EMERALD CLOUD LAB

The automated laboratory facility at Emerald Cloud Lab in South San Francisco, California.

CLOUD LABS: WHERE ROBOTS DO THE RESEARCH

A host of companies provide a remote, automated workforce for conducting experiments around the clock. **By Carrie Arnold**

As a chemistry PhD student, Dmytro Kolodieznyi was used to running experiments. But in early 2018, his research advisers asked him to take part in one run by robots instead.

They wanted Kolodieznyi, who was developing intracellular fluorescent probes at Carnegie Mellon University in Pittsburgh, Pennsylvania, to spend a month attempting to recreate his research at Emerald Cloud Lab (ECL). The biotechnology company in South San Francisco, California, enables scientists to perform wet-laboratory experiments remotely in an automated research environment known as a cloud lab. If the trial went well, it would help pave the way to the wider use of cloud labs at the university.

Unlike in his Pittsburgh lab, where Kolodieznyi and his fellow students conducted their own experiments, the workhorses at ECL's 1,400-square-metre headquarters were rows of machines run by lines of code issued by researchers around the world, with occasional assistance from waist-high white robots that whirred around the room. There were hundreds of machines at work, but only one or two human technicians were needed to manage the entire process.

It took just one week of hands-on time for Kolodieznyi to replicate several years of his PhD research — everything from organic synthesis of fluorescent tags to advanced microscopy. He says that he only scratched the surface of the company's capabilities, which include cell culture, DNA synthesis, liquid chromatography and structural-analysis methods, such as mass spectrometry and nuclear magnetic resonance. But the experience left its mark:

"We're using our robotic capabilities to industrialize science and make it more reproducible and reliable."

in 2020, after earning his PhD, he joined the company as a scientific developer.

Kolodieznyi's positive feedback, together with disruptions to research in 2020 as a result of the COVID-19 pandemic, led Carnegie Mellon University to invest US$40 million in a partnership with ECL to build a Pittsburgh-based cloud lab — the first such facility to be built in an academic setting. Construction of the Carnegie Mellon University Cloud Lab began in November 2021, and it is set to open in mid-2023. The university's faculty members, staff and students will have priority access to the lab, so every researcher there has the chance to use the technology, according to Rebecca Doerge, the Glen de Vries Dean of the university's Mellon College of Science.

Academics, small start-up firms and big pharma are increasingly turning to cloud labs as part of a trend to outsource work. The approach is like "having a laboratory that is operating 24/7", says Germano Coppola, executive director of research and development at the biotechnology firm CSL Behring in

Melbourne, Australia, which is a client of ECL's.

Cloud labs provide "tremendous potential for scientists to generate a lot of data without even having to enter a lab," he says.

The virtual bench

ECL co-founders Brian Frezza and D.J. Kleinbaum didn't set out to turn the lab bench virtual. Friends as children, the pair attended Carnegie Mellon, and in 2010, they founded Emerald Therapeutics in South San Francisco to focus on developing antiviral drugs. But Frezza and Kleinbaum spent much of their time trying to get the machinery in their new lab to work. Their solution was an ever-expanding set of computer codes to manage the equipment and run round-the-clock experiments. Frezza noticed not only an increase in productivity from the set-up, but also a rise in reproducibility.

"I was turning experiments into code," Frezza says. "At the end of the day, there's no ambiguity in this text, I can push a button and reproduce it."

The pair realized that other labs could benefit from this virtual system, and formed ECL that same year to sell subscription access to their equipment and software. The best way to think of it, Frezza says, is like the streaming services Netflix or Spotify for the lab. Just as users of those services pay for access to a virtual library of digital content without ever purchasing a song or television episode, ECL and other cloud labs provide access to a vast warehouse of equipment without having to invest any capital.

Researchers can log on to the ECL dashboard and specify what experiments they want to conduct and when; configure the equipment to their liking; make adjustments along the way; and get live progress updates on their experiments and watch the process on video. An artificial-intelligence-based 'expert' acts as a highly skilled technician, giving users the ability to tweak default values and identify issues that can halt experiments.

