"Quorkforce": Developing a National Quantum Workforce

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May 2021

Summary

The Biden-Harris Administration should establish a national initiative to develop a workforce pipeline for the new and emerging quantum ecosystem - call it the "*Quorkforce*." Due to the rapid growth in the fields of quantum computing and technology along with fears of losing competitiveness, both the public and private sectors are struggling to find skilled employees. Quantum skills are derived from a mixture of many disciplines such as physics, computer science, applied mathematics and engineering, and there is no unique path to enter the quantum sphere. Through partnerships between the National Science Foundation (NSF), the Department of Education, the Department of Energy, and the private quantum industry, the Biden-Harris Administration should establish an educational plan to train the next quantum generation across K-12, undergraduate, graduate and postgraduate levels. The Administration should initiate an open call to create ten national quantum education centers with a baseline funding of $300M over a period of 10-12 years. The short-term goal would be to train the existing workforce with adequate quantum skills, while the long-term goal would be to provide a steady flow of quantum-literate graduates capable of advancing the field and fulfilling the needs of this growing industry.

Challenge and Opportunity

In December 2018, the U.S. Congress passed the National Quantum Initiative (NQI) Act to establish goals and priorities for a ten-year plan to accelerate the development of quantum information science and technology applications.[1] Quantum information science is defined as the use of the laws of quantum physics for the storage, transmission, manipulation, or measurement of information. Title III of the NQI states that the National Science Foundation shall carry out a basic research and education program on quantum information science and engineering, and award grants for the establishment of Multidisciplinary Centers for Quantum Research and Education. This proposal aims at extending these efforts with a special focus on preparing a steady stream of quantum-ready workers.

The acceleration in the advancement of quantum technologies has created an urgent need to develop a workforce pipeline by expanding the number of researchers, educators, and students with training in quantum information science and technology. Human capital in this field is necessary both for national security purposes and in order to remain dominant in the present and the future. Already, both the Federal Government and the private sector are facing a significant talent problem in quantum technologies due to the shortage in quantum-trained college graduates. In the related field of computer science, only 400,000 graduates from U.S.

[1] "National Quantum Initiative Act," H.R.6227 (2018, December 21), *115th Congress, 164:132 STAT. 5092*, accessed April 30, 2021, https://congress.gov/bill/115th-congress/house-bill/6227

universities were available to fill the 1.4 million computing jobs open in 2020 (~29%).[2] This gap between labor force demand and supply is only expected to grow as the applications of quantum information science become more germane to innovation and global technology competition. A steady flow of quantum-literate workers on all levels will make the US stand out among its allies as well as surpass its adversaries.

Quantum education and research fall under the big STEM umbrella (Science, Technology, Engineering, and Mathematics). Broadly speaking, the demand for STEM workers is projected to continuously increase for the foreseeable future. The Education Commission of the States estimates that in the next decade, STEM-related jobs will increase by 13%, while non-STEM-related jobs will only grow by 9%. Currently, there are around 18 million STEM employees in the US out of a total of 160 million total jobs, which accounts to roughly 11.25% of the American labor force.[3]

The main challenge for the fast-growing quantum industry is that the quantum-ready workforce supply is not keeping up with demand. This has the potential to hinder long-run scientific advancement and impact US dominance in the quantum field of research on the global level. China in particular has aggressively invested in quantum research and development at a rate that may soon surpass U.S. research and development funding levels. In 2019 for example, China's patent office received more than twice as many applications as its US counterpart, indicating the increase in the Chinese scientific workforce.[4] To address this pressing issue, a longitudinal educational path needs to be established with the aim of closing the workforce gap in the next 10-15 years. Three main pillars will be essential for the success of this endeavor: middle/high school outreach, undergraduate/graduate education, and current employee training. To ensure the success and the longevity of such a mission, central hubs must be created for coordination purposes. At a time when U.S. officials worry that the country is losing ground to other nations, it is important to realize that the American people are the real asset, and that quantum education is the key to fortifying the country's status as a global leader in quantum discovery and innovation.

The National Science Foundation has been the leader of science innovation and education for over 70 years. This institution is the best fit to lead the effort of creating and managing the quantum centers. Such an endeavor could be accomplished either through existing research directorates (Computer and Information Science and Engineering, Engineering, Mathematical and Physical Sciences, and Education and Human Resources), or via the establishment of a new directorate for quantum research and education.

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[2] "Civilian Labor Force Level (CLF16OV)," *Economic Research, Federal Reserve Bank of St. Louis*, accessed April 30, 2021, https://fred.stlouisfed.org/series/CLF16OV

[3] "Vital Signs: United States," *Education Commission of the States* (2020), accessed April 30, 2021, https://vitalsigns.ecs.org/state/United-States/demand

[4] "World Intellectual Property Indicators," (2020), accessed April 30, 2021, https://www.wipo.int/publications/en/details.jsp?id=4526

Plan of Action

The Biden-Harris Administration should work through the White House Office of Science and Technology Policy (OSTP) to oversee and strengthen federal support for quantum education in the United States. In order to ensure the widest spread of a successful initiative, the National Science Foundation should, as a first step, dedicate seed funds for the establishment of ten quantum hubs across the United States Northeast, South, Midwest, and West. Once the top candidate for each of the centers is announced, a follow-up grant of $15 million per center should be provided for founding and launching these centers over a period of 2-3 years. A similar amount of funding for the following 5 years will give sufficient time for these centers to take root and succeed. The underlying mission of the quantum educational centers will be three-fold:

1. Facilitating the wider accessibility of undergraduate/graduate degrees to develop a larger and more diverse quantum-ready workforce.
2. Training current employees to ensure the quantum workforce remains relevant and up to date in the field.
3. Planning outreach activities for middle and high school students to encourage the future generation to pursue this exciting new career path.

This ten-year plan will gradually fill the current workforce gap in the quantum industry as well as furnish a steady flow of workers skilled in quantum science and technology to keep up with the growing demands of the field.

1. Tertiary Education

Because quantum skills stem from a mixture of academic departments such as physics, chemistry, mathematics, computer science and engineering, they cannot be acquired via an existing, simple, old-fashion major or degree. The quantum centers should form a consortium of universities within their geographical bounds that offer courses and classes in the disciplines that together form quantum science and technology. It is crucial to understand that quantum education is not only relevant for PhD programs at elite universities but should be considered from the earliest years of science and engineering education. The ultimate outcome will be the creation of well-defined paths for students to pursue degrees at the bachelor's, master's, and doctoral levels. Having a commonwealth of colleges in a common geographical region guarantees the long-term continuation of a quantum education program: a single institution might not realize sufficient demand from students and sponsors to make a quantum program financially sustainable.

Building quantum laboratories within the centers will be their most pressing task. Experimental skills related to quantum technologies are equally, or even more, important for entering the workforce than courses in complex quantum theory, which is still ahead of industrial quantum systems. As quantum concepts are being transformed into commercial products, there is an urgent need for a workforce which possess hands-on experience with quantum systems.

Building a successful quantum education program will require that each center gather subject matter experts, develop strong relationships with industry, ensure institutional commitment, acquire resources for laboratories, hire faculty clusters, and set up dissemination mechanisms. Most current educational systems stress separate academic subjects rather than a multidisciplinary approach to quantum education, a trend that has led to the graduation of physics majors with very little experience in building quantum devices and engineering majors with little to no exposure to quantum mechanics. The role of the centers in this context will be to install cohesive benchmarks and standards across the multiple disciplines involved rather than create a unified curriculum for all degrees and specializations.

Partners from the private sector will play a major role in this paradigm. They are the main drivers of workforce demand in the quantum industry in their respective areas of operations (sensors, networks, communications, computing, etc.). The skills the private sector requires range from hardware knowledge to quantum programming, and even pure quantum information theory. Due to its very early stage of development, it remains challenging to quantify the number and size of companies within the quantum industry, let alone the distribution of jobs. There must be a continuous dialogue between higher education institutions and quantum employers to ensure that the former are preparing graduates to fulfill the needs of the latter. Mutual contributions will enable smooth supply and demand dynamics and avoid the potential for misuse of resources. A town hall every 3-6 months with the main players on each side would allow for exchanging ideas, sharing successful milestones, and anticipating potential challenges.

2. Current Workforce Training

In 5-10 years, the centers will be providing a steady flow of college graduates ready to be employed in the quantum industry. However, there is a dire need to fill the intermediate gap in the quantum workforce across a range of applications from devices to software and everything in between (e.g., fabrication of novel quantum materials, software compilers for quantum computers, etc.).

In the past couple of years, quantum technology has been transitioning into commercial products with the potential to solve real-world problems. As a result, many companies have begun to hire more engineers and technicians to ensure the new systems are reliable. Due to the shortage of such skilled employees, many physicists and engineers are facing the challenge of learning a whole new set of skills to prepare themselves to participate in the quantum revolution.

Hence, another overarching goal for the quantum centers will be to provide substantial training for current employees in the quantum industry. Week-long workshops, monthly seminars, summer training, etc., will each focus on a specific topic or a specific technology (optical-metrology, cryogenics, microwave electronics, etc.). On the experimental level, the centers' labs will be responsible for designing hands-on training at their facilities to give physicists, engineers, and chemists the practical skills they need for proficiency in the latest quantum technologies. This endeavor could be sponsored by private quantum companies, which will be the main beneficiaries from the re-training of their employees.

3. K-12 Outreach

To ensure the long-term success of these efforts, special attention should be devoted to the K-12 sector. The quantum centers should each have a division for outreach to public and private middle/high schools within their geographical boundaries. This is an essential step to introduce the younger generation to quantum science and technology, which is generally not already included in their current curricula.

It is impossible to change middle and high school science curricula overnight. The centers should work with existing STEM educational material and make strategic additions to it. The goal is to give American teenagers a glimpse into the area of quantum research and ignite their curiosity and motivation to pursue a future career in the field. Moreover, the centers should organize summer boot camps for advanced students at their facilities to give them hands-on experience with quantum lab demos, invite them to meet-the-scientists events, and introduce them to toy models and experiments. Such activities could range between 7-10 weeks in the summer and introduce students to quantum algorithms, quantum computer prototypes (D-wave, Microsoft, Google, IBM, etc.), post-quantum cryptography (PQC), and other topics in the field. Many similar efforts have been initiated by private companies to do outreach to and site visits with students; the task of the centers would be to strengthen this kind of collaboration and make it more established for the long run. The overarching goal would be to motivate these students to pursue further explorations in and around the quantum area of research and applications.

All the above efforts should be coordinated with several relevant associations such as the American Association of Physics Teachers (AAPT), the Association of Mathematics Teacher Educators (AMTE), the American Association of Chemistry Teachers (AACT), and the Computer Science Teachers Association (CSTA). Most importantly, centers around the country should organize workshops in the form of "train the trainer" events in order to equip high school teachers with the right tools and set them up for success.

Inclusion and Diversity

As the National Science Foundation continues to expand its investments in the quantum space, it is important to improve the diversity of the quantum workforce. The foundational work in both quantum research and education should be diverse and inclusive across multiple attributes:

geography, demographics, and technology. Broadening participation in STEM fields is a challenge that has not yet been overcome. However, to ensure that the quantum community will meet the workforce needs of the present and the future, it is imperative to utilize the broadest possible range of human capital. If research and education in the quantum field progresses without addressing barriers to diversity and inclusion, these problems will be solidified in the next generation. Therefore, each center should prioritize efforts to ensure that the quantum community is representative of the country's diversity in race, gender, ethnicity, social class, etc.

To date, the field of quantum research has been developed primarily by disciplines with some of the lowest representation of women and minority populations. For example, women make up 21% of Computer Science (CS) bachelor's degree graduates and 20.3% of CS doctoral graduates, and domestic underrepresented minorities make up 14.7% of CS bachelor's degree graduates and only 3.1% of doctoral CS graduates.[5] The most significant barrier to fostering students' passion for STEM education at all age levels is the persistent and still-widening gap in opportunity in underserved communities. Educating parents in these communities about the opportunities that STEM education in general -- and quantum education in particular -- can offer their children should start with showing them hard data on the continued growth of these jobs.

Many initiatives in the past decade have shown their effectiveness in reaching previously marginalized communities. The great successes achieved by movements like CS for all, AI for all, Black in AI, etc. should be a strong motivation to launch the next organization: *Quantum for all* or *Q4ALL*. Such a movement would promote wider inclusion in the quantum fields of research and education. Primary channels which these models have established to accomplish this include scholarships, fellowships, national meetings, summer camps, workgroups, and other activities geared towards a diverse student corps around the country. Previous successes have been accomplished by setting a collective agenda with the cooperation of content providers, education associations, researchers, and supporters to help schools and districts provide all students with rigorous K-12 STEM education. The national quantum centers could support a Quantum for all movement by serving as a platform for connecting diverse stakeholders, providing support to new and developing initiatives, tracking and sharing progress, and communicating about the work to local and national audiences.

The national quantum centers, separately and in collaboration, must make the issue of inclusion and diversity a priority. Some relevant organizations and events are already emerging, such as the Women in Quantum Development Symposium, the American Physical Society Bridge Program, the Inclusive Graduate Education Network, etc. They are shaping how PhD programs approach admissions, retention, and professional development with the aim of increasing participation of underrepresented racial and ethnic minority groups.[6] The quantum centers should coordinate these efforts, while engaging both public and the private industry to reduce factors that hinder participation in the future quantum workforce such as pay disparities,

[5] Stuart Zweben & Betsy Bizot, "2019 Taulbee Survey", *Computing Research Association*

[6] "Kavli Meeting" (2019). Accessed April 30, 2021, https://quantum-workforce.kavlimeetings.org

discrimination in hiring, affordable childcare provision, inappropriate expectations for working hours.

National Collaboration and Monitoring

Critical to this plan's success will be the collaboration with two partners: government labs and the private sector. Government labs like Brookhaven National Laboratory (BNL), Pacific Northwest National Laboratory (PNNL), and Argonne National Laboratory (ANL) play an important role in developing quantum systems through their facilities. The private sector, meanwhile, will be the main beneficiary of the development of a quantum workforce, and their participation in the efforts led by the centers will be vital to the appropriate allocation of resources and focus areas. To monitor the plan's success, the NSF should audit the progress of the centers and engage them in annual general meetings to share, evaluate, and coordinate their respective efforts and accomplishments. Finally, the US Bureau of Labor Statistics should start taking into account purely quantum jobs in their census, as this will be the main metric for measuring the saturation of the quantum job market and hence the successful outcomes of this plan.

Conclusion

As the quantum industry is growing rapidly, there is an urgent need for a workforce skilled in quantum science and technology. By creating a group of national centers under the guidance of the National Science Foundation, education in quantum information science can be provided on all levels from middle school to post-doctoral, while simultaneously training the current non-quantum workforce for this new and exciting field. Over the next decade, this plan would achieve job market saturation in the quantum industry and furnish a steady flow of quantum-ready workers.

Frequently Asked Questions

Why do we need centers? Don't we have enough universities in the US?

Creating and maintaining a quantum department at any given university is a huge task, and most generally it is not sustainable due to many factors such as lack of funding and resources, supply and demand of courses and students, and the absence of labs. Centers encompassing a geographical region would bypass these difficulties and ensure a more centralized and diverse way to provide a meaningful quantum education.

Are current degrees in universities not enough?

All educational routes are important to the development of the quantum-ready workforce necessary to meet future demand from complex quantum computing businesses and their customers. However, most current programs focus on only one facet of the quantum field. Specifically, degrees in single departments like mathematics, physics, chemistry or engineering will not prepare future employees for the many different pillars of quantum research. A broader educational path is desperately needed to ensure the adequate preparation of the future quantum workforce. Efforts have been undertaken recently by several universities to start master's programs in quantum-related fields, e.g., an MS in quantum computing at the University of Rhode Island, a quantum computing concentration at Duke University, an MS in quantum computing at the University of Wisconsin, and many more. This underscores the existing need for central hubs to coordinate different tracks and avoid redundancy and waste of resources.

How can a quantum curriculum be implemented?

A thorough inquiry should be developed by each center to implement an adequate curriculum for undergraduate and graduate studies. Some key elements will likely be:

- Creating a core course dedicated to quantum principles and applications that will provide students from different backgrounds a common language. Designed for non-physicists, it would likely be heavily based on a linear algebra approach to quantum mechanics.
- Distinguishing between the hardware track and the software track, with the former geared towards engineering students and the latter focused on computer science students.
- Emphasizing the interplay between the theoretical and experimental landscapes, together with teamwork, design and business knowledge skills.

Are we going to face a similar diversity problem in 10 years as in STEM?

The problem of inclusion and diversity in STEM-related fields is a persistent one. One important task of the national centers will be to reach out to underrepresented and underprivileged communities within their geographical boundaries to make sure these young people have an equal opportunities to pursue education and careers in the quantum field. It is crucial that such an action be implemented and incorporated in the early stages of planning as well as throughout the process so that underrepresentation is offset early and continuously.

About the Author

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