LEADING THE QUANTUM REVOLUTION

Many of today's technologies – from lasers and computers to GPS and LEDs – rely on the interaction of matter and energy at extremely small scales. By exploiting the interactions of these tiny systems, next-generation technologies for sensing, computing, modeling and communicating will be more accurate and efficient. At the National Science oundation (NSF), we're driving the research that will advance quantum information science and engineering (QIS) from laboratory theory into practical reality and lay the foundations for the next century of quantum discovery.

10 BIG IDEAS: QUANTUM LEAP

For a fi e-year period beginning in fiscal ear (FY) 2019, NSF has allocated dedicated funds to a new suite of activities collectively known as the **Quantum Leap Big Idea**. Quantum Leap will support researchers as they work to observe, manipulate and control the behavior of particles and energy at scales a million or more times smaller than the width of a human hair. This Big Idea capitalizes on the full breadth of scientific and engineering disciplines suppo ted by NSF, bringing together researchers from many different fields to address the fundamental science and engineering questions unde lying all areas of quantum science and its applications.

Through the Quantum Leap, NSF is following three approaches to accelerate progress towards the next quantum revolution:

- Exploit quantum mechanics in order to find n w ways to explore the behavior of particles.
- Enable new discoveries in quantum systems, both natural and human-built.
- Develop quantum technologies that will revolutionize measurement systems, information processing, communications and computing.

ADVANCING QUANTUM FRONTIERS

NSF has a long history of investment in QIS research, including funding for seven major research centers. Now, frontier knowledge generated through NSF-supported quantum projects will open new vistas and opportunities in the QIS arena, such as new materials, circuits, and algorithms that enable applications such as powerful computers, incredibly precise sensors and detectors, and secure digital communications. NSF investments are accelerating progress towards a new age of quantum technology, with groundbreaking innovations poised for rapid development over the next few years.

Building Practical Quantum Computers

From codebreaking to aircraft design, every field has p oblems that even today's most advanced supercomputers cannot solve. Quantum computers have the potential to help scientists answer those unsolvable questions thanks to enhanced computing power lent to them by quantum phenomena. To accelerate the development of the first p actical quantum computer, NSF has awarded $15 million over fi e years to the multi-institution **Software-Tailored Architecture for Quantum co-design (STAQ) project**.

Seeking Secure Quantum Communications

Researchers have long sought to encode photons – particles of light – with information that could travel through fiber optic cables across vast distances. A stream of encrypted data would follow behind each encoded photon, enabling secure digital communication. To advance the technology necessary for practical quantum communication, NSF invested $12 million in the **Advancing Communication Quantum Information Research in Engineering (ACQUIRE)** research area to support interdisciplinary teams seeking to engineer systems that use entangled photons in pre-determined quantum states as a way to encrypt data.

CONVERGING ON THE QUANTUM LEAP

A quantum workforce requires a superposition of multiple disciplines working together to solve some of science and engineering's most challenging problems. NSF is uniquely positioned to build bridges connecting all quantum field , enabling a community of researchers from different disciplines to come together to conduct truly convergent, innovative research. NSF is focused on encouraging convergence in three areas related to quantum science:

- **Convergence in disciplines needed to design and build quantum information systems.**
  In FY 2018, NSF made a $25 million investment through **Transformational Advances in Quantum Systems (TAQS)** awards to support small interdisciplinary teams of researchers seeking to address fundamental and applied questions in QIS. Projects focus on quantum functionality and will result in experimental demonstrations, transformative advances towards quantum systems, and/or proof-of-concept validations. An additional investment of $26 million is to follow in FY 2019 with the TAQS-II program.
- **Convergence in the science applications leveraging quantum research.**
  The NSF Workshop in **Quantum Information and Computation for Chemistry** convened experts from directly quantum-oriented fields – including algorithm , chemistry and machine learning – and those in related chemistry field seeking to leverage a quantum information perspective in addressing fundamental research questions. Together, they worked to identify target areas where cross-fertilization among these fields ould result in the largest payoff for developments in theory, algorithms and experimental techniques.
- **Convergence in workforce development.**
  The **NSF Quantum Computing & Information Science Faculty Fellows (QCIS-FF)** program seeks to build capacity in QIS and computing, while welcoming cross-disciplinary and multi-department hires. Through QCIS-FF, NSF is investing $6.75 million to grow academic research capacity in the computing and information science field , with the specifi goal of encouraging hiring of tenure-track and tenured faculty in quantum computing and communication.

TRAINING THE NEXT GENERATION OF QUANTUM LEADERS

The quantum revolution requires a highly-trained workforce that can advance the boundaries of what is possible through research and development of practical solutions for quantum technologies. NSF investments are building capacity through support for research and education in quantum field , building the workforce that is essential to progress and commercialization in this rapidly emerging field.

NSF has invested in a distinctive new intellectual infrastructure for training of students in convergent quantum information science and engineering disciplines. This activity – called **"Triplets"** – links the talents, resources and approaches of both the academic and industrial environment by creating connections between a student, an academic researcher, and an industry partner, who work together on quantum challenges for three years. With partners at the Department of Energy, NSF supports the **Quantum Science Summer School (QS^3)** – an annual summer school whose mission is to train graduate and postdoctoral students in condensed matter, materials, and related fields or the next quantum revolution. This two-week immersion program focuses on education through hands-on experiences, including programing an actual quantum computer.

AMPLIFYING INVESTMENTS THROUGH PARTNERSHIP

Collaboration with other government agencies, industry and private foundations is key to fostering progress in QIS at a critical juncture in its development. NSF is working to enhance its investments in quantum research through partnerships, information-sharing arrangements and agreements on common goals with key stakeholders. For example, NSF co-chairs the **National Science and Technology Council's Subcommittee on QIS** to coordinate a national agenda on quantum information science and technology.

CENTER-SCALE QIS ACTIVITIES

With the Quantum Leap Big Idea rolled out in full force, NSF is continuing its multi-disciplinary investment approach, focusing on center-scale activities. **Quantum Leap Challenge Institutes (QLCI)** are large-scale interdisciplinary research projects that will span the focus areas of quantum computation, quantum communication, quantum simulation, and/or quantum sensing. **Convergent Accelerated Discovery Foundries for Quantum Materials Science, Engineering, and Information (Q-AMASE-i)** seek to rapidly accelerate quantum materials design, synthesis, characterization, and translation of fundamental materials engineering and information research for quantum devices, systems, and networks by establishing Foundries with mid-scale infrastructure for rapid prototyping and development of quantum materials and devices.

Image Credit: Nicolle R. Fuller/NSF