ECL provides three levels of access, based on how many experiments users wish to run at once. The lowest tier allows three to run in parallel and starts at $24,000 per month. It's not cheap, Frezza admits, but compared with the cost of buying the equipment, he says it saves researchers money in the long run. Strateos, which has a cloud lab in Menlo Park, California, customizes its access levels and pricing, allowing users to tailor their experience to their budget.

For Coppola and CSL Behring, cloud labs provide what is effectively a 24-hour service. Coppola sends his samples and reagents to ECL's headquarters or purchases them from its existing inventory, programs his commands into a point-and-click user interface and waits for the results to roll in. He can watch his experiments on a webcam and get read-outs in real time.

Cloud labs aren't the only option for research teams that lack the infrastructure or expertise to perform certain experiments: contract research organizations (CROs) are another. But the two approaches are very different, says Daniel Rines, vice-president of Technology Enabling Services, who is based at Strateos's other facility in San Diego, California. With a cloud lab, scientists perform all of their own experiments. You might be running them from thousands of kilometres away, but they remain your ideas and your results.

> **"Students can use equipment they would not normally have been able to access."**

By contrast, "CROs are very labour-driven," Rines says, meaning that they tend to rely on humans to do much of the work. "What we're doing is using our robotic capabilities to industrialize science and make it more reproducible and reliable."

Because of this, when experiments fail, cloud-lab users can dive back into their data to work out what went wrong, without relying on anyone else. Kolodieznyi describes the process as like having an army of highly talented, highly trained undergraduates at your beck and call. They might not be able to design studies at first, but once they are trained, they can run your experiments – and do it in the same way every time, he says.

"I cannot remember how many times I've read something in a paper, tried to do it and, not surprisingly, it didn't work. But in a cloud lab, if I just copy and paste my experiment, it will work again," Kolodieznyi says.

STRATEOS

One of the robots at a Strateos lab facility.

Advocates of cloud labs say that as well as the reproducibility advantage, providing affordable access to the equipment needed to do science helps to democratize research. "It doesn't matter who you are or where you are. You're all using the same laboratory. That's a huge thing," Frezza says.

Huaiying Zhang, a bioengineer at Carnegie Mellon, has proposed use of the university's cloud lab by high-school students in a low-income district in the state of Georgia – work for which she was awarded a grant by the US National Science Foundation. Not all students who are interested in science can get access to sophisticated equipment, she explains, but running experiments in cloud labs removes those barriers. Once the Carnegie Mellon cloud lab is up and running, she hopes to give students the chance to perform real experiments on equipment normally reserved for PhD students and postdocs.

"You're not just memorizing facts. You're getting real data," Zhang says. "Students can use equipment they would not normally have been able to access."

At University College London, researchers have teamed up with the London-based Synthace Life Sciences R&D Cloud to provide a no-code user interface that will let researchers automate tasks and create experimental workflows remotely. This partnership will enable scientists to "future-proof" their experimental designs against unexpected disruptions to their work, according to a statement from Synthace.

However, writing in the *Bulletin of the Atomic Scientists*, researchers Filippa Lentzos and Cédric Invernizzi note that, by lowering the barrier to expensive equipment, cloud labs could enable bad actors, such as terrorist groups, to misuse the technology to perform "malevolent" experiments (see go.nature.com/3nsbg9e). When asked for comment on this issue, spokespeople at both Strateos and ECL say they use the highest-level data encryption possible, and that they've never had any security concerns, although they do not have any active checks in place to guard against those contingencies.

For Doerge, the benefits of cloud labs outweigh such concerns – especially amid the ongoing pandemic. Much of the university's research ground to a halt as COVID-19 took hold in early 2020. A cloud-lab facility would have allowed much of this research to continue, as well as many lab courses at the university, she says.

"This was the transformation that science needed, much like the cell phone, much like the self-driving car," Doerge says. "The process of science hasn't kept up with the technology."

Carrie Arnold is a science writer based near Richmond, Virginia.