

Nine structures on the campus burned, but the sheltered students were unharmed. It was, says Harris, "a spectacular win," but a highly unusual one.

With each devastating wildfire in the US West, officials consider new emergency management methods or regulations that might save homes or lives the next time. In the parts of California where the fire-ready hillsides meet human development and where the state has suffered recurring seasonal fire tragedies, that search for new means of survival has especially high stakes. Many of these methods are low cost and low tech, but no less truly innovative. With climate change bringing more communities under wildfire threat across the world, adaptation may require more social change than materials engineering.

"When people think of wildfire, they think of getting away as quickly as possible,

Nine structures on the Westmont College campus burned as the 2008 Tea Fire swept through Montecito, California. But students who sheltered in fire-resistant structures were unharmed.

right? Like that's the messaging that everyone hears—evacuate, evacuate, evacuate," says Jason Tavarez, Harris's successor at Westmont. "And that's 99 times out of 100."

But the other scenario is this: a conflagration too fast and violent to escape, with no better option than to hunker. It is a "shelter in place" or "stay and defend" approach to wildfire. Evacuations from western US wildfires have routinely caused significant casualties themselves, with fleeing people trapped on narrow roads behind debris or in traffic jams. For that reason, coupled with the more destructive pace of recent fires, there is a new spotlight on the shelter-in-place strategy. Despite some notable successes, however, it is not very popular.

"In the US it's something people are struggling to wrap their heads around," says fire researcher Crystal Kolden, a professor at the University of California, Merced. "When is it okay to shelter in place? And more importantly, what is the minimum need in terms of the facility, and how do you do that risk-benefit trade-off in a moment of crisis?"

In order to effectively live with fire, we can build places that are easy to escape from or places that are easy to defend. These are by no means mutually exclusive, but the US West hasn't done either. Meanwhile, the population has grown into the spaces on the rural edges of cities and suburbs, in the foothills and canyons and drainages where fire lives—what's called the wildland-urban interface. While fires have grown in size and destructiveness over the past two decades, so has the population in these hazard areas—roughly doubling between 1990 and 2010, with the more dangerous areas growing the most. In fact, the wildland-urban interface is the fastest-growing land-use area in the US.

Sheltering is not passive but active, whether it involves advance preparation in open-air safety sites and enclosed buildings or, in some cases, fire defense as the flames move in. In rural areas with few routes in or out, a shelter-in-place plan can mean the difference between life and death in the face of a fast-moving fire. It means planning for a worst-case scenario but not a truly rare one: a fire that moves faster than one can flee. That is the kind of fire California has seen time and again.

In response to the increasing threat, some institutions and communities are taking a cue from Australia, where officials have employed a policy of "leave early or stay and defend" since the 1990s. But even Australia has had second thoughts since the 2009 Black Saturday fires, when more than half of the 173 people killed had been sheltering inside a home. And for the most part, the US has been slow to adopt shelter-in-place policies for wildfire. The optics are not good—even the best-laid plans can look like abandonment or imprisonment, like leaving people to nature's violent whims. Fire researchers and officials can't agree on the science that should guide the planning. And with little adoption, there is little data on how well the approach works. Experts point repeatedly to the same handful of success stories like the one at Westmont College.

"We have to get over this idea that it's always the best thing to actually evacuate," says Kolden. "We used to have community bomb shelters, right? These are functionally community fire shelters. Those are the sort of conversations that we haven't had. And if we really want to build fire-resilient communities, we have to have those going forward."

Our shelters

The basic science of preventing a building from burning is not especially high tech or expensive, but it is counterintuitive to how we have long thought about wildfire. In the 1970s, when Jack Cohen pioneered the concept of "defensible space," a zone cleared of flammable vegetation or other fuel around a structure, the US Forest Service largely ignored him. It was a paradigm-shifting innovation—an easily implemented retrofit, at least wherever the space was available—but it meant considering wildfire from a defensive position instead of the offensive one the Forest Service had adopted for nearly 100 years.

The basic science of preventing a building from burning is not especially high tech or expensive, but it is counterintuitive to how we have long thought about wildfire.

Today regulators have come around, and California building standards for wildland areas at high and very high fire risk now require 100 feet of open space around structures, at least where there is 100 feet available to clear. Other home-hardening measures are comparably small scale, even cheap: replacing flammable roofs, closing window seams and junctions, using fine wire mesh to cover vents where sparks might enter. And the latest fire-resistant materials won't save a house where the gutters have been allowed to fill with dry kindling. Form tends to follow function: flat roofs, steel windows, clean lines that leave no harbor for a stray ember. Each devastating fire is bound to encourage a new innovation as fresh weaknesses are revealed.

California's strictest fire code applies only to homes in a clearly designated high-risk area (where, according to the California Department of Forestry and Fire Prevention, roughly one in four residential structures lies)—and only to those

PREVIOUS SPREAD: DON BARTLETTI/LOS ANGELES TIMES/GETTY IMAGES

DAVID MCNEW/GETTY IMAGES

that are newly built. In Paradise, where a fire in 2018 killed at least 85 people and destroyed more than 18,000 structures, nearly 40% of homes built after 1996 survived, versus just 11% of those built before.

The incremental addition of more and denser housing in flammable dead-end canyons is a concern, says Thomas Cova, an evacuation researcher and professor of geography at the University of Utah. The space between houses, or lack thereof, is a significant predictor of whether or not they'll burn. Building suburban infill is in many ways good housing policy for a state suffering from a severe lack of affordable homes, but it is bad land-use policy for a state with recurring intense wildfires. Still, there's little clear incentive for local officials to prevent the construction of new homes, even ones that will increase the risk for the entire community. One more flammable structure on the hillside, one or two more cars on the road—but also revenue collected from one more property tax bill.

Extensive retrofitting of the built environment in towns and cities established nearly a century ago is essentially off the table—it is work that isn't required under state codes, and no clear funding source is available. Even where communities are wiped out by fire, existing roads don't fall under the purview of minimum fire regulations when it comes time to rebuild. But entirely new housing tracts are held to much higher standards.

"I've always thought of shelter-in-place as a backup plan in emergencies, and it would be really wise to consider what options you might have," says Cova. "But now, I think it's also entering into the discussion associated with [new] development."

That's especially true in light of California's acute housing affordability crisis, which has put the state under severe pressure not only to continue building new homes but to build them on cheaper, more rural, more fire-risky land. A new guidance issued in October 2022 by the California state attorney general explicitly calls for local agencies to "avoid overreliance on community evacuation plans" and consider shelter-in-place options.

"The conversation turns to not whether we'll develop these areas, but how shelters are becoming part of it," says Cova. In California, "they're trying to chart a course where development in these areas can continue. You end up with public-safety and affordable-housing goals conflicting."

Stay and defend

Even among shelter-in-place advocates, there is broad agreement that it is always better to evacuate if there is the time and ability to do so safely. The problem is with wildfires that move so fast there's no time to get out. A secondary, no-evacuation plan could mean the difference between guaranteed death and a chance of survival. It may be as counterintuitive a cultural innovation as defensible space, forcing us to look at wildfire as an even greater threat.

"We don't have formal methods for designating safety zones for the public. But the concept has been used," says Cova. In past blazes, firefighters have, for example, moved people to golf courses and turned on the sprinklers.

One of the first shelter-in-place successes in the US was a result of quick thinking rather than advance planning. In 2003, with the Cedar Fire whipping across San Diego, fire officials chose to lock down the Barona Resort and Casino instead of attempting to evacuate the hundreds of people inside. The fire chief parked his truck across the sole exit, "so that if anybody got the idea of leaving, they weren't going anywhere," says Cova. "The fire burned around the casino's parking lots on all sides, all the hills around it. And the people just stayed there and gambled."

Westmont College began its shelter-in-place planning that same year, at the urging of the local fire department. In 2009, just six months after surviving the Tea Fire, Westmont was threatened by the Jesusita Fire. This one was a little further away, and slower moving—so there was time to leave. That's when Harris realized "we had a stay plan, but we had yet to develop a go plan." In evacuating from Jesusita, "it was clear it was a multi-hour thing. There's just no real fast way to get 1,000 people off the hill."

Tavarez is quick to point out that the Westmont students are not held against their will. But most everyone at the school at this point has bought into sheltering in place. And if anyone hasn't, he says, "we explain very kindly but firmly that with the number of students that we have here, and the plans that we have in place, and the contingency that we built into how we do things on campus, this is actually a lot safer than trying to fight the fire down the hill."

Nonetheless, college populations are easier to keep contained than other communities, and Westmont isn't the only example. In 2018, ahead of the massive and fast-moving Woolsey Fire that burned through the Santa Monica mountains, officials evacuated a quarter-million people from their homes while Pepperdine University in Malibu sheltered hundreds of its students on campus. They were protected by wide defensible spaces, expansive irrigated lawns, and hardened buildings equipped with sprinklers. The school has had a shelter-in-place plan for decades, but some officials were nonetheless critical. "This shelter-in-place policy is going to have to be reassessed," state senator Henry Stern told a crowd at a community meeting shortly after the fire. Even when it works as intended, choosing to stay while a fire rages is not popular public policy.

"It is just a bad plan for people to leave Pepperdine when they already are in the safest location you can be for survival," says Drew Smith, LA County's assistant fire chief.

LA County fire officials reevaluate the plan annually and haven't found it wanting. But Smith is skeptical of expanding the concept to smaller institutions or community buildings—there is not enough space in those structures for enough people to weather the extreme heat and smoke of a wildfire, he says. His measure is 50 people for 15 acres, or about four people in the space of a football field. Some state fire planners, though, use standard occupancy measurements to determine shelter-in-place capacity, resulting in a standard closer to a few square feet per person. The scarcity of data means there's no consensus.

"Shelter-in-place was really a theory and it's still a work in progress."

Fire-planned communities

Individual homes can also serve as shelters given the right conditions. In 2004, five communities in Rancho Santa Fe, an affluent, semi-rural part of San Diego County, were designed with this in mind. Thousands of homes were built to resist ignition; fire hydrants were spaced every 250 feet along roads in and around the community; a defensible zone and other open spaces such as golf courses and parks were maintained to buffer the neighborhoods from the chaparral and eucalyptus hillsides expected to burn; and homeowners' associations were set up to enforce and maintain fire protection measures.

Each home was considered to be built to shelter-in-place standards, with ignition-resistant construction and materials—a cutting-edge approach for the time, though the standards have since been adopted into state and local codes. They are little fortresses of tile roofs, stucco walls, hardscape patios, and covered eaves. Early evacuation is still always the primary emergency plan, and the roads are designed to facilitate it. But the heavy fortification gives the communities—both the structures and the people who shelter in them—an extra chance to survive.

"One of the core principles is that it's community wide," says Brandon Closs, fire prevention specialist for the Rancho Santa Fe Fire Protection District. San Diego's building code has long been at the vanguard of fire safety—it was used as a model for the state regulations, and it is still more stringent than the state requires.

"Shelter-in-place really was a theory, and it's still a work in progress," says Closs. He and others are confident in Rancho Santa Fe's design, but the communities haven't yet been thoroughly tested by a blaze.

And nearly two decades after Rancho Santa Fe was built, it is still an outlier in the state.

Cost alone is one likely hurdle. The nonprofit Insurance Institute for Business and Home Safety estimates it costs 4% to 13% more to build a home to the highest level of fire safety, far exceeding current state standards. But achieving the level of community hardening now in place in the wealthy, gated neighborhoods of Rancho Santa Fe requires a much larger investment.

Homes in these developments are priced in the low millions at the least: a 2,400-square-foot three-bedroom house in Rancho Santa Fe sold for $3.2 million in 2022. Lower-priced homes and communities in equally fire-risky parts of San Diego County, and across California, have none of this protection. Many homeowners in the area are also covered by insurance policies that offer private mitigation or firefighting services from their own or contracted fire crews—or at least they used to be. Even in perhaps the best-designed fire-ready wildland community in California, insurance companies are canceling policies to reduce their risk load. "The dollar is going to move a lot of things quicker than regulations can," says Closs.

A cultural shift

It is infinitely easier to upgrade one's own roof or vent mesh than it is to implement community-scale hardening measures. The factors making California's wildfires more acutely destructive to people and their homes are more socioeconomic than they are climate driven.

"We're not accustomed to thinking about what shelter-in-place looks like, because the term is most commonly associated with people's individual houses," says Kolden. Preparing for fire is in many ways treated as an individual problem, with homeowners responsible for their own go plans and for the full cost of any hardening measures or landscape management. This also makes wildfire a deeply unequal problem: some high-risk areas are filled with multimillion-dollar homes surrounded by plenty of open space, whose owners have the means to keep them updated with the latest construction innovations, while others are packed in on small lots overgrown with trees that residents can't afford to cut down. Every step toward putting the burden of safety at the community level relieves some of that inequality.

"Civilization has always progressed based on community cooperation," says Kolden. "And we need to do this for fire to have any chance of averting a lot of the disasters that we've seen the last few years as we move forward." ■

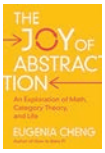
Susie Cagle covers climate change and inequality in California.

There is no shortage of popular books and lectures on math—but they can take us only so far.

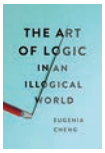
By Pradeep Niroula
Illustrations by Jenny Kroik

Rocky journeys to the land of mathematics

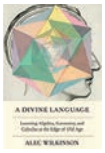
How to Bake Pi: Easy Recipes for Understanding Complex Maths
Eugenia Cheng



The Joy of Abstraction: An Exploration of Math, Category Theory, and Life
Eugenia Cheng



The Art of Logic in an Illogical World
Eugenia Cheng



A Divine Language: Learning Algebra, Geometry, and Calculus at the Edge of Old Age
Alec Wilkinson

Mathematics has long been presented as a sanctuary from confusion and doubt, a place to go in search of answers. Perhaps part of the mystique comes from the fact that biographies of mathematicians often paint them as otherworldly savants—people who seem to pull nature's deepest truths from thin air and transcribe them in prose so succinct and self-assured it must be read meditatively, one word at a time. As a graduate student in physics, I have seen the work that goes into conducting delicate experiments, but the daily grind of mathematical discovery is a ritual altogether foreign to me. And this feeling is only reinforced by popular books on math, which often take the tone of a pastor dispensing sermons to the faithful.

In physics, the questions we ask and the theories we come up with aim to explain the underlying reality better. Indeed, certain concepts—like the fact that opposite charges attract or that disorder or entropy tends to increase—are so universally ingrained in our experience that they creep into everyday language as metaphors. I often catch myself resorting to the vocabulary of research and analogies from physics to explain myself. But despite having been close to math for most of my life, I continue to be bewildered by mathematics research. What motivates it, and what is its ultimate endgame? What does the world look like to someone steeped in the culture of mathematics? So when I discovered that Terence Tao, a living legend of contemporary math, was offering an online class on his approach to "mathematical thinking," I had to check it out.

The movie-length course, distributed by MasterClass, starts out invitingly enough. Tao exudes calm and confidence. A mathematical mindset, he says, makes "the complex world a bit more manageable." He suggests that his class might be "even more suitable for those without formal math training." But very soon, the futility of this attempt to pierce the mystique of mathematics becomes inescapable.

For most of the session, Tao is seated in a white armchair; there are no blackboards, no pens, no paper. "Mathematics is a language of precise communication," Tao says, and yet here, he is without the most powerful tools for achieving that. Although he tries to be approachable,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$(E1)\ f \circ id_X = f, \quad id_Y \circ f = f,$
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1_C
$A \xrightarrow{f} B \xrightarrow{g} C$
$g \circ f$

talking about how he once did poorly in an exam and struggles to assemble window curtains, I felt no closer to the world of math. After 90 minutes of watching, the pithy takeaways I was left with were indistinguishable from what I might learn at a mindfulness retreat: "Everything is united" and "Embrace failure."

I am not the only person who has tried—and failed—to break into the church of math. Recently, Alec Wilkinson, a writer for the New Yorker and a longtime believer in self-improvement, took on a yearlong project to conquer some of the basic mathematics that evaded him in his youth: algebra, geometry, and calculus. In his 2022 book *A Divine Language*, he describes his journey as a quest for redemption after those struggles with high school math. "It had abused me, and I felt aggrieved," he writes. "I was returning, with a half century's wisdom, to knock the smile off math's face."

Wilkinson has a better plan than mine: he starts with standard textbooks. And he has help. His niece, a math professor, agrees to hold his hand through this journey. But even the first steps through algebra are backbreaking. The skepticism of an adult gets in the way; he cannot seem to accept the rules—the way variables can be added and multiplied, how fractions and exponents work—as readily as children do. What's more, he finds the textbook writing atrocious.

"There is a boosterish quality to the prose, as if learning math is not only fun! but also obscurely patriotic, the duty of an adolescent citizen-in-waiting," he writes. "In addition to leaving things out, they were careless about language, their sentences were disorderly, their thinking was frequently slipshod, and their tone was often cheerfully and irrationally impatient." Though he wrestles algebra with decidedly determined rigor, six hours a day for six to seven days a week, and obsesses about it the rest of the time, simple competence continues to elude him. Revisiting algebra as an adult, he declares, is "like meeting someone you hadn't seen in years and being reminded why you never liked him or her."

When Wilkinson is not hunched over textbooks, he is dazzled by the mysticism surrounding math. The mathematicians he talks to speak of their profession with quasi-religious sentiments and think of themselves as mere prospectors of a transcendental order. When Wilkinson complains to his niece that math is not yielding to him, he is told, "For a moment, think of it as a monastic discipline. You have to take on faith what I tell you." Where his niece and others see patterns and order, he perceives only "incoherence, obfuscation, and chaos"; he feels like a monk who sees lesser angels than everybody around him. He is now reproachful of his education and his younger self: Why hadn't he learned all this better when he had the impressionability of a child?

A year later, Wilkinson can solve some calculus problems, but the journey was difficult, the terrain harsh and often unwelcoming. Math often gets talked about as a language with logic as its grammar. But when you learn a language like Spanish, you can casually pick up some words and immediately unlock a new culture. The introductory steps to formal math, on the other hand, demand a commitment to rigor and abstraction while withholding any usefulness. Among mathematicians, as Wilkinson discovers, there is even a general derision toward those who seek useful application. There is G.H. Hardy's famous jeer in 1940, "Is not the position of an ordinary applied mathematician in some ways a little pathetic?" Or a more recent remark by John Baez: "If you do not like abstraction, why are you in mathematics? Perhaps you should be in finance, where all the numbers have dollar signs in front of them." Math's only promise in return for unwavering fealty is that of a higher plan, much as in a cult. Wilkinson is left as dazed and exhausted as a victim of a shipwreck stranded in the Arctic.

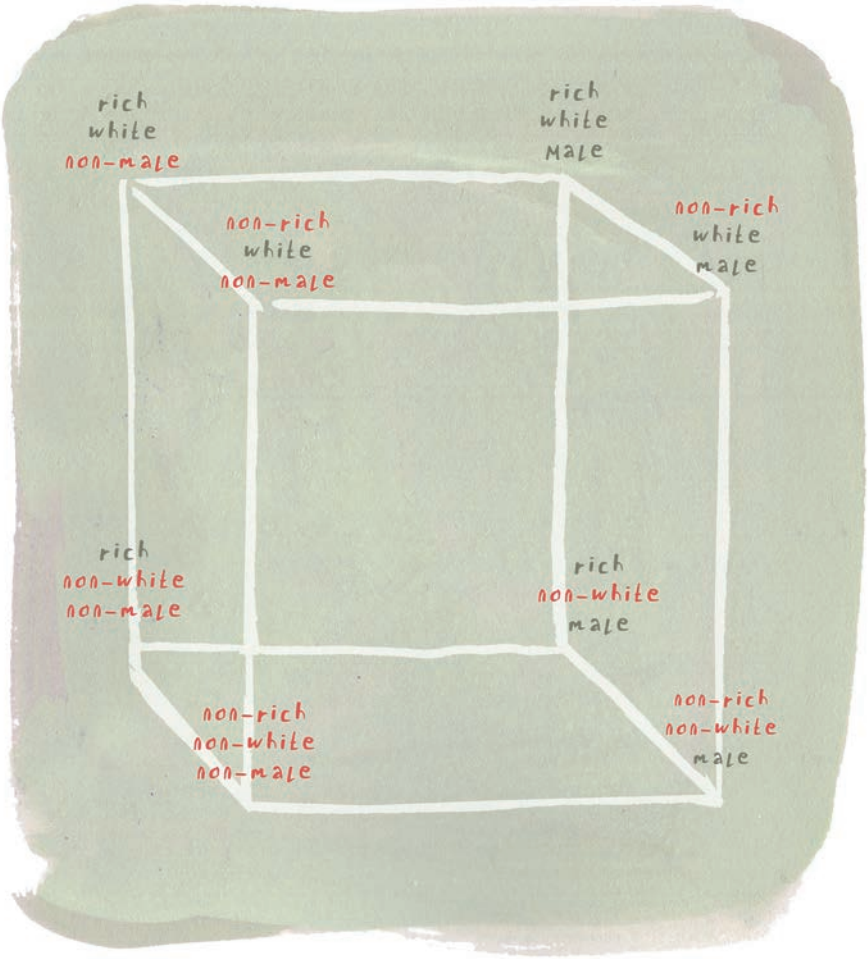
My frustrations and Wilkinson's highlight the inadequacies of the mediums usually employed in teaching mathematics. Textbooks aren't always written with accessibility in mind. They vacillate between pedantry and hand-wavy dismissals, and the exercises they present can appear to be a series of pointless drills. At the same time, attempts at an overview can feel frustratingly empty. What Wilkinson and I really needed was a sympathetic voice—the testimony of one who has climbed the heights of abstract math but also has the patience to guide a newcomer.

