Schools around the world are again the site of a large, and largely uncontrolled, experiment.

When schools from New Zealand to Norway to Japan reopened in April and May as the first wave of COVID-19 cases subsided, the virus stayed mostly at bay. Health and education officials cheered, having bet that the huge benefits of in-person schooling outweighed the risk of viral spread among children and teachers—and from schools to wider communities.

As a result, many places that had moved cautiously at first threw open classroom doors in August and September. Schools in the United Kingdom, Denmark, and the Netherlands shifted from cycling in small groups of students to full-size classes. Cities like Montreal that had kept schools shuttered welcomed students back inside. In Manaus, Brazil, a city with a COVID-19 death toll among the world’s highest, more than 100,000 students returned to class-

GRADE: INCOMPLETE

As COVID-19 soars in many communities, schools attempt to find ways through the crisis

By Gretchen Vogel and Jennifer Couzin-Frankel

Science’s COVID-19 reporting is supported by the Pulitzer Center and the Heising-Simons Foundation.

In California, a child confronts the new reality of school in the time of COVID-19.
rooms. Teenagers thronged hallways in Georgia, Iowa, and Texas. But the backdrop is very different now: In many areas, COVID-19 has surged to even higher levels than early in the year.

In July, *Science* examined the mostly encouraging lessons from the first reopenings, among schools in areas with minimal COVID-19 percolating. Now, scrutiny of school openings in countries where the virus is resurgent paints a more complex picture of the risks and how they might be managed.

The virus has exposed disparities between and within countries, and among the most unsettling are in schools. In many countries, such as India, Mexico, and Indonesia, most schools remain shut. In the United States, students enrolled in urban public schools from Los Angeles to Chicago, which in normal times may struggle to provide enough soap and toilet paper, continue to learn from home, whereas wealthy private schools have installed tents for outdoor learning and hired more teachers to shrink already-small classes. “The inequities from school to school are inexcusable and heart-wrenching,” says Tom Kelly, head of the Horace Mann School, a private school in New York City that drew on many resources to open.

Early evidence, often gathered by researchers with children in school or a teacher spouse, suggests schools can stay open even in the face of significant community spread, given strong safety measures and political will. Many countries are closing restaurants, bars, and gyms, and begging residents to steer clear of social gatherings in bids to contain spread and keep schools open. Sometimes, that hasn’t been enough: The Czech Republic, Russia, and Austria closed schools in the face of skyrocketing case numbers in October and early November.

“I think schools should close last,” says Michael Wagner, a microbial ecologist at the University of Vienna who is part of a consortium of four universities studying the prevalence of the virus in Austria’s schools. But he cautions that it’s wishful thinking to suggest open schools can’t fuel spread of the virus. Closing them can be “one of the most powerful measures we have, but also one of the most costly” to children.

In Austria, schools hung on until 17 November. However, other countries, such as South Korea and Australia, have closed many schools at the first sign of rising cases as authorities worked to quash even modest community transmission. “The conversation is fairly polarized right now as to whether schools should be open or should be closed,” says pediatric infectious disease doctor Nisha Thampi of the Children’s Hospital of Eastern Ontario. “People interpret the data one way or another to justify one end or another.”

### How common are school outbreaks?

A gnawing anxiety for teachers and parents is the silent spread of virus through hallways and classrooms. Most schools have layers of protection such as mask requirements and physical distancing to impede an outbreak if a student or staff member brings COVID-19 into the building. But with virus cases surging in many communities, those guardrails are facing a stress test.

“You’re on pins and needles all the time,” says Bradford Gioia, head of Montgomery Bell Academy in Nashville, Tennessee, an 800-person boys’ school that runs from seventh to 12th grade.

So far, scientists say, school outbreaks appear less common than initially feared, although data are sparse. At Duke University, Danny Benjamin and Kanecia Zimmerman, both pediatricians and epidemiologists, are collaborating with more than 50 North Carolina school districts as well as local health departments to study COVID-19 in schools. The effort includes gathering data on clusters and single cases from a subset of six school districts—50,000 students and staff—in the first 9 weeks of in-person school. Community spread has been high, and the team has recorded 197 COVID-19 cases acquired outside of school and just eight confirmed to be “secondary transmission.”

