The quantum frontier

Researchers and students are helping shape quantum computing, which could revolutionize health care, materials discovery, supply chains and more

By Lisa Robbins, ASU News
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Story by Makeda Easter

When ASU's Christian Arenz starts teaching quantum mechanics, he expects to see plenty of confused faces.

But a few weeks into the semester, that uncertainty often turns into excitement. Arenz, an assistant professor in the School of Electrical, Computer and Energy Engineering, who came to ASU from Princeton, watches as students begin to understand the potential of quantum computing. It's a fast-growing field that aims to solve problems too complex for today's supercomputers and speed up the process of making new medicines and improving cybersecurity, financial modeling and more.

At ASU, scientists already are applying quantum computing to accelerate materials discovery, improve supply chain logistics and develop new approaches to artificial intelligence. They are also working on improving the underlying technical challenges to make quantum technology more practical.

"When people hear the word quantum, everyone thinks, 'Oh that must be really complicated, and hard mathematically,'" says Arenz. "It has a lot to do with motivation and approach … everyone can learn it."

While experts say quantum computing is not going to replace classical computers — the cell phones and laptops we use daily — or the supercomputers researchers use for groundbreaking discoveries, they envision the various types of computing power working in tandem to solve problems currently out of reach.

Although quantum computing remains somewhat experimental, global interest is exploding. According to McKinsey & Company, quantum computing could generate up to $72 billion in revenue in 2035.

Quantum computers are costly — one estimate suggests tens of millions of dollars — and complex to build and maintain. ASU doesn't have its own quantum computer. But through support from the Research Technology Office, researchers and students can access tools that allow them to simulate quantum computing algorithms to run their experiments on classical high-performance computers with the possibility of connecting to quantum computers remotely, says Gil Speyer, director of ASU's Computational Research Accelerator.

The university also leads the Quantum Collaborative, which connects national laboratories, companies, academic institutions and startups. Through it, students gain direct access to top-notch education and training opportunities that offer the skills needed to be at the forefront of quantum innovation.

And ASU is invested in growing a quantum-ready workforce. Arenz's introductory class is part of a series of courses, and one of many offerings across campus alongside research programs and workshops designed to prepare the next generation of quantum scientists.

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> **Justin Earley**
> Assistant professor, ASU's School of Molecular Sciences

Supporting student discoveries

Most students who take classes with Gennaro De Luca, an instructor in the School of Computing and Augmented Intelligence, begin with zero quantum experience. The course goes from the basics of quantum computing into his own area of research — quantum generative models.

To introduce students to these concepts, he starts with cats.

De Luca walks students through a thought exercise: Using a limited set of cat pictures, what does it take to generate entirely new pictures of cats? At a basic level, generative models analyze patterns in the details — the fur, shapes and colors — to produce new cat pictures.

"Theoretically, it's been shown that quantum computers can learn from fewer images than classical," De Luca says.

De Luca's students have used university resources to pursue quantum projects — from an educational project to simplify quantum machine learning for others, to building a Lego robot car controlled entirely by a quantum image-processing algorithm.

One tool they use is Nvidia's CUDA-Q, a software package that takes advantage of the accelerated processing power from specialized computer chips, called GPUs, or graphics processing units. CUDA-Q can simulate a quantum environment and can be run on a laptop, or for larger projects, on ASU's Sol supercomputer, which is among the most powerful in the world. Sol is nearly 2,000 times more powerful than a modern-day laptop. CUDA-Q can also support cloud-based access to real quantum computing platforms, such as the one at IBM, across the country.

Another tool is an accelerator card called a Vector Engine, which simulates a “specialized quantum computing platform used for quantum optimization,” Speyer says. This tool was recently used by a team of researchers at the W. P. Carey School of Business’ Department of Supply Chain Management to work on problems related to transportation logistics.

Inside a quantum computer

On regular computers, from cell phones to supercomputers, all information is stored as bits. Each bit is either a 0 or 1, like a switch that is turned off or on.

Quantum computers work differently, using quantum bits, or qubits. Instead of just a 0 or 1 value, qubits can exist as both at the same time. Like a midair coin flip, which could be heads or tails, qubits have the probability of being 0 and 1. This is called superposition.

