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Thank you, Chairman Lucas, Ranking Member Lofgren, and distinguished committee members for the opportunity to testify before you. I'm Dr. Emily Edwards, the Executive Director of the Illinois Quantum Information Science and Technology Center at the University of Illinois Urbana-Champaign (UIUC). Since its inception, I have co-led the National Q-12 Education Partnership through a grant from the National Science Foundation (NSF). This consortium was spearheaded by the White House Office of Science and Technology Policy and NSF in 2020. I also co-lead education and workforce programs for one of the NSF Quantum Leap Challenge Institutes: Hybrid Quantum Architectures and Networks, which spans UIUC, the University of Chicago, and the University of Wisconsin-Madison. These programs have given me the opportunity to combine my background in physics, science communication, and public engagement to help advance quantum education. In my remarks, I will focus on the need for expanding investments in quantum workforce development.

Leadership in Quantum Information Science Requires Many People, Many Disciplines

Quantum information science (QIS) takes our knowledge of how nature works at very small energy and length scales and applies it broadly to sensing, computing, and networking. With innovative research and engineering, supported by sustained federal and industrial investments, we are translating the fundamental physics of quantum mechanics into novel technologies that will complement, enhance, and even secure our current infrastructure. Future advances in quantum will also let us pursue science in ways that were not at all possible in the 20th century.

While the level of research and device maturity varies across this field, and the timelines for translation to market are evolving, one thing remains clear and constant: We need people across many areas of science and engineering with different levels of quantum education, from awareness to niche capability to proficiency. Moreover, we must also engage members of the public so that people are prepared for a future that is influenced and underpinned by emerging quantum research and technologies.

The health of the U.S. quantum enterprise increasingly depends on a diverse range of technical professionals with expertise in fields such as physics, computer science, engineering disciplines, materials science, chemistry, mathematics, and more. Initial studies, partially supported by the Quantum Economic Development Consortium, have started to outline the needs and opportunities from the academic and industry perspectives, but the data are limited and the scope of the current studies is relatively narrow. *To ensure that we can be effective at building the quantum workforce we need rigorous, comprehensive studies with regular data collection.* This could build on the previous studies and, for example, provide foundational material for the National Academies study of the quantum workforce called for by the CHIPS and Science Act.

Additionally, many articles also point to the lack of diversity across quantum-related fields and how that contributes to shortages and limits our competitiveness. Others articulate the need for supporting more educators at a broader array of institutions, as well as more programs for helping current workers pivot into quantum-related jobs. *To build capacity within our educational institutions, the future studies should regularly collect data for examining these issues as well.*

Overview of the National Q-12 Education Partnership

The National Q-12 Education Partnership (Q-12) spans industry, academia, government, and professional societies, and its activities align with the National Strategic Plan for quantum workforce development. Currently, the NSF grant “Q2Work,” which is a collaboration among UIUC, the University of Chicago, and the University of Pittsburgh, provides a backbone for the partnership and engages teachers directly in the development of K-12 quantum education. This approach recognizes that scaling the quantum workforce relies on empowering educators as mentors, role models, and ambassadors. The Q-12 has been instrumental in convening stakeholders around the development of a quantum workforce that draws on the diverse strengths and backgrounds of people across the country. Achieving this vision will take time, and in the coming years, it will be necessary to identify pathways for sustaining cross-sector partnerships/consortiums, like the Q-12, that support workforce growth.

Through the Q-12, our team has gathered input from numerous people and organizations to identify and address challenges regarding the quantum workforce. There is wide agreement that students need exposure to quantum information science, starting in K-12, to ensure continued US leadership in this competitive and fast-evolving field. This is reflected in the CHIPS and Science Act, which calls on NSF to increase the integration of quantum into STEM curricula at all levels, establishes a quantum education pilot program, and requires the workforce assessment study I mentioned. I want to thank Congress–and this Committee in particular–for including these provisions in the legislation. Currently, through the Q-12 and Q2Work, we are making progress on an initial framework for infusing quantum into K-12 classrooms. *For success in the long term, we need to invest in programs that significantly expand the participation of teachers and educational institutions across the country*. I summarize the framework and the current gaps in quantum education later in my testimony.

The Q-12 Partnership is dedicated to increasing quantum readiness through expanded access. The National Quantum Initiative Act (NQIA) reauthorization is an opportunity to double down on this. What do we mean by access?

- Teachers across the US are asking for access to professionally develop their knowledge of this frontier science. At higher levels, educators need access to cutting-edge laboratories to teach the next generation or provide upskilling for the current workforce.
- More researchers should have access to state-of-the-art devices as they come online–whether through cross-disciplinary user facilities or within the marketplace.
- Students are excited about quantum and need access to science classes that let them tinker with it. Building on the work that Q-12 and others have done for World Quantum Day, we must inspire and support more students as they consider careers in this field.
- The public of all ages should have a front-row seat to the development of quantum information science in places like museums and libraries.
- We must ensure that education and training opportunities, which are two different facets of workforce development, are readily available no matter where you live in the US, and no matter your background. This is relevant to all parts of the pipeline, including graduate school, as we develop a domestic workforce.

Current Progress in K-12 Quantum Education

Through Q-12 and Q2Work, my collaborators Prof. Diana Franklin (University of Chicago) and Prof. Chandralekha Singh (University of Pittsburgh) organized meetings with teachers, education experts, and related quantum programs to gather their input on how best to approach quantum learning at the K-12 levels. Since 2020, we have also co-organized and facilitated discussions that include industry, academia, professional societies, STEM teachers and organizations, and government agencies and labs. From all of these interactions, we have learned that infusing quantum into current curricula is a promising path forward for scale.

America's teachers and our educational system have a foundation in STEM that quantum information curricula can build upon. In high school physics and chemistry, teachers already introduce a small number of quantum-related concepts. For example, superposition currently appears in chemistry classes in the context of electron orbitals. Electrons can have a likelihood of being in two different energy states of an atom prior to us measuring them. Superposition is also a key feature, along with entanglement, for gaining a quantum advantage in the technologies that the NQIA invests in. Another example is in physics, where students learn about the wave properties of light. This provides an opportunity for teachers to introduce polarization, which can encode quantum information.

What's missing across the board are the curricular materials and teacher training (professional development) to connect ideas like superposition to quantum information science. *Coupled with this, we need to invest in experiential learning opportunities.*

An initial K-12 quantum information science framework, developed with teacher input, is currently available through the Q-12 website. The infusion approach meets science classrooms and teachers where they are at and offers information for school systems and decision-makers to make choices on how best to implement programming changes.

There is still significant work to be done on curriculum development and implementation. This is especially true in the computer science and math communities, as well as at the middle school levels. Current programs across different states are also consistently finding that teachers need more scaffolding to demystify quantum and build their confidence in teaching the topic.

The NQIA has increased activity in this area and seedling programs have been successful. For example, the Q-12 partners, along with federally funded programs and centers, are supporting small cohorts of teachers in bringing quantum into their classrooms. Examples include summer teacher research experiences, small-scale professional development, activity kits and online games, and classroom visits. For scaling, we are also currently collaboratively developing a network of quantum professionals who can do outreach to classrooms and work with teachers directly. For instance, the American Physical Society piloted a program for connecting to classrooms, "Quantum to-go," for this year's World Quantum Day.

Internationally, quantum topics already exist in the K-12 curriculum, and this is also true for a handful of U.S. states. Furthermore, the establishment of an international World Quantum Day has ignited activity across all sectors, including many government agencies, and engaged hundreds of educators, translating to tens of thousands of students nationwide. Early indications suggest that these programs are helping to dispel the notion that quantum concepts are only accessible to a small sector of the population. Rather, they can inspire young learners and teachers alike, and empower them to understand a host of emerging technologies that are so vital to the future of the United States.

Gaps in the Quantum Workforce: K-12 and Undergraduate

Through the Q-12 community meetings and individual discussions with experts, we have developed a list of gaps around quantum education. These challenges span K-12, higher education, and public sectors. What is distinct from the general challenges in STEM education are the *insufficient infrastructure and spotty programming for quantum workforce development*. This is an acute issue given the rapid speed at which quantum science is advancing worldwide. The gaps include:

- Information about quantum careers, pathways, and examples of people working in QIS. This information should be developed for parents, educators, communities, and students.
- Access to experts/experiences to complement digital information, with robust mechanisms to build relationships between K-16 educators and QIS experts working in different sectors.
- Hands-on experiences for learners across the K-12, public, and undergraduate levels to inspire them and deepen their awareness, appreciation, and understanding.
- Professional development to train and empower K-16 educators. This will take different forms at the K-12 and undergraduate levels.
- Assessed and age-appropriate learning materials for K-16 learners, educators, and the public.
- Communication/collaboration among quantum education and workforce development programs.

The NQIA outlines a science-first approach to accelerating advances in the field. Recognizing we need people to succeed, the current investment has also enabled a number of programs that are just beginning to address some of the gaps above. Expanded investment is needed to avoid losing ground, and to scale existing small programs. At this stage, this will only happen with new infrastructure and programs that will ultimately equip our teachers and educational institutions with the necessary tools and knowledge to flexibly offer quantum learning opportunities and pathways to more than a small number of communities.

At the current pace, we expect that in 10 years there will be significant advances in all aspects of quantum information technology development. According to the U.S. Bureau of Labor Statistics, slightly more than 6 in 10 graduating seniors go to college. If this remains the same, 10 years from now the majority of this fall's 6th-grade class, including my oldest daughter, will have graduated from college or be already working. Capitalizing on the momentum we have now around quantum education will ensure that these students and future generations are ready to lead this field forward and work in other emergent areas whenever they enter the workforce.

NQIA Reauthorization Recommendations: Quantum Education Centers and Infrastructure Investments

At the heart of the NQIA are National Centers that focus on different aspects of computing, sensing, and communication networks with a goal of advancing knowledge and translating science to the marketplace where possible. Not everything is known or ready to go, and different parts of the research are at different stages of maturity. This uncertainty is normal in a field that is at the frontier of what we can do in science and engineering. The Centers are doing exceptionally well in terms of the science and added infrastructure, and agencies have been, to my knowledge, developing new funding opportunities that complement these investments. Leaders and personnel within the NQIA Centers, in my experience, recognize the need for targeted workforce efforts and have developed tailored programs that leverage their resources. In some cases, Centers are directly working with Q-12 or with each other. Additionally, many organizations, some supported by federal investments, have also started to launch new quantum education and/or training opportunities. However, *focused quantum workforce development programs, outside of graduate student support, still make up a relatively small portion of activity under the original NQIA investments.*

Therefore, there are two elements that I would like to highlight as the Committee works to reauthorize the NQIA:

- First, *I urge the Committee to consider authorizing at least one National Center for Quantum Education and Workforce* that will leverage existing programs, accelerate the readiness of educators, and serve as a resource for federal and private research investments to scale their local impact in communities across the country. A center-scale investment in focused education and workforce development will concretely link

K-12, higher education, and public engagement sectors to advance quantum efforts for the United States. The new center would amplify and connect workforce programs, such as those supported by DOE, NSF, DoD, NASA, and NIST. The Center could also provide an avenue for comprehensive, regular studies of the workforce. This new infrastructure would enable us to tackle the challenges of the quantum workforce with the same rigor with which we are approaching the global race in quantum technologies.

- Second, *there is a critical need for investments and possibly incentives for public-private partnerships to build modern facilities for undergraduate quantum educational programs, and design hands-on laboratories for K-12*. Investments should extend beyond the borders of the current quantum centers. This new infrastructure could also support graduate programs at different levels.

Because quantum spans so many areas of science and engineering, creating these new investments will also serve our nation's overall S&T enterprise. Expanding quantum educational programs will help American workers have depth and agility over their careers, allowing more people to contribute and make decisions regarding quantum and quantum-adjacent technologies, or whatever else comes next.

Thank you for your time today and your work on moving this forward. I am happy to answer questions.

Related resources:

World Quantum Day Activities and Videos for K-12 audiences
"This is Quantum" https://www.youtube.com/watch?v=RypSQKIKhyo
"What YOU can do with quantum science, featuring LeVar Burton, Astronaut Josh Cassada, and more!" https://www.youtube.com/watch?v=q0fqxPUDVpw
Quantime: https://q12education.org/quantime

K-12 Framework for QIS
https://q12education.org/learning-materials-framework

Papers

Chandralekha Singh, Abraham Asfaw, and Jeremy Levy, *Preparing students to be leaders of the quantum information revolution,* Physics Today, https://doi.org/10.1063/PT.6.5.20210927a (2021)

Justin Perron and Shahed Sharif, *Educators Needed for a Quantum Future,* Physics 16, 59, 2023

H. K. E. Stadermann, E. van den Berg, and M. J. Goedhart, *Analysis of secondary school quantum physics curricula of 15 different countries: Different perspectives on a challenging topic,* Phys. Rev. Phys. Educ. Res. 15, 010130, 2019

Michael F. J. Fox, Benjamin M. Zwickl, and H. J. Lewandowski, *Preparing for the quantum revolution: What is the role of higher education?*, Phys. Rev. Phys. Educ. Res. 16, 020131, 2020

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NSF Quantum Leap Challenge Institute Hybrid Quantum Architectures and Networks
https://hqan.illinois.edu

Illinois Quantum Information Science and Technology Center
https://iquist.illinois.edu