A nagging concern among teachers and parents is the silent spread of virus through hallways and classrooms. Most schools have layers of protection such as mask requirements and physical distancing to impede an outbreak if a student or staff member brings COVID-19 into the building. But with virus cases surging in many communities, those guardrails are facing a stress test.

“You’re on pins and needles all the time,” says Bradford Gioia, head of Montgomery Bell Academy in Nashville, Tennessee, an 800-person boys’ school that runs from seventh to 12th grade.

So far, scientists say, school outbreaks appear less common than initially feared, although data are sparse. At Duke University, Danny Benjamin and Kanecia Zimmerman, both pediatricians and epidemiologists, are collaborating with more than 50 North Carolina school districts as well as local health departments to study COVID-19 in schools. The effort includes gathering data on clusters and single cases from a subset of six school districts—50,000 students and staff—in the first 9 weeks of in-person school. Community spread has been high, and the team has recorded 197 COVID-19 cases acquired outside of school and just eight confirmed to be “secondary transmission.”
Do open schools change risk perception?

Sports. Dating. Birthday parties. Orchestra practice. When schools open, students’ other activities may be more likely to resume. And that has researchers worried. “Families look to schools to communicate what’s OK,” says Jennifer Lerner, who studies the psychology of judgment and decision-making at Harvard University. Even when schools are doing all they can to mitigate COVID-19 spread inside their buildings, the mere act of opening can send an unintended message that mixing together is benign—and provide more opportunities to do so.

In considering how people assess risk, Lerner points to a seminal paper published in 1987 in Science, in which psychologist Paul Slovic at the University of Oregon wrote that the more uncertain and uncontrollable something seems, the riskier people deem it. Activities associated with school feel familiar and controllable and so may seem less risky, says Greer, of the University of Guelph. She found in a national survey that 40% of families have their children in at least one after-school activity, and some “have kids participating in extracurriculars 5 days a week.”

To many people, it’s especially hard to imagine school without sports. But the potential for the virus to spread there looms. In the United States, numerous outbreaks in August were traced to football practices. Early this month, the Iowa High School Girls Athletic Union hosted a state volleyball championship that brought together 20,000 fans and players in an indoor arena, as cases in the host city, Cedar Rapids, hit record highs and hospitals filled to capacity. In Canada, outbreaks have been linked to youth hockey; whether COVID-19 spread during play itself or gatherings with family and friends afterward is not known. “Schools are going to have a really tough time with sports,” says Benjamin, of Duke University. “It’s hard to make them safe.”

Parties, too, have been an issue around the world. In Cape Town, South Africa, a gathering of high schoolers at a bar sparked an outbreak that ultimately infected more than 80 people. At Lerner’s daughter’s school, all families signed a pledge that, among other points, stressed compliance with state restrictions on social gatherings. When several girls held a party, they were required to quarantine at home for 2 weeks.

For health officials, a tricky balancing act may be in order. The message to school communities, Lerner says, needs to be, “There’s such an enormous benefit to having schools open.” And to sustain that, “We have to make sure that we are reducing risk in all other possible places.”
How much fresh air is enough?

As temperatures drop in the Northern Hemisphere, many schools aren’t radiating the comforting warmth they used to. The coronavirus pandemic has created a new routine: Open windows, no matter the weather.

In Germany, students wear coats and winter hats in class. In the United Kingdom, they’re permitted to don extra clothes over uniforms. It’s part of an effort to disperse any exhaled viral particles before someone can breathe them in.

“The air flow patterns you have inside make a lot of difference to your potential exposure,” says Paul Linden, who studies fluid mechanics at the University of Cambridge and in September published a paper on how ventilation can help prevent viral spread. But with variability in weather, ventilation systems, and window size and placement, guidance is elusive. “It’s very hard to be prescriptive,” he says.

Rather than dive into calculations for every indoor space, scientists like Linden are embracing a simple alternative: high-quality carbon dioxide (CO₂) monitors, which cost as little as $100. Because CO₂ is exhaled as people breathe, it can serve as a proxy for how much exhaled air, and possible virus, has accumulated. Outdoors, the CO₂ concentration is about 400 parts per million (ppm). “What we’ve been recommending for schools is that CO₂ be below 700 ppm,” even if everyone is wearing a mask, says Jose-Luis Jimenez, an aerosol scientist at the University of Colorado, Boulder, who models transmission risk. In a church in Washington state where a March outbreak among choir members originated, Jimenez’s modeling suggests the CO₂ levels were about 2500 ppm.

Preliminary evidence from CO₂ monitors in schools suggests there’s still work to be done. Linden found CO₂ levels in classrooms before the pandemic were about twice as high in winter as in summer. In Madrid, Javier Ballester, a fluid dynamics expert at the University of Zaragoza, found that, when windows are closed, a standard classroom with 15 students passes 1000 ppm in just 15 to 20 minutes.

Part of the challenge is practical. If children are “freezing cold, that’s not going to help their learning experience,” says Henry Burridge, a fluid mechanics specialist at Imperial College London. But Ballester’s calculations suggest opening multiple windows by 15 centimeters each is likely sufficient. Germany is trying a different compromise: Classrooms can leave windows closed for 20 minutes and then open them wide for 5 minutes. (Berlin schools had to install tens of thousands of new handles on windows that had been secured shut.)

Some schools are adding professional-grade air filters to try to remove virus, and scientists are developing other creative solutions. Frank Helleis, a physicist at the Max Planck Institute for Chemistry, has developed a system of fume hoods over students’ and teachers’ desks. He and his colleagues are testing the setups at a school in Mainz, Germany, where his wife is a teacher. Cone-shaped hoods hang from the ceiling, connected to tubes that lead to a window, where a fan blows air outside. Warm air around a person rises, carrying exhaled aerosols to the hood, which collects and removes about 90% of aerosols before they can circulate, Helleis says. “It happens fast—within 10 seconds.” Built from supplies available at home-improvement stores, the design is freely available.

Ballester, whose wife is also a teacher, has tried attaching a standard air filter to a fan. Initial tests show it’s almost as effective as professional-grade machines. Most schools can’t spend $500 per classroom, Ballester says, “but if it’s $50 or $60, they might.” Fans with filters that clean indoor air “work very well,” Jimenez says, and are already used in regions with forest fires or air pollution. Such solutions may be especially valuable for classrooms with few or no windows—a common setup in U.S. schools that has fueled worries about reopening.
Does testing make a difference?

Since May, teenagers at the Gymnasium Carolinum, a school in Neustrelitz, Germany, have swabbed their own throats twice a week. Along with students, staff, and family members at six other schools and one day care, the teens send the samples to Centogene, a biotechnology company. The company’s website trumpets, “School in spite of coronavirus, but safe!” It has run nearly 40,000 tests so far, which Volkmar Weckesser, Centogene’s chief information officer, says have identified “multiple” cases and no outbreaks. “We can’t say what would have happened if we hadn’t been there,” he acknowledges, but isolating the cases removed their chance to spark more infections.

Coronavirus testing in schools is scattershot, reflecting key uncertainties including how much children spread the virus and varying accuracies of tests. Some programs use tests for surveillance, as in New York City, with monthly tests on 10% to 20% of staff and students at many public schools. Wagner, of the University of Vienna, and colleagues are testing students and teachers in Austrian schools, and this fall found that roughly one in 250 people were infected without symptoms.

Blanket testing has its uses. But it takes up potentially scarce resources and can give a false picture, Duke’s Benjamin warns. Even the most accurate tests can miss early stage infections. “Your public health interventions should assume that everybody’s infected,” he says.