Qubits also can be entangled, or intrinsically linked with each other while in a state of superposition.

These properties allow quantum computers to perform many calculations at once, giving them a potentially exponential boost over classical computers’ computing power.

Supercharged material discovery

Discovering new materials often requires years of trial and error. At ASU’s School for Engineering of Matter, Transport and Energy, Associate Professor Houlong Zhuang is using quantum computing to dramatically accelerate that process.

In recent years, he has used the emerging technology to help develop high-entropy alloys, a type of material which does not melt or weaken in extreme heat, stress and radiation. This class of materials is often used in advanced defense systems such as hypersonic aircraft and nuclear-powered submarines.

Quantum computing can significantly speed up the design and production of new materials in a lab.

“Typically if we run a simulation, it takes several weeks. Now it can take several days using a hybrid strategy,” Zhuang says. As quantum computing continues progressing, “Ideally, we can reduce the several days to maybe one day or several hours.”

Zhuang, whose research and educational outreach efforts earned a $537,000 Career award from the National Science Foundation, is also using these methods to advance sustainability research, working to identify materials that can address carbon-dioxide capture, hydrogen transport and storage, and developing new semiconductors for solar energy conversion.

Making quantum technology more available

Other researchers at ASU are focused on improving the technology itself.

Quantum computers can be prone to errors. The incredibly intricate and fragile nature of quantum systems makes them susceptible to noise — disturbances that produce errors in quantum computation. Noise can be caused by physical vibrations of the hardware, temperature changes, cosmic rays and other microscopic interruptions.

Arenz studies noise mitigation and suppression, an area of research that could make quantum computers more reliable.

Quantum hardware is also physically complex, often requiring elaborate refrigeration systems that cool processors to temperatures colder than outer space. At the School of Molecular Sciences, Director Tijana Rajh backs research to build quantum computers that don't need such precise extreme cold.

In her role, she supports faculty like Assistant Professor Justin Earley, who is interested in designing and building quantum devices that work in everyday conditions. Earley studies qubits — the most basic units of information in quantum computing — made from molecules. Molecular qubits show the potential to operate at higher temperatures, which could support quantum technology's shift from the lab to the real world.

"We have to start thinking about how we move away from this ultra-cold temperature," Earley says. "Otherwise it's going to be resource prohibitive and cost prohibitive."

Earley is also excited by how the technology can be applied to health care. Quantum sensors could one day be used in medical diagnostics, detecting diseases far earlier than current technologies.

Addressing a labor shortage

Like others in quantum at ASU, Earley works with students at nearly every stage of the pipeline, from high school interns to PhD candidates, helping them move past early intimidation and pursue projects that deepen their understanding and advance real-world applications.

One of Arenz's students, Vicente Peña Pérez, a PhD candidate, is an intern at Sandia National Laboratories and will go full time this summer, working at the intersection of quantum computing and materials science.

Advancing quantum computing and mentoring the next generation go hand in hand. Today, there is a broad range of opportunities to pursue quantum computing across industry, academia and government, in roles like quantum algorithm developers, data scientists and designing quantum chips. There is also a need for people who can advise companies that invest in the technology, and nontechnical roles working in business development.

"There's a huge shortage in the workforce," Arenz says. "I tell everyone in class that even if you don't end up going to quantum, the expertise or what you learn through that is very crucial."

Quantum technology businesses are even moving into the ASU Research Park in Tempe, including Quantum Computing Inc. with its state-of-the-art quantum photonic chip foundry.

Arenz reflected on his own experience as an undergraduate and how rapidly the field is evolving. At conferences about 20 years ago, researchers began talking about the basic building blocks of a quantum computer.

“I could not believe that some day researchers would like to make a computer out of these large and complex experimental settings. But, here we are,” he says.

Now, “Companies like IBM and Google have built quantum devices.”

By the time more of his students transition into careers, he hopes quantum computing will have achieved its next milestone in the next five to 10 years: outperforming a classical computer.

About the author

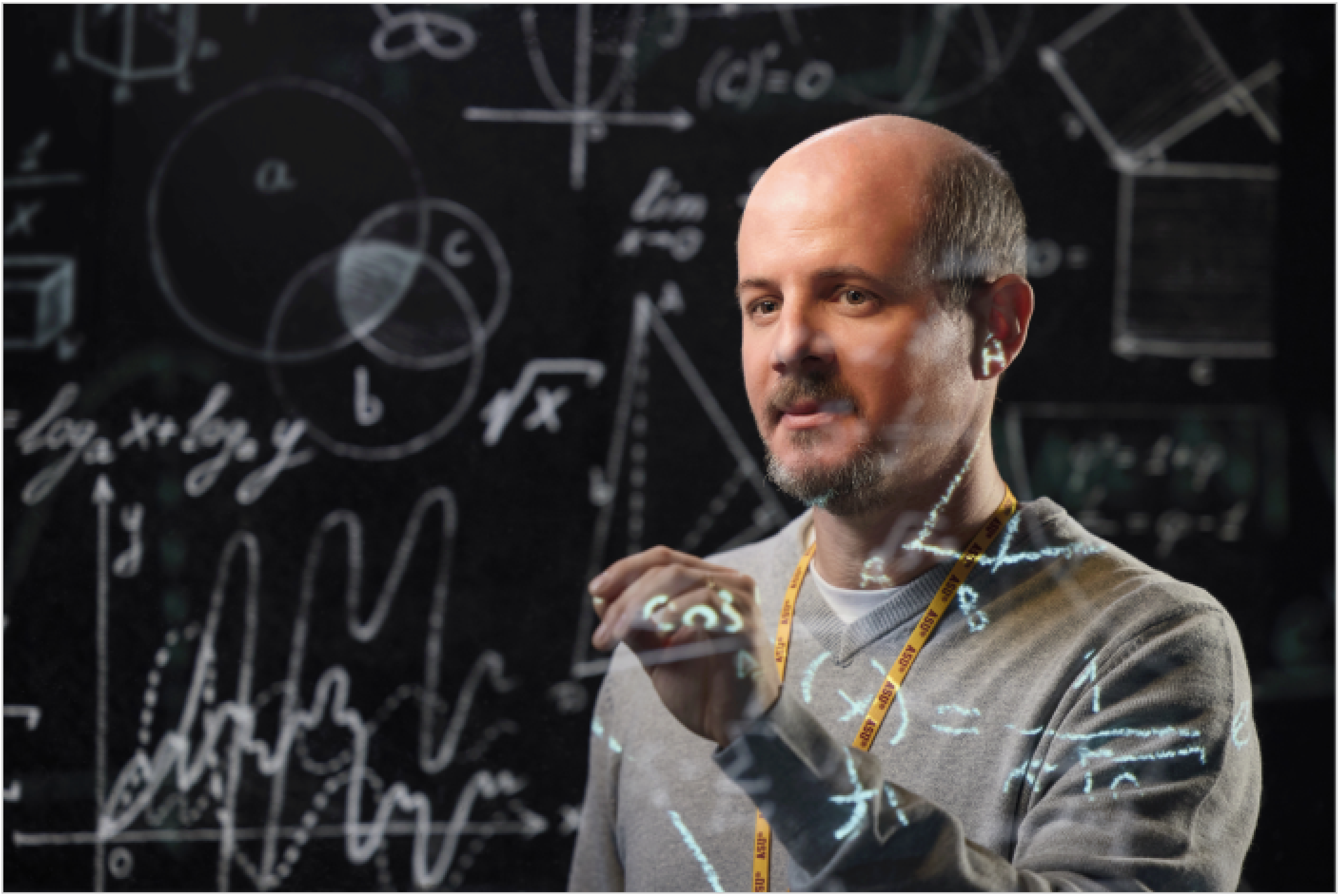
A journalist, Makeda Easter was previously a staff writer at the Los Angeles Times and a science writer for a supercomputing center at The University of Texas.

This story originally appeared on ASU News.

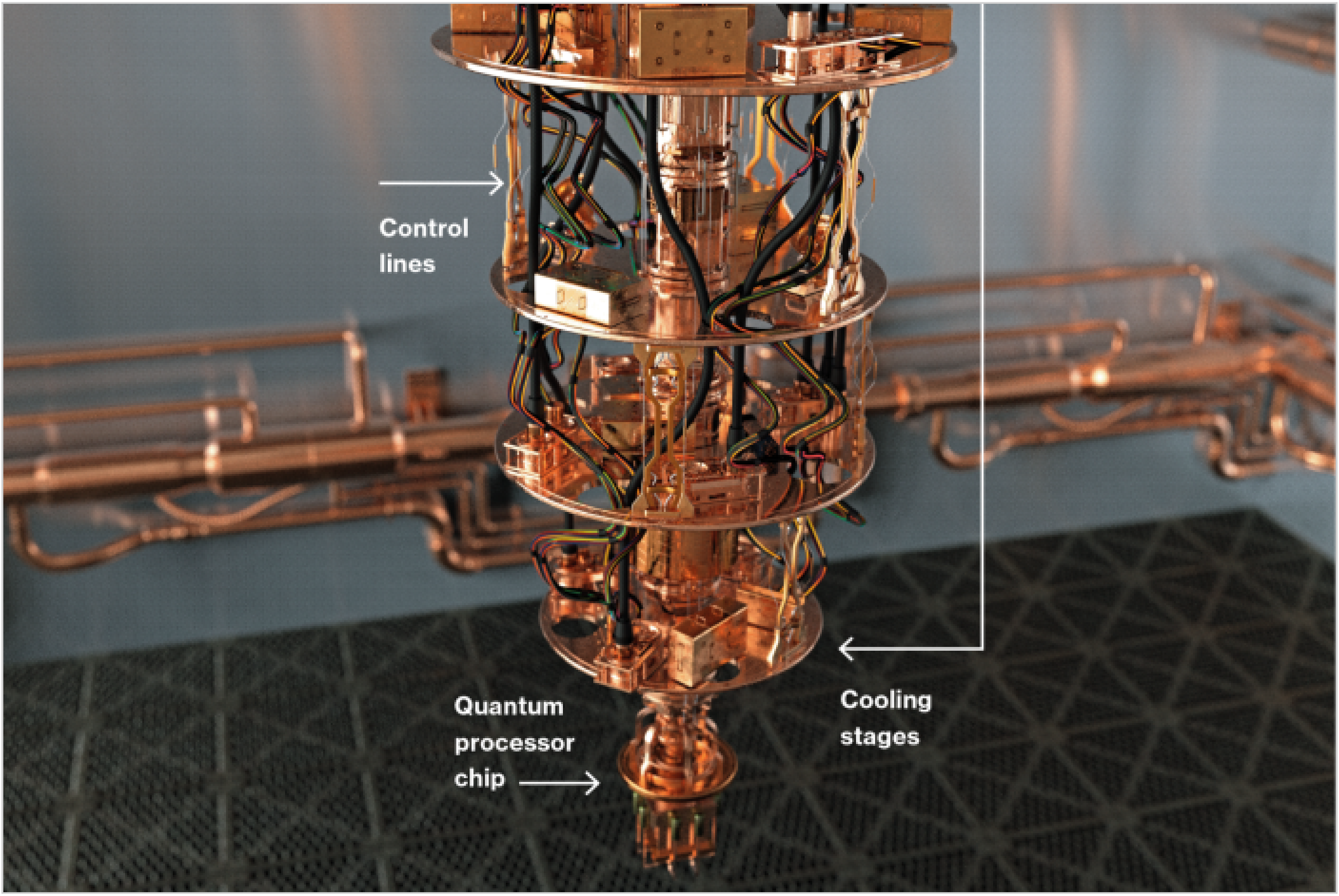
Main image

Houlong Zhuang is using quantum technology to create materials that withstand extreme heat and cold. Photo by Jeff Newton

Text image(s)



"There’s a huge shortage in the workforce. I tell everyone in class that even if you don’t end up going to quantum, the expertise or what you learn through that is very crucial." — Christian Arenz, assistant professor in the School of Electrical, Computer and Energy Engineering. Photo by Jeff Newton



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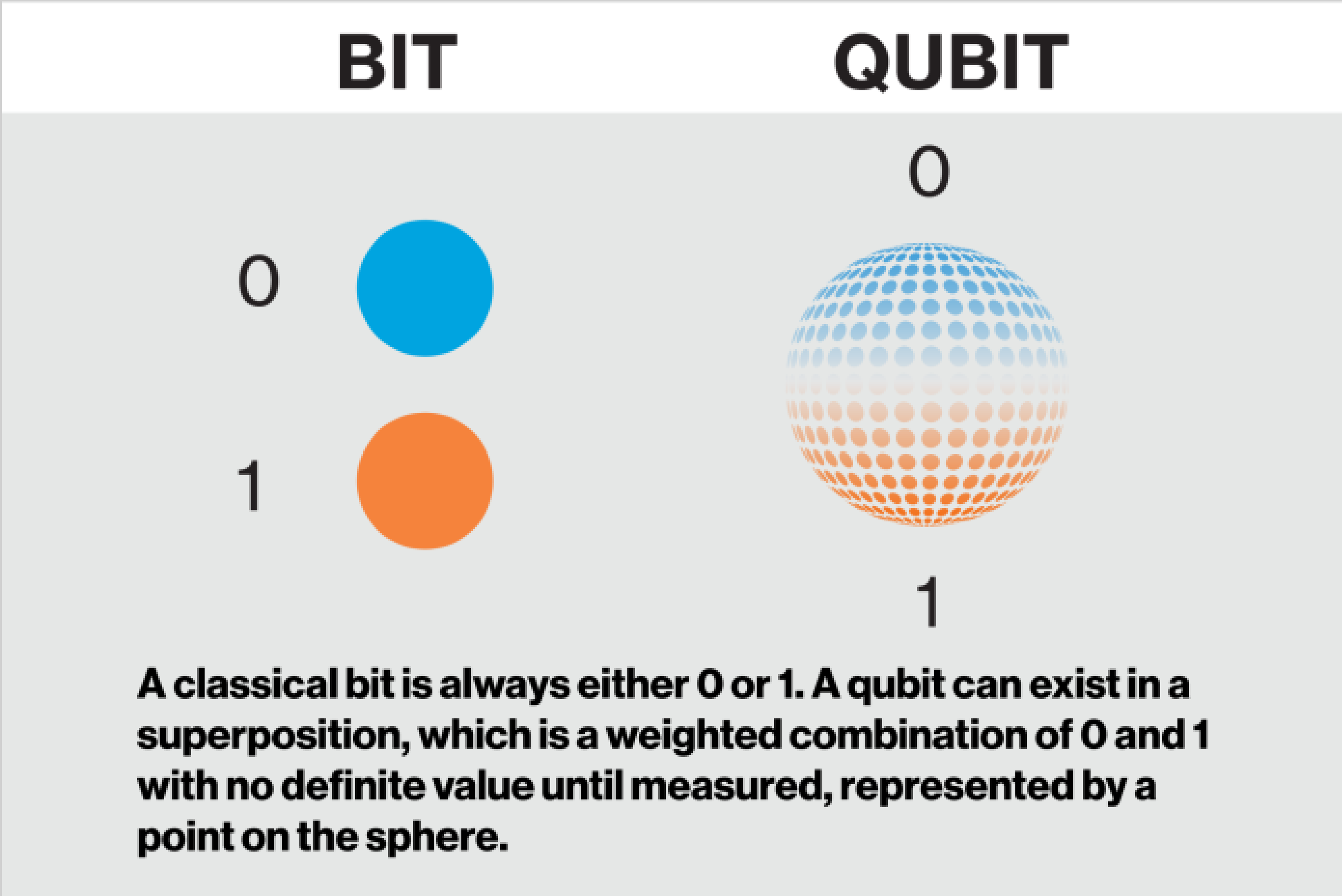
BIT
QUBIT
0
1
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1
A classical bit is always either 0 or 1. A qubit can exist in a superposition, which is a weighted combination of 0 and 1 with no definite value until measured, represented by a point on the sphere.

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Tijana Rajh is trying to help build a quantum computer that does not require temps as cold as outer space. Photo by Jeff Newton


ASU

Justin Earley is excited about how quantum computers can help with medical discoveries. Photo by Jeff Newton