The past, present, and future of US Government investment in quantum information science

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By **Cullen Walsh**

The US National Quantum Initiative Act (NQIA) was passed in 2018 to encourage research and investment in quantum information science over 10 years. The NQIA has provided an overarching framework to both strengthen and coordinate quantum information science (QIS) R&D activities across US departments and agencies, the private sector, and the academic community. This has resulted in the establishment of multiple National QIS Research Centers through the US Department of Energy (DOE), a Quantum Economic Development Consortium, and over USD$2.8 billion worth of QIS R&D being spent by federal agencies over the past four years. At the same time, USD$4.68 billion has been invested in quantum technology startups in the past two years alone, according to a McKinsey report.

To build on this momentum, the US House Committee on Science, Space and Technology held a hearing this past June entitled "Advancing American Leadership in Quantum Technology" to discuss the progress that has been made over the past four years of the Act and to inform legislation to reauthorize the program for the next five years.

Dilution refrigerator set with an aluminum cavity for device testing at Fermi National Accelerator Laboratory. Credit: Ryan Postel.

"The NQI was launched with a science-first strategy," said Dr. Celia Merzbacher, executive director of the Quantum Economic Development Consortium, during the hearing. As a result, the first five years of the NQIA have focused on bridging the gap between fundamental research and applications. This has resulted in numerous breakthroughs in fundamental quantum science research.

"Major accomplishments included: at Oak Ridge [National Laboratory], development of a quantum computing hub; extensive quantum networks tested at Caltech, Brookhaven, Fermi Lab, and Argonne; IBM fabricated a quantum processing chip with a record 433 qubits on its path to a quantum supercomputer; Google developed a high-fidelity quantum processor and developed quantum simulations, including a wormhole teleportation protocol; and Berkeley Lab researchers received the Nobel Prize last year in experimentally proving quantum teleportation for networking," noted Paul Dabbar, the Former Under Secretary for Science, speaking at the Committee hearing.

"By all accounts, the first five years of this initiative have been a big success," said Congressional Representative Zoe Lofgren (D-Calif.), ranking member of the House Committee on Science, Space, and Technology, at the hearing. "The first five years focused primarily on the fundamental science advances needed to make quantum systems work. While investments in fundamental research need to continue […] [we also] need to invest in human and physical infrastructure that's going to allow us to move quantum technologies from the lab to the marketplace."

Moving forward, both the congressional members and invited panelists at the hearing emphasized *three key areas* of focus for the next phase of the NQIA: (1) creating shared infrastructure for both academics and startups, (2) continuing to enhance public–private partnerships, and (3) building up the quantum workforce.

Shared infrastructure

At the Committee hearing, Congressional Representative Haley Stevens (D-Mich.) said, "One of the major barriers to research development and education in quantum information science is the relative lack of shared research infrastructure and instrumentation." Access to shared infrastructure is particularly important for both startups and academia because quantum computing hardware can be prohibitively expensive. For example, IBM recently announced in May a USD$100 million partnership with The University of Tokyo and The University of Chicago to develop a 100,000-qubit supercomputer.

"You don't want to become a professor at NC [North Carolina] State then have to wait five years to get the tools in place to actually do your job," said Dr. Charles Tahan at the hearing. "How do we give researchers access to the tools that can sometimes cost three-to-five million dollars apiece in a more efficient way so that we can move the science forward?" Tahan is the director of the National Quantum Coordination Office at the White House Office of Science and Technology Policy.

Another bottleneck, according to Professor Mark Hersam at Northwestern University, is the limited supply of quantum instrumentation. "If you consider superconducting qubits as one example, our research is bottlenecked by the limited number of dilution refrigerators that are available for device testing," says Hersam. "Similar arguments could be made for other quantum technologies (e.g., limited number of electron paramagnetic resonance apparatuses for spin-based qubits, limited number of low-temperature optical spectroscopy tools for photon-based qubits, etc.)."

One proposed solution to these bottlenecks comes from the NQI Advisory Committee, which advises the President and relevant congressional committees, and would involve Congress establishing a fund for infrastructure investments across the country in the reauthorization of the NQIA.

Public–private partnerships

Another avenue for improving access to quantum infrastructure is through continued support of public–private partnerships between national laboratories, academia, and industry. One successful example of this has been partnerships between the Quantum Science Center (QSC) headquartered at DOE's Oak Ridge National Laboratory (ORNL), one of the five DOE National QIS Research Centers established through the NQIA, and Microsoft and IBM.

"Microsoft and IBM are key partners contributing to QSC research priorities," says Dr. Travis Humble, a Distinguished Scientist at ORNL and director of the Quantum Science Center. "Microsoft has played a key role in developing new tools for quantum computing that help program and evaluate applications, while IBM has proven essential to our work on developing applications of quantum computing to study materials science and chemistry. Additionally, the QSC is transitioning ideas produced within the Center to the broader QIS ecosystem. A great example is our development of the open-source hardware platform known as the Quantum Instrumentation Control Kit, or QICK, which has been adopted by collaborators in industry and at multiple national laboratories."

Workforce development

Beyond physical infrastructure, the other major area of focus over the next five years of the NQIA will be the development of education in QIS.

"Students need exposure to quantum information science early," said Dr. Emily Edwards, executive director of the Illinois Quantum Information Science and Technology Center, speaking at the Committee hearing. "[Quantum Information Science] is an opportunity akin to the space race, an opportunity to take this moment to inspire students and to inspire the current workforce to build up public literacy," she said. "We can use the NQI reauthorization and continued federal investments to build up the infrastructure to take the next step forward."

To help achieve this, Edwards proposed that Congress establish a National Center for Quantum Education as part of the NQIA reauthorization. This would draw together and leverage the existing quantum workforce development efforts currently happening across the United States.

One such NQIA-sponsored effort has been the Quantum Education for Students and Teachers program (QuEST) at Stony Brook University, The State University of New York, and the New York Hall of Science. "The greatest impact has been on the high-school students who attended our camp, who demonstrated learning gains and more positive attitudes toward quantum information science and technology [QIST]," says Professor Angela Kelly, a lead principal investigator for the QuEST program. "One experience the students enjoyed was visiting the laboratory of an experimental quantum physicist—this gave them a tangible sense of what a career in the field entails," she says. "This helped them understand how QIST is transformative in revolutionizing computing capabilities and making our lives better."

Another successful NQIA effort, this one specifically targeted at college students and early-career scientists, has been facilitated by the Quantum Science Center at ORNL. "The QSC facilitates day-long visits, weeklong summer schools, and other events to educate and train students and early-career staff on essential topics in QIS," Humble says. "For example, we recently hosted a diverse cohort of students from The University of Tennessee, Knoxville for a daylong visit to the QSC's headquarters at ORNL."

The United States could also encourage researchers to enter the field of QIS by establishing prestigious graduate and postdoctoral research fellowships, similar to the National Science Foundation Graduate Research Fellowship program, Hersam says. "I am confident that a similar fellowship program at the postdoctoral level would have a comparable (if not larger) return on investment simply because there are so few domestic postdoctoral fellowships currently available in the physical sciences."

Continued and expanded funding of such initiatives over the next five years of the NQIA will be key to encouraging more students to participate in QIS. For instance, during the hearing, Merzbacher highlighted how exposure to industry at a young age can be transformational for students. "I come from a background, my previous job was in the semiconductor space, where I saw the magic that happened when industry and academia worked together and the students had exposure while they were a student in industry jobs and experience," she said. "Mostly when you are at a university you are seeing the university world and if you can get industry engaged with the academic enterprise, you get those students seeing life outside of that bubble and it's hugely valuable for the students during their education."

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