Several studies are turning to tests to probe a big unknown: whether people with no symptoms spread SARS-CoV-2 at school. At the Charité University Hospital in Berlin, a team is working with 48 schools and day cares to regularly test staff, students, and their family members for both virus and antibodies. In Nashville, a team from Vanderbilt University decreases every 2 weeks on a school, where children as young as age 4 spit into a cup and hand over their sample. “Does it even matter if a small percentage have detectable virus in saliva but they’re not symptomatic and they’re masked?” wonders Ritu Banerjee, one of three pediatric infectious disease specialists running the study, along with Sophie Katz and Kathryn Edwards. So far, she and her colleagues have collected four batches of more than 180 samples each and received test results on three of them. One positive case turned up in each batch, and none seemed to have infected anyone at school.

In Montreal, health surveillance expert David Buckeridge and pediatric infectious disease specialist Caroline Quach-Thanh at McGill University are planning an experiment in two schools. They want to know whether it’s safe to shave a 14-day quarantine for close contacts to 7 days with a test before returning to school. The Montreal and Nashville researchers have something in common: Their own children attend the schools that welcomed the researchers in. That connection, Buckeridge says, was vital to making the work possible.

Should schools stay open as cases surge?

Early school reopenings spurred optimism. But many experts caution that that experience has limited relevance to high-transmission regions today. “The areas that reopened schools in the spring ... had very, very little circulating virus in the community,” says Matthew Oughton, an infectious disease doctor at McGill. But Denmark, for example, has had more than five times as many cases per week as in spring and France more than 10 times. Officials are facing difficult decisions about whether and when schools should close.

Scientific uncertainties aren’t helping. Initial studies suggested children under age 10 were less likely than older ones and adults to catch and transmit SARS-CoV-2. But newer data have muddied the picture. In September, a study of families of U.K. health care workers found no difference in susceptibility by age. Antibody surveys in Brazil and southern Germany reported similar results. In a day care in Poland, five toddlers, none with symptoms, apparently infected nine family members. “I think asymptomatic infections have allowed children to fly under the radar,” says Zoë Hyde, an epidemiologist at the University of Western Australia, Perth.

Yet some countries are finding they can suppress the virus while schools stay open. In mid-October, Ireland shut down many businesses and restricted people to within 5 kilometers of their home, but in-person instruction continued. Around the same time, the Netherlands closed restaurants, bars, and museums but also kept schools open. In both countries, new cases have fallen significantly.

Without clarity on in-school transmission, schools are hunting for signposts on when to throw in the towel and shift to remote learning. Officials in Iowa won’t consider local school closures until a county’s test positivity rate exceeds 15%, whereas New York City closed schools on 19 November, after reaching 3%. Other areas analyze virus levels in neighborhoods from which a school draws. Berlin authorities focus on what’s happening inside a school, assessing weekly the numbers of new cases and people in quarantine.

Hyde and David Rubin, head of the Policy-Lab at the Children’s Hospital of Philadelphia, both think schools should probably shut if there are so many cases that contact tracing in the community is no longer feasible. In the Philadelphia area, “contact tracing is falling apart,” Rubin says. In mid-November, with transmission rates escalating, he recommended area schools consider closing, especially for older children, until January 2021.

Numbers can act as a guide, but many say decisions around opening and closing schools are as much moral and political as they are scientific. “I don’t think the right question is, at what point do we close schools,” says Greer, of the University of Guelph. Instead, it’s what do we need to do to keep schools open?

Like Ireland and the Netherlands, France, Spain, and Germany have kept students in classrooms while shutting other parts of public life. But U.S. cities including Boston and San Francisco have held off on or reversed public school openings, without major clampdowns on businesses. “A lot of school districts are not getting the support they need,” including funding for safety measures, says Meagan Fitzpatrick, an infectious disease modeler at the University of Maryland School of Medicine.

Ultimately, she says, researchers can only offer so much. Until the pandemic subsides, likely with the help of a vaccine, officials, parents, and teachers face questions that lie outside science: “What do you mean by safe? And what levels of risk are you willing to accept for opening your school?”

With reporting by Linda Nordling and Emilian Rodriguez-Mega.