The mathematician and concert pianist Eugenia Cheng is the closest I've come to finding such a voice.

I got into Cheng's books because I share her love of baking. For the proud owner of a stand mixer and several pastry brushes, the title *Cakes, Custard and Category Theory* sounded too delectable to pass up. Its first chapter, about the epistemic nature of mathematics, starts with a recipe for brownies. Cheng tells you that stumbling into new ideas in math is like screwing up a soufflé recipe so badly that you end up with cookies. I was easily drawn in.

Many popular books on mathematics try to be approachable by talking about

Revisiting algebra as an adult, Wilkinson declares, is "like meeting someone you hadn't seen in years and being reminded why you never liked him or her."



Cube of privilege

Cheng illustrates the idea of intersectionality with representations like this one, showing privilege along multiple dimensions.

stock markets or poker odds. Others wax poetic about prime numbers and the mystery of infinity. Cheng's books lift readers to the rarefied heights of mathematical abstraction by teaching them category theory, which she believes is the most foundational kind of math.

Category theory may seem esoteric, but it is the underlying grammar of mathematical logic. Cheng's books pull back the curtain to show how pedestrian mathematics research can be; the act of chaining simple inviolable axioms into complex arguments is simply the ivory-tower equivalent of building a Lego spaceship from tiny, indestructible pieces. More important, they are an invitation to change your worldview, to simplify thinking with abstractions, to interpret and analyze the world in mathematical terms.

Reading *Cakes, Custard and Category Theory* (also issued as *How to Bake Pi*), one soon discovers that the desserts are mere gambits. Each chapter begins with a recipe followed by an analogy between math and baking. Puff pastry is a reminder that extreme precision is a part of mathematical research; elsewhere, we learn that there is really no right way to make a cake and that we should embrace flexibility in ingredients as well as techniques. These analogies can feel tenuous, sometimes even forced. But thankfully, they quickly fade away to make room for a casual conversation about mathematical topics.

Cheng's latest book, *The Joy of Abstraction,* builds on similar themes but feels more like an undergraduate textbook. Its chapters, with titles like "Isomorphism" and "Functors," provide a fairly rigorous introduction to category theory and are replete with theorems, proofs, and exercises. Occasionally, Cheng goes on a tangent about how certain concepts have etymological and semantic parallels to real life—a "function" can be thought of as a vending machine, a "set" may represent a group of people (and you can divide that set into "partitions" of "friendships"). But having set up the stage using familiar objects, she quickly gets to the hard work of manipulating them using logic. In short, her books are a humane introduction to foundational math, and they paint a good picture of what mathematicians spend their time thinking about.

There is, however, one major way her math books markedly differ from undergraduate textbooks. A persistent theme running across Cheng's writing is that the world is best understood in a stripped-down form, and that insights from abstract math can even nourish empathy and a sense of justice. Friends trying to be sympathetic to a heartbreak by prying into painful details should content themselves with simply knowing that a) there was something you loved and b) you recently lost it. It's as simple as that; all other details are superfluous.

Cheng's more unorthodox contention—one best presented in her book *The Art of Logic in an Illogical World*—is that category theory can, in fact, be deployed in our daily lives to make discussions around privilege, sexual harassment, racism, and even "fake news" less divisive. For instance, she thinks that the debate about social welfare can be described in terms of "false positives"

and "false negatives": "a false negative in this case is someone who deserves help but doesn't get it; a false positive would be someone who doesn't deserve help but does get it." The debate, her argument goes, isn't about whether we should help people (of course we should!) but rather about the extent to which we accommodate such false positives and false negatives. Someone who wants to reduce the amount of money spent on social welfare is probably bothered by the idea that false positives are abusing the system by collecting benefits they don't deserve. Cheng thinks the steely vocabulary of logic can help people caught in a heated argument realize that the divide between them isn't so irreconcilable (after all, they both want to help people) and steer them toward a more nuanced conversation of "to what extent" and "under what circumstances."

Cheng believes we can encourage empathy through logically related analogies. Initially befuddled by men who protest sweeping accusations of privilege or aggression, she finds it helpful to compare their protests to the exasperation she feels when people resent graduates of elite schools (like herself) for having success handed to them by parents even though Cheng herself had to work hard. This, we are told, has made her more empathetic toward men: emotions rightfully flare up when individual experiences contrast with group generalizations.

However, applying such arguments to more complex cases feels increasingly suspect. A diagram that appears in many of Cheng's books is the "cube of privilege." In one corner of the cube is the empty set {}. Starting from that corner (bottom front left in the illustration on page 73), you can move in three directions to collect one of three types of privilege: white, male, and rich. If you move in all three directions, one after another, you end up in the opposite corner with all privilege points: {white, male, rich}.

To a category theorist, this is the most succinct description of intersectionality: the idea that attributes like class, gender, and race can interact to produce complex manifestations of inequality. Cheng's diagram shows how combinations of privilege in multiple dimensions can form complicated hierarchies, so that people with three types of privilege are necessarily better off than people with only two types. But when Cheng uses this diagram for insights on thornier questions, like why "white men who did not grow up rich" may feel particularly aggrieved by nonwhite men who are richer and better off, her answer is unsatisfying: in the cube of privilege "there is no arrow from rich nonwhite men to non-rich white men (the two groups inhabit disconnected corners of a diagonal), so the theory of privilege does not say anything about the relative situation of these two groups." The cop-out may be logically consistent, but it is certainly not the rhetorical coup de grâce one hopes to learn after engaging with abstract reasoning for several weeks.

Cheng thinks the steely vocabulary of logic can help people caught in a heated argument realize that the divide between them isn't so irreconcilable.

One may equip people with rigorous tools to avoid the slipperiness and ambiguity of everyday language, but these tools don't always come with ethical guidelines. The Malthusian panic over population explosion, for example, emerged from observations about the exponential function and has been used to justify anti-immigration policies as well as genocides. Mathematically inspired computer models are routinely shown to have bias. A highly controversial book from 1994 hid its dubious efforts to connect race with intelligence behind the mathy title *The Bell Curve*. As in the Bible, Tocqueville's *Democracy in America*, and other revered tomes, there is enough in the vast literature of math to justify and reinforce any kind of thinking, however contrarian, problematic, or silly.

Yet there is still a sense in which Eugenia Cheng's mission of demystifying math is extremely noble. Her books try to replicate the humdrum ritual of constructing arguments from ironclad proofs, and—more important—they show what a math-inspired view of the world could look like, both in its oddity and in its permissiveness. You may find such a worldview odious and disagreeable, but the key lesson from Cheng's books is that communicating a complex thought from one mind to another, let alone across cultures and languages, is no easy feat and that the art of expressing ideas charitably and with clarity is something we all would benefit from getting better at.

What I find most inspiring about the culture of mathematics is how it has endured through the ages, needling a common thread across civilizations. Math has managed to unify disparate discoveries across the globe, and the puzzles raised centuries ago are still being pondered. One reason this culture may appear mystifying for a beginner is that contemporary math has whittled down millennia-old ideas, once rich and vivid, into terse symbols and esoteric terminologies that aren't always easy to master. Popular math books seek a fresher take on these old ideas, be it through baking recipes or hot-button political issues. My verdict: Why not? It's worth a shot. ■

Pradeep Niroula is doctoral candidate in physics based in Washington, DC.

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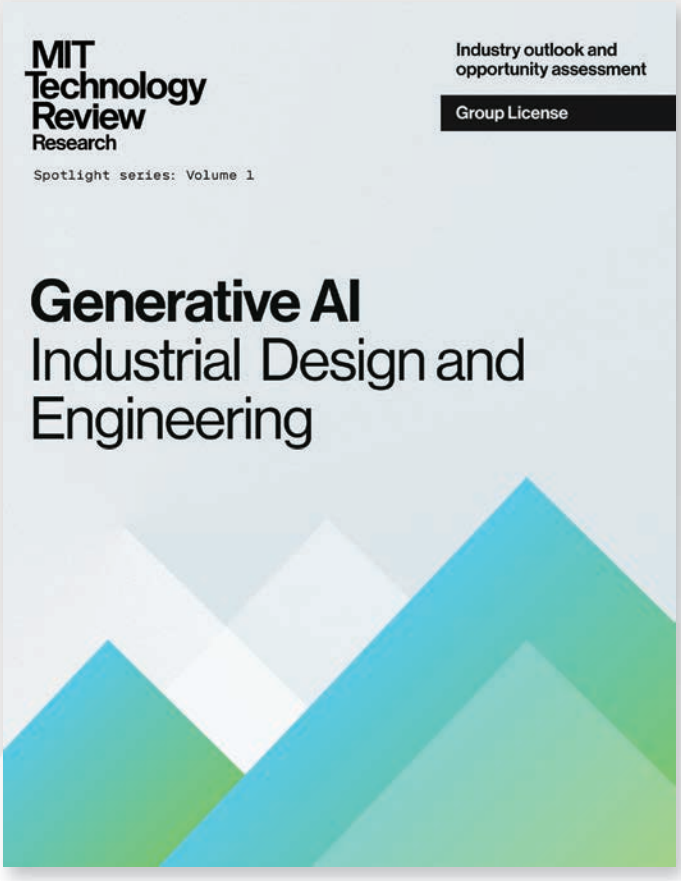

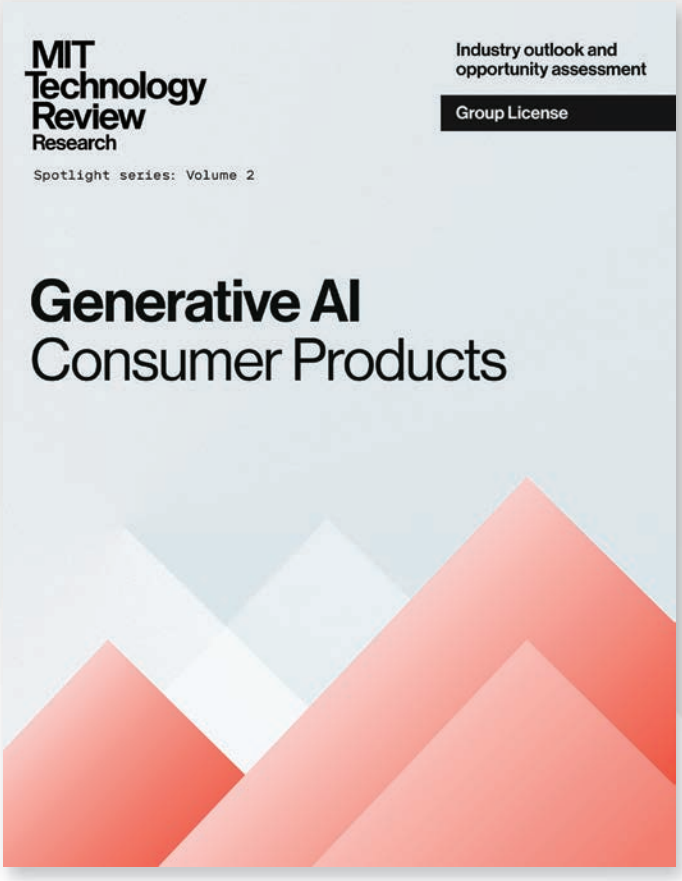

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THE HOME MANAGER
ATARI 1064

After discovering that a history of keyboards—from typewriters to iPhones—had yet to be written, this designer/typographer got to work.

Shift happens

Opposite: Marcin Wichary and his keyboards. "It sounds really boring, right?" he says. "But if you look at it throughout the ages ... it becomes a lot more interesting."

Below: The Maltron enables people with special needs to enter computer data much more easily and quickly than with conventional keyboards.

By Allison Arieff

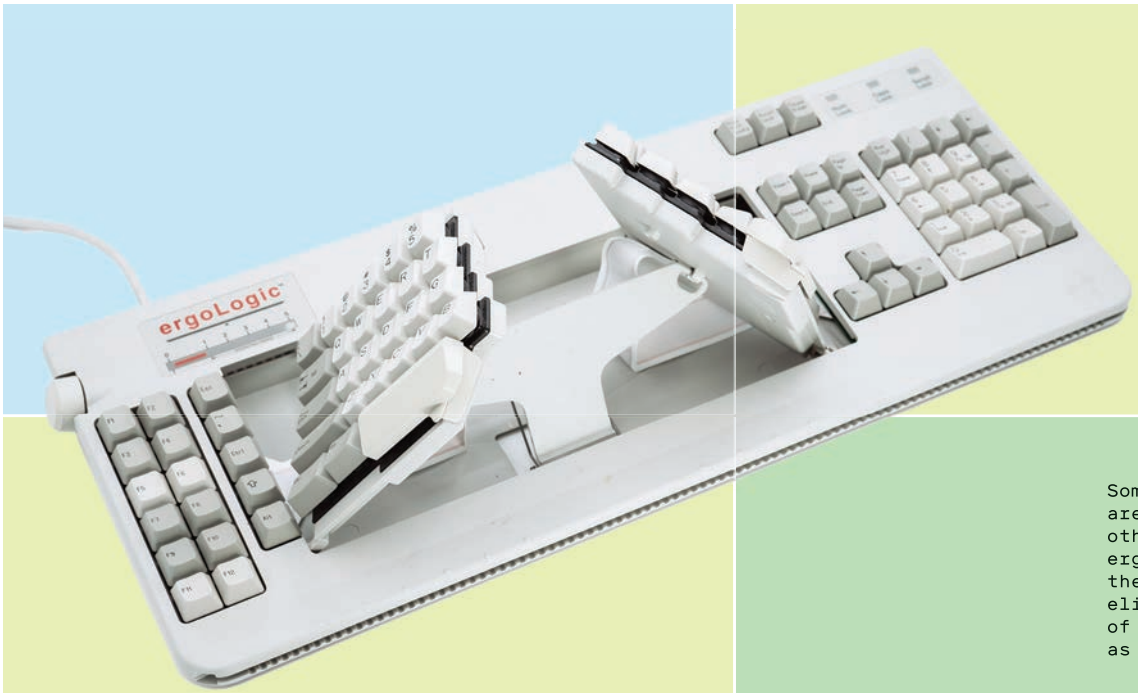
When the designer and typographer Marcin Wichary stumbled upon a tiny museum just outside Barcelona five years ago, the experience tipped his interest in the history of technology into an obsession with a very particular part of it: the keyboard.

"I have never seen so many typewriters under one roof. Not even close," he shared on Twitter at the time. "At this point, I literally have tears in my eyes. I'm not kidding. This feels like a miracle."

He'd had a revelation while wandering through the exhibit: Each key on a keyboard has its own stories. And these stories are not just about computing technology, but also about the people who designed, used, or otherwise interacted with the keyboards.

Take the backspace key, he explains: "I like that [the concept of] backspace was originally just that—a *space* going *backward*. We are used to it erasing now, but for a hundred years, erasing was its own incredibly complex endeavor. You needed to master a Comet eraser, or Wite-Out, or strange correction tapes, and possibly all of the above … or give up and start from scratch whenever you made a typo."

The deeper he researched, the more fixated he became. Amazed that no comprehensive book existed on the history of keyboards, he decided to create his own. When not working at his day job as design lead for the design software company Figma, he began producing *Shift Happens*, a two-volume, 1,216-page hardcover book—and raised over $750,000 for the project on Kickstarter in March of 2023. Wichary was only a bit surprised by the support and the keyboard's wide appeal. As he points out, "It's such a crucial device that occupies a lot of our waking life."



Some of these keyboards are adjustable and others fixed. The ergoLogic FlexPro and the SafeType (below) eliminate pronation of the forearms as well as wrist extension.

These days, even the cheapest desk keyboard is in some way "ergonomic," allowing for reduced effort and improved response compared with even the best of the mechanical and electric typewriters that preceded them.

But some keyboards go further than most, rotating or tenting their respective halves to allow a less stressful hand and arm position.

Other keyboards go even further, questioning the very nature of keys.

Clockwise from top left, the orbiTouch, Intellikeys, Big Keys, and DataHand are each designed for people with physical, cognitive, or visual disabilities.

Some keyboards enable communication between people who might find that difficult. Shown here are a simple keyboard connected to a singular Braille cell; a typewriter making it possible to print in Braille; and a machine that allowed people who are hard of hearing to type over telephone wires.

KEVIN WALKER

In the late 1980s, Stacy Horn launched ECHO as a place for quirky, tech-savvy New Yorkers to congregate online. A few users never left.

By Nika Simovich Fisher

Opposite: Stacy Horn, photographed in 1994, still lives in the West Village apartment that was her home when she launched ECHO.

The lasting impact of an online salon

One January afternoon last year, a bouquet of balloons arrived at Karen Rose's residence in Delray Beach, Florida. She wasn't expecting a delivery, since it wasn't her birthday or wedding anniversary, and she thought someone had made a mistake until she noticed the words "AND NOW?" printed on each balloon.

"AND NOW?" is the prompt that follows every action on ECHO, a 34-year-old text-based social network that still hosts a community of former and current New Yorkers. When you log in: AND NOW? After checking who's online: AND NOW? Upon joining one of ECHO's chat rooms, called conferences: AND NOW?

And now Rose, whose handle was KZ, was presented the same question, six and a half years into a battle with lung cancer that she'd documented on a section of ECHO devoted to health. When she notified the community that she was turning to hospice care, her fellow "Echoids" responded with the balloons, along with flowers and chocolate.

Then last spring, ECHO's founder, Stacy Horn, announced KZ's death on ECHO. KZ was one of the platform's 20 inaugural members, having joined in its first year at Horn's invitation and remained until her death at 72. She was the host of the network's sex conference, a real estate agent, artist, self-proclaimed "dance snob," taiko drummer, tennis player, and general "doer." People of such eclectic interests were central to establishing the vibrant cultural personality of this online community.

ECHO stands for "East Coast Hang Out," and when Horn founded it, she wanted to create a digital space that was social and unequivocally New York. Members had to meet two requirements: they had to be geeky enough to navigate a cumbersome, text-based digital platform in the early days of the internet, but culturally in tune enough to foster the types of conversations you might hear at a West Village dinner party. Horn enlisted her graduate school friends (she was a recent graduate of New York University's interactive telecommunications program), as well as members of other bulletin-board-style platforms.

One primary source of inspiration was the California-based online community known as the WELL (for "Whole Earth 'Lectronic Link"), started by Stewart Brand in 1985. Brand is well known for being a counterculture impresario in the Bay Area during the 1960s, editing the widely distributed *Whole Earth Catalog*. Just as the WELL brought together experimental, self-sufficient individuals who foresaw the endless possibilities of computers, ECHO defined the New York web scene and influenced the design of contemporary social networks, creating lifelong friendships in the process.

When ECHO was founded, the World Wide Web was still being invented, and browsers weren't a thing. Users congregated in interest-based forums, but Horn found most of them to be male-centric, heavy in technical jargon, and, just like the WELL, centered on the West Coast. She craved a destination like the vibrant and artistic 20th-century salons of Gertrude Stein's era, where users could exchange ideas and meet one another while getting lost in discussion.

What she ended up making was a hotbed of culturally minded early internet enthusiasts—a social network before there was a term for that. Through the evolution of this ecosystem, users would meet one another and contribute to the changing digital economy by starting businesses and cultural programming. They would forever transform their lives in a way that wouldn't otherwise have been possible, all while making a lasting mark on New York's budding tech community. ECHO was a blueprint for the larger-scale social networks that we see today, and it serves as a reminder that behind all networks are people, with a lot of words to exchange.

Horn, who is now 66, still lives in the same West Village apartment that was her home when she launched ECHO. When I met with her to discuss its origins, she had a neatly trimmed bob with bangs and wore denim jeans with a fitted black T-shirt—conjuring both Steve Jobs and downtown "it girl." She said the idea for ECHO came out of her day job as a telecommunications analyst at Mobil, where she was the only woman in her department.

Week after week, she'd pitch the idea of "computer conferencing," an efficient strategy to manage machines in different time zones that would post updates to one continuously synced document. "I would stake my entire future that this is going to be the thing," Horn enthusiastically told the team of corporate men about her plan. She got the impression they thought the idea was laughable, and the answer was a firm no. Her boss suggested that obtaining a graduate degree would help Horn climb the corporate ladder, and while her interests were shifting toward writing, she thought graduate school sounded exciting. She picked the NYU program because it had "telecommunications" in the title, so Mobil would cover it as a work-related expense.

Horn expected the program to be as dry and technical as her job designing telecommunications networks, but she was taken by the school's experimental philosophy. She wrote a play called *Corpse in Space* that took the form of a conversation between a talking sofa, a praying mantis, and a dead saint. As she went to turn it in, a pang of doubt overcame her; she sheepishly placed her draft at the bottom of the stack of assignments and quickly left the room. The next time she was at school, Red Burns, ITP's renowned chair, brusquely called out, "Stacy Horn! Stacy Horn!" Horn interpreted the tone as ominous, but to her surprise, Burns embraced her and said her paper was more fun than anything she'd read in years. In that moment, Horn's worldview changed. "Oh my god, I can just go crazy and somebody might actually like it," she recalls thinking. Technology didn't have to be cold and impersonal. She became dedicated to experimentation and play in her work.

Back at Mobil, Horn decided that if her team could see a social network in action, they'd never go back. She started a trial program called MoNet (a portmanteau of "mobile network"), but to her dismay, it flopped. (A few years after she left Mobil, she says, the head of the telecommunications department told her that everyone on the team had agreed to tank the project. They were concerned that the platform would expose everyone's work habits and amplify their mistakes.)


JARGON WATCH

The Latest Game Box (It's Not 3DO)

Net Living: The East Coast Hang Out

FREDERICK DUPOWERS; MAGAZINE FROM THE COLLECTION OF MIT LIBRARIES

"There wasn't a velvet rope to get in, but you had to have certain chops to be able to hang with those people."

Social butterfly
From a 1993 profile in Wired (above): "I was pissed off that everyone was exploiting this incredible communications device except women." Right: demoing ECHO on Charlie Rose in 1994.

Upon leaving Mobil, Horn used the software behind MoNet, known as Caucus, to set up ECHO. She pitched it as a social community where interesting, thoughtful New Yorkers could connect about the books they were reading and the places they were going, and ultimately get to know one another on a deeper level. She wanted to create a "small town" feeling where residents had a sense of pride.

None of the investors she approached were interested. At the time, she says, the consensus was that the only people who would want to talk to others online were socially inept weirdos. So she started the platform with $20,000 of her savings and ran it out of her apartment.

In those days, most people had only one phone line at home, while businesses would have a few more. Horn asked NYNEX, the local phone company, to connect additional lines to her apartment. Before long she needed up to 24 lines, which was more than the maximum available for the whole building. But with the internet beginning to take off, the phone company realized that soon she wouldn't be the only one needing additional capacity. NYNEX ripped up the street and installed new cables that would support not only ECHO but the neighboring buildings' communication needs for the foreseeable future.

Horn recalls her neighbors being irritated with the logistics of an internet business running out of the apartment complex, particularly during the cable installation, but in the end, their neighborhood was one of the first with stronger internet connections that everyone could enjoy. Back in her apartment, ECHO's modem, housed in a custom cabinet with crimson sequins along the edges and gold tassels in the front, would get so hot it warmed up the whole space. ECHO's server bounced around New York before ultimately moving to a more stable facility in Oregon.

At its peak in the late '90s, ECHO had 3,500 members. Among them: writers, artists, musicians, actors, therapists, and even, briefly, Robert F. Kennedy Jr. Horn hand-picked early members to help seed the community. To make women feel welcome, she gave them free one-year memberships (ECHO cost $10 a month and $4 an hour for online time when it first launched) and made sure to assign women to host various conferences. Those efforts paid off—40% of ECHO's users were female at a time when women made up a tenth of the online world. Membership snowballed after the appearance of a 1990 New York Times story headlined "Coming to the East Coast: An Electronic Salon," placing ECHO at the forefront of New York's "Silicon Alley."

To extend the artistic component of the platform, Horn did outreach at art openings and museums. She and David Ross, then director of the Whitney Museum of American Art, created an ongoing series in which they'd pick a topic related to visual culture and invite a panel of experts to discuss it at a nonprofit performance space in the East Village. Other events the community organized included "Dinner Theatre of the Mind," a monthly seminar of philosophical discourse held by two members known as "Neandergal" and "Miss Outer Boro 1991"; an independent film group; and the World Wide Web Artist Consortium, where participants met in real life to talk about the internet.

Kyle Shannon, an actor and graphic designer who founded the consortium, says he initially joined ECHO to surround himself with people who knew more about the web than he did. "There wasn't a velvet rope to get in, but you had to have certain chops to be able to hang with those people," he says.

When Shannon and his wife, Gabrielle, tried to post an e-zine called Urban Desires online, his images didn't load, and he logged on to ECHO to see if anyone could help. A fellow Echoid, Chan Suh, responded and revised his code. A month after the e-zine launched, in 1994, Shannon learned that the French newspaper Libération had run a full-page article about it. "The distance between putting something in the world and having an impact just went to zero," he said after seeing the publication

VIDEO STILL VIA PBS

on a newsstand in Times Square. By 1995, Urban Desires had 100,000 site visits a day. He later partnered with Suh to found an online marketing business called Agency.com. The company was bringing in $200 million in revenue at its largest before Omnicon acquired it in 2002, Shannon says, and made interactive websites for Fortune 500 companies, including British Airways' first ticketing system and Sirius Satellite Radio's online player.

There were weekly "F2F" (or face-to-face) sessions at downtown watering holes. After the parties ended, members would log back on and keep chatting, sometimes in private conferences. Online romances blossomed. In her 1998 book *Cyberville: Clicks, Culture, and the Creation of an Online Town*, Horn described cyberspace as the most erotic medium because of the anticipation and thrill that messaging provided. "Stacy always likes to say that [there are] children [who] wouldn't exist if it wasn't for ECHO," says Jim Baumbach, who met his wife, Liz Margoshes (a.k.a. Neandergal), on the platform in the early '90s. Now they're married, 70-something therapists who still use ECHO daily— even going as far to send "YO's," ECHO's version of a direct message, to one another while in the same East Village apartment.

Shannon attributes ECHO's success to its rootedness in a specific local scene. "A strong culture, by definition, has exclusion criteria, whether they're explicitly stated or not," he says.

Omar Wasow, an assistant professor at UC Berkeley, was on ECHO in his college years, when he was a student at Stanford. He'd grown up in New York, so the regional aspect of the platform intrigued him, as did the focus on discussion. But Wasow says he was more of a lurker than a participant. After college, where he studied race and politics and taught entrepreneurship at a nonprofit helping former drug dealers start businesses, he moved back to New York. Living in the Brooklyn neighborhood of Fort Greene, which was going through a Black renaissance, he became part of a large community of Black professionals. He realized he wanted to create a digital space that was inspired by ECHO but reflected his own interests and experience of the city, for a community he connected with beyond the screen.

In 1994 he started New York Online, a social network focused on highlighting a multicultural experience in New York City. In a New York Times article from the year of its launch, he compared the platform to the subway: "It's a network that connects you to the whole city, and you are always surrounded by a really eclectic mix of folks."

Horn described cyberspace as the most erotic medium because of the anticipation and thrill that messaging provided.

A few years later, as the internet became more widespread, he launched BlackPlanet, a platform focused on Black Americans that became a precursor to social media platforms that updated in real time, like Myspace and Facebook. When Wasow sold the site, in 2008, it had around 20 million members and was the fourth-most-visited US social network. Kanye West mentioned flirting with women on BlackPlanet in his 2004 song "Get Em High." Wasow says that both ECHO and his platforms challenged the dominant ideas about who these technologies were for, why they should be used, and who should use them: these communities "were prototyping the future in which the internet belonged to everyone."

Both Wasow and Horn have experienced the pains of legislating a social network. On BlackPlanet, there was a "fuck filter" that searched for curse words in screen names and blocked them. But when a user with the last name Bowcock was prevented from accessing the site, the need for a human touch became clear. ECHO's population was always small enough to afford a more casual style of rule enforcement. Most incidents could be resolved with a face-to-face meeting, says Horn, who is still involved in everyday administration of the social network—"babysitting us senior citizens," as one user recently put it.

Today, with just 43 active users, ECHO is a much quieter destination than it was in the '90s, but members still chat and bicker with one another. After one recent dispute between three members, two of them were demoted to "read only" and Horn considered closing the platform. When she announced what she was thinking, users balked: "If a plea would help you change your mind, ECHO has seen me through some of the most dramatic times of my life, and that is entirely due to your vision and your patience. I hope you will find a solution," a user named Schuyler Sue wrote.

When not online, Horn spends her time working at the ASPCA and writing; her seventh book is in progress. Although she is not yet ready to step away from ECHO, she has considered passing it on to someone else to administer. And when it ultimately fades away, she plans to donate ECHO's archives to the New-York Historical Society, securing any private conferences from release until those who participated in them are no longer living. She takes pride in the online culture she helped foster, one in which language documents a communal experience of passing time.

"On ECHO you own your own words," Horn says. It's one of a handful of guidelines that help keep the peace. ■

Nika Simovich Fisher is a writer, graphic designer, and assistant professor of communication design at Parsons School of Design in New York City.

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Screen time

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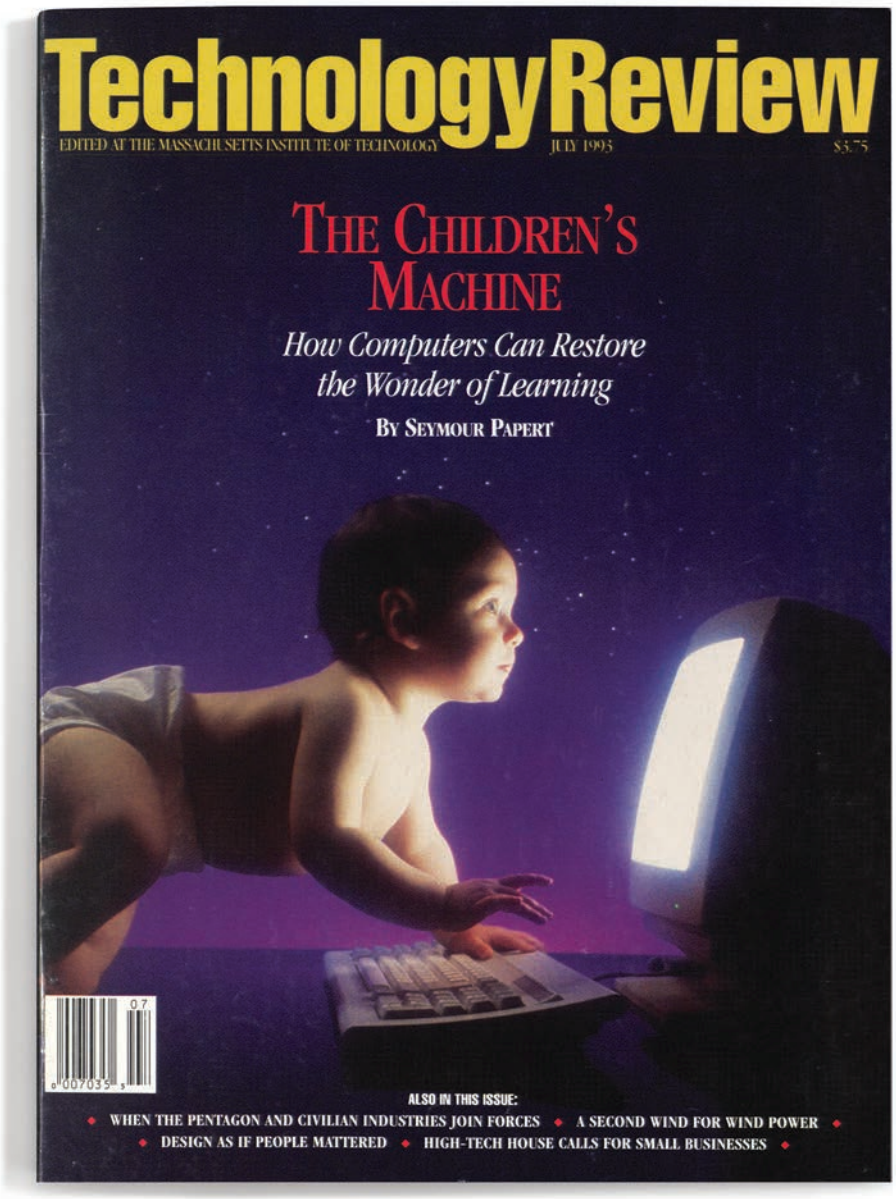

"Around the world, children have entered a passionate and abiding love affair with the computer. Notoriously, as with most other love affairs of their children, parents fail to understand it. In this case, they are frightened by its intensity and especially distressed by what many perceive as the mindlessness of the games that have become its most visible manifestation and a peephole into the future. The intensity of feelings reflects children's avid response to a new medium that matches their ways of knowing better than either print or television. If the word 'mindless' applies here, it is not to the children but to the adults—especially to School, a sleepwalking dinosaur of an institution that lumbers along a set path, more and more out of alignment with the society it thinks it serves and less and less able to channel the energy and vision of teachers who try to work in it."

—SEYMOUR PAPERT, 1993

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