Guide to Building a Quantum Technician Workforce

Reskilling and upskilling recommendations to prepare a workforce of quantum technicians

October 2023

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About the Quantum Economic Development Consortium

The Quantum Economic Development Consortium (QED-C) is an industry-driven consortium managed by SRI International. With a diverse membership representing industry, academia, government, and other stakeholders, the consortium seeks to enable and grow the quantum industry and associated supply chain. For more about QED-C, visit our website at quantumconsortium.org.

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Executive Summary

- The quantum industry is advancing rapidly and need for qualified talent at all levels is growing; while efforts are underway to prepare students at the undergraduate, masters, and PhD level for quantum engineering and scientist roles, there are few associate degree and certificate-level programs geared toward training technicians
- Quantum technicians fill multiple critical functions, including system and component fabrication, assembly, characterization, testing, operation, and maintenance; demand is expected to grow as the industry continues its rapid development, and there is a clear need to start developing this workforce now
- A combination of domain knowledge (e.g., experience with vacuum, cryogenic, and optical systems), programming, and soft skills are commonly required; while most of these skills are not unique to the quantum industry, there are several that, in combination, are critical and distinguishing to quantum
- Current hiring approaches often focus on recruiting candidates out of adjacent fields that have shared skill requirements (e.g., microelectronics, semiconductor, photonics) and rely on in-house shadowing programs to train new hires; however, a more coordinated approach specifically geared toward filling the quantum workforce pipeline could increase productivity and progress, especially in small companies
- Several gaps have been identified as impediments to building a quantum technician workforce, including funding for education, experimental asset access, and public awareness
- QED-C recommends the following actions to address the identified challenges:
    1. Create a framework to define the types of quantum technician roles and invest in marketing to build awareness about career trajectories
    2. Map existing training programs versus the knowledge, skills, and abilities (KSAs) that are defined as being critical for the quantum technician role
    3. Build local partnerships between higher education, industry, and national labs
    4. Establish an accreditation program for quantum technology curricula
    5. Expand teacher training programs across disciplines
    6. Increase access to assets to enable hands-on-learning opportunities
    7. Expand co-op and internship opportunities to non-graduate degree students, with greater emphasis on diversity, equity, and inclusion
    8. Allocate more funding for institutions focused on training and education rather than research requirements

Introduction

Motivation

Quantum Industry Advancements

The quantum industry is advancing rapidly, with many startups, large corporations, universities, national labs, and other research institutions engaged in its development. In the coming decades, quantum information science will have a transformative impact on many industries, with implications for the US economy and national security. As the technology moves from the lab to industrial application, workforce needs are also evolving.

Physicists and other scientists have led most quantum development to date. However, a significant share of this work is now shifting to engineers, whose focus is on productizing these technologies and scaling up manufacture. As the industry matures, it will be necessary to cultivate a skilled workforce of technicians and tradespeople capable of supporting development and manufacturing of commercial products.

Need for Quantum Technicians

Through recent surveys, discussions, and a workshop, QED-C identified a growing need in industry, government, and university labs for qualified talent at all levels, from scientists and engineers with advanced degrees to technicians, assemblers, and quality control inspectors capable of working with quantum information science and technology systems.[1]

While efforts are underway to prepare students at the undergraduate, masters, and PhD level for quantum engineering or scientist roles, there are few associate degree and certificate-level programs geared toward training technicians. Quantum technicians are generally defined as professionals with a bachelor's degree or less who support scientists and engineers; tasks will vary by application and employer, but may include laser alignment, setting up ion traps, cryogenic and high vacuum system maintenance, operation of fabrication and characterization equipment, or sub-system assembly.

Manufacturing of quantum systems has not yet scaled to high-volume production. As such, many assume that demand for quantum technicians is low or non-existent. This is a common misconception – in fact, quantum technician roles are highly relevant in the experimental and prototype stages. According to QED-C's 2022 workforce survey (see Appendix 3), most respondents anticipate hiring more technicians with quantum skills, either immediately (46%) or in the next few years (43%). Almost half of respondents stated that 25% of the work currently performed by engineers can be done by technicians. One workshop participant anecdotally confirmed this insight, sharing that a PhD-level engineer at his startup was spending 70% of their time soldering wires. By hiring a technician to support this task, they were able to get three times more work done.

[1] Detailed results from a November 2022 survey are presented in Appendix 3

To build a greater understanding of current demand for quantum technicians, SRI International's Center for Innovation Strategy and Policy (CISP) analyzed the National Labor Exchange Data Trust.[2] Using natural language processing techniques, they filtered various job postings to isolate those related to quantum fields and pinpointed specific indicators that categorized these jobs as technician-level positions. This analysis identified a total of 1,044 quantum technician job postings between January 2019 and May 2023. The methodology used to filter, identify education levels, and analyze postings is described further in Appendix 2.

Demand for quantum technicians will continue to grow as the industry continues its rapid development and shifts from prototyping and smaller demonstrations (today) to commercial-scale production, and there is a clear need to start developing this workforce now. This report highlights potential pathways and obstacles to educating skilled technicians, including upskilling or reskilling existing workers.

Report Outline

The report summarizes the current state, as well as challenges and gaps, related to creating a quantum technician workforce based on inputs from a survey of QED-C members, discussions and recommendations developed in the workshop, and 1:1 stakeholder interviews. First, it defines the specific roles and responsibilities that a quantum technician performs; what knowledge, skills, and abilities (KSAs) are needed; and current hiring and training practices. The report highlights outstanding gaps and challenges that stakeholders anticipate could limit success. Finally, the report concludes with specific strategies and recommendations for potential solutions to the identified gaps.

In doing so, the report provides a starting point for addressing the high-level goals in the QIST Workforce Development National Strategic Plan (see below). More information is available on quantum.gov.

Strategic Goals

- Develop and maintain an understanding of the workforce needs in the QIST ecosystem, with both short-term and long-term perspectives
- Introduce broader audiences to QIST through public outreach and educational materials
- Address QIST-specific gaps in professional education and training opportunities
- Make careers in QIST and related fields more accessible and equitable

[2]The National Labor Exchange (NLx) Data Trust bears no responsibility for the analyses or interpretations of the data presented here. The opinions expressed herein, including any implications for policy, are those of the authors and not of the NLx Data Trust members.

Quantum Technician Roles & Responsibilities

The specific responsibilities performed by a quantum technician will vary by the system type (e.g., application or specific quantum technology).

Common tasks in industry, academic, and national labs include those in the following categories:

- *System and Component Fabrication and Assembly*: Soldering, wiring, machining, microfabrication of devices (including clean room assembly), optical component alignment, wire bonding
- *System and Component Characterization and Testing*: Using measurement and testing devices on systems and components to confirm quality and performance – e.g., cryo testing, PCB testing; may also include data analysis and coding
- *System Operation and Maintenance*: Helium transfer, vacuum and cryogenic system operation, routine lab equipment standard maintenance

Specific knowledge and skills needed to be successful in these functions are outlined below.

Requisite Knowledge, Skills, and Abilities (KSAs)

Industry and government lab hiring managers defined discrete KSAs that they would look for in a quantum technician. Potential employers articulated over 100 unique KSAs, which were then grouped into categories. While most of the skills are not unique to the quantum industry, there are several – experience with vacuum, cryogenic, and optical systems – that, in combination, are critical and distinguishing for quantum.

Many of these skills are currently learned through undergraduate research at institutions with large quantum or physics departments or graduate studies with a focus on experimental atomic, molecular and optical (AMO) or condensed matter physics. New programs focused on building the technician workforce could have multiple benefits:

- Enable students to directly enter the quantum technician workforce without requiring an advanced degree
- Provide on-ramp to advanced degree programs for a more diverse set of students who may not otherwise be prepared to pursue them

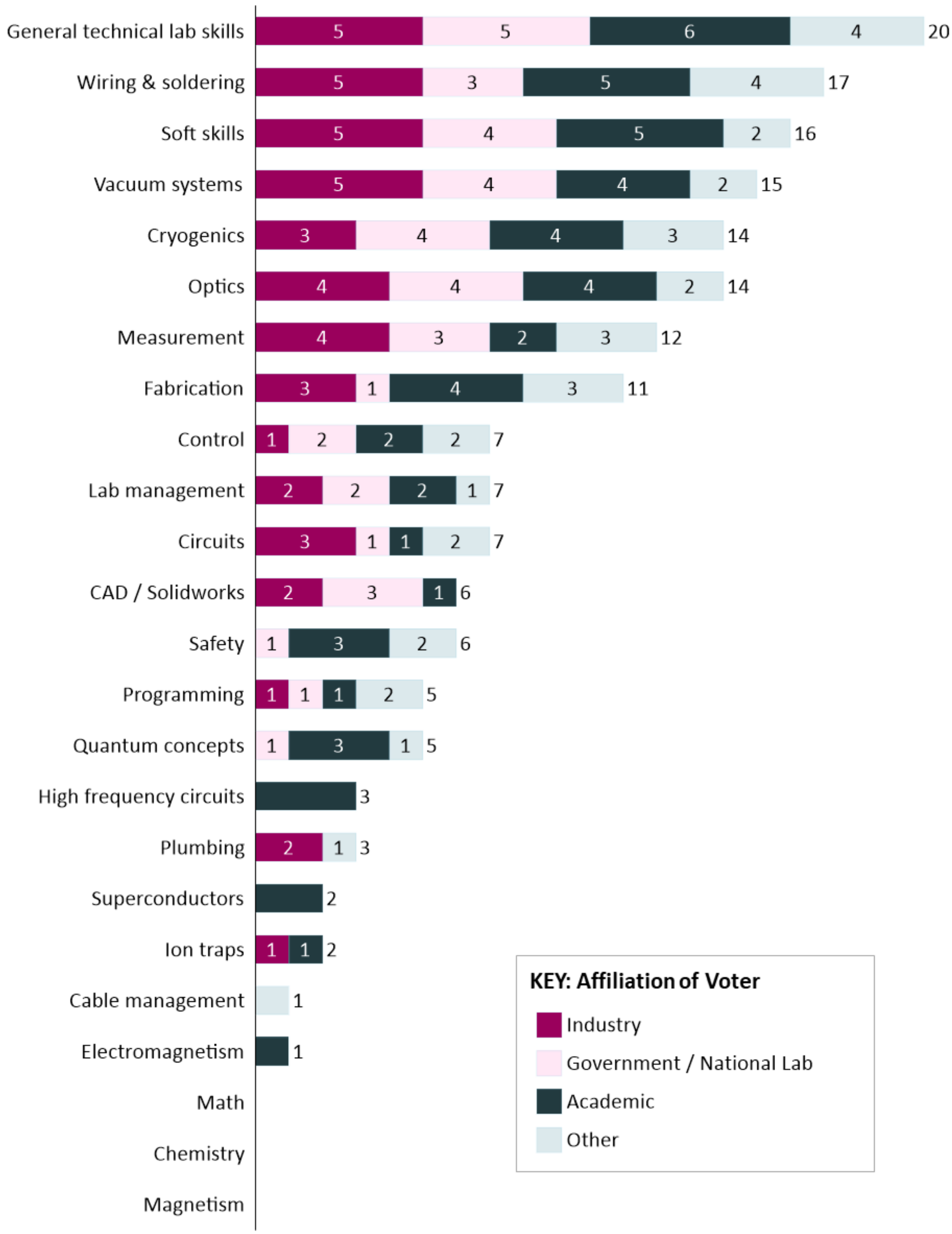
Quantum Technician KSA Categories

Category	Additional Notes
Cable Management	-
CAD / Solidworks	Mechanical and optical CAD
Chemistry	-
Circuits	Including high-frequency circuits
Control	Software / computational control of hardware – e.g., PIDs, Arduino, Python
Cryogenics	Dilution refrigerator operation and maintenance; high-pressure gas lines; temperature and pressure measurements; leak testing; fittings, piping, and pump mechanisms
Electromagnetism	-
Fabrication	Basic machining (e.g., drill, lathe, mill, wrench); cleanroom operation and fabrication skills / lithography; thin-wall stainless steel welding; polishing; nanofabrication; building / making chips
General Technical Lab Skills	Technical communication and writing skills; data collection / organization; project management; knowing how to check results for reasonableness; maintaining good lab notebooks; file organization and version control; spreadsheets and transformation of data; numeracy; analytics; reading and using documentation
Ion Traps	Setting up ion traps
Lab Management	Infrastructure management / maintenance (e.g., HVAC, water lines, power lines); shipping and receiving; inventory tracking; chemicals stocking / management (e.g., methanol, acetone); device monitoring
Magnetism	Operating superconducting magnets in a cryogenic system for silicon-spin systems
Math	Probability; linear algebra; trigonometry; some derivatives; 2x2 matrix math; ZX calculus
Measurement	Basic electrical measurement; multimeters; oscilloscopes; RF signal measurement; VNA measurement; counting electronics; microscopy for chip inspection; noise characterization; other advanced measurements (e.g., AFM, microwave, magnetic)
Optics	Laser and optical alignment / assembly; fiber and free space light sources (power measurement, basic setup / alignment, polarization); fiber optics (cleaning, inspection, fusion splicing, fiber and connector types, familiarity with mirrors, lenses, etc.); classical photonics (wave theory, interference, absorption, emission, double slit experiment, etc.); photonic integrated circuit fabrication; impact of lasers on atom cooling; Alian MZI; set up down-conversion of photons; optical anodic bonding (with epoxy)

Category	Additional Notes
Plumbing	-
Programming	Python; Qiskit; computing foundations; algorithm complexity; manipulating logic circuits; numpy, pandas, mat plotlib, use of SDK library / APIs
Quantum Concepts	Basic terminology and building blocks – e.g., qubits, lasers, vacuum, cryogenics, wave / particle duality, Heisenberg uncertainty principle, different types of architectures (e.g., trapped ion / neutral atom, photonic, superconducting, etc.)
Safety	Electricity; high-pressure gas; lasers (enclosures, design, machine assembly, interlock)
Soft Skills	Teamwork; adaptability; know how to learn; communication; troubleshooting; critical thinking; growth mindset; understanding big picture / societal impact; resourcefulness; creativity; persistence; professional disposition; problem-solving skills; tenacity; positivity; ability to give and receive constructive feedback; ownership; collaborative; inclusiveness; ability to handle incomplete / inconsistent information; know the scope of their expertise / job and when to ask for help; mentorship; teaching and leading others; detail orientation; ability to thrive in an interdisciplinary knowledge context (math, programming, chemistry, engineering, etc.); open minded; humility; inquisitive; entrepreneurial; time management
Superconductors	Physics of how they work
Vacuum Systems	Operation, surface preparation, surface inspection, leak detection; experience with ultra-high vacuum systems specifically
Wiring & Soldering	Electrical wiring and soldering (including NbTi for some systems); fine manipulation / metalworking (e.g., to wire with semi rigid coaxial cables); wire bonding

From these categorical groupings of identified KSAs, technical lab skills, wiring / soldering, soft skills, vacuum systems, cryogenics, and optics scored highest on criticality from both the educator and employer perspective.

Highest Priority Technician KSA Categories
Number of Votes Allocated by Workshop Participant (n=23)



Employers also highlighted the importance of skills that would enable technicians to troubleshoot effectively (e.g., problem-solving and communication skills, knowing how to check results for reasonableness, ability to deal with ambiguity and handle incomplete or inconsistent information). Given that many quantum systems are still being prototyped, the work is less predictable and repetitive than in more mature industries where technicians may be supporting highly optimized manufacturing operations.

There was debate about the importance and relevance of understanding quantum-specific concepts (e.g., superposition and entanglement). The general view was that while building awareness of these concepts could help technicians be more involved members of the team, especially in early-stage R&D roles, in-depth understanding of the fundamentals is not necessary. Multiple experts drew parallels to the auto repair market, sharing that while mechanics are not responsible for designing the powertrain, they do know how the system should work and how the basic parts fit together.

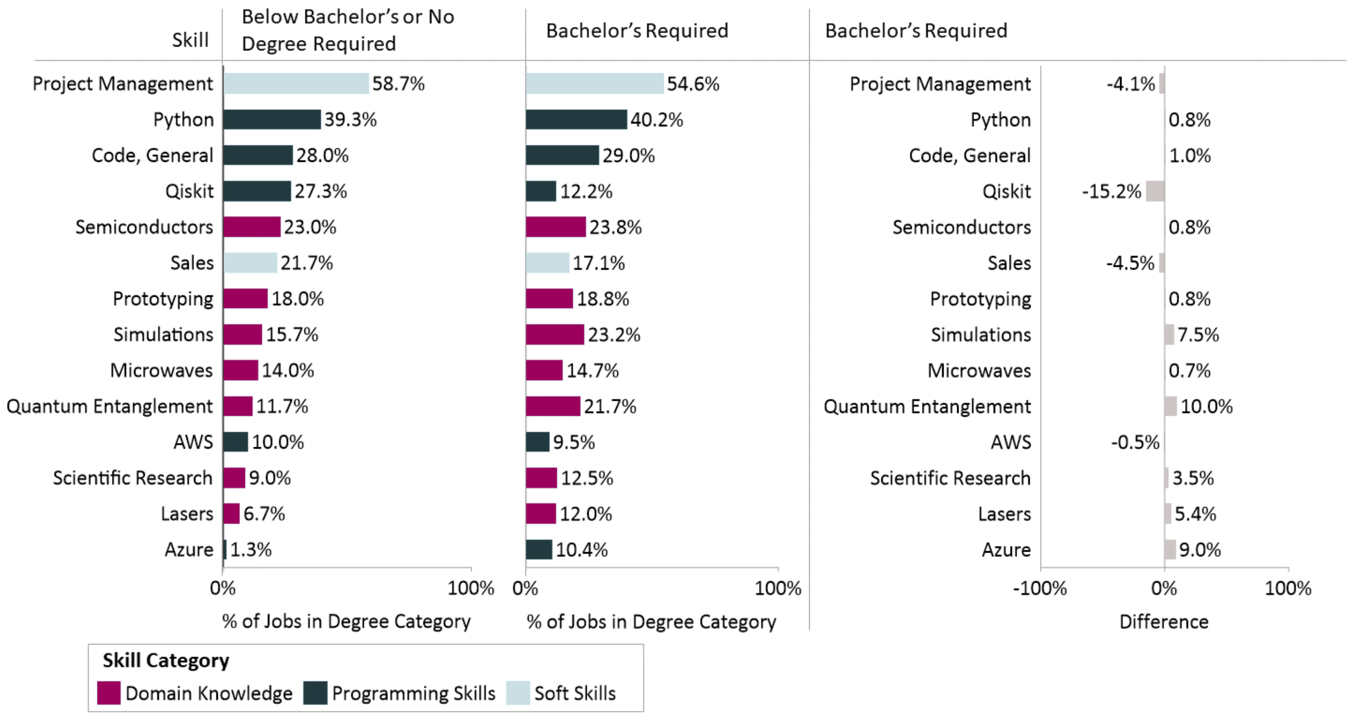
Given the variation of needs between companies (based on their system design) and specific functional areas within that company, a technician typically would not need to possess all the skills outlined above to be qualified and successful. Other industries with similar needs, such as semiconductor manufacturing, have hired specialized technicians for electrical work, plumbing, and similar trades to build their workforce. Quantum could do the same. Further delineation of the different types of technicians needed could support future workforce development efforts (described in more detail in the recommendations section).

Quantum Technician Job Postings Analysis

SRI used the National Labor Exchange database, a data repository maintained by the National Association of State Workforce Agencies, to analyze quantum technician job postings that were posted in the United States from January 2019 to May 2023.[3] SRI identified 1,044 unique quantum technician job postings. SRI then used natural language processing techniques to analyze the skills and education requirements commonly listed in the job postings (see Appendix for methodology).

The analysis found that the majority of jobs that do not require a graduate degree still require some level of formal higher education, most commonly a bachelor's degree. Very few positions specified interest in candidates with only an associate degree, though 28% of postings did not specify any level of education as a requirement. The skills analysis of job postings identified three primary groups of skills: soft skills, domain knowledge skills, and programming skills. The majority of jobs required proficiency with at least one programming language or specified a requirement to be able to code without listing the particular language desired; Python was the most commonly specified programming language. Domain skills were listed as requirements in a majority of both below bachelor's and bachelor's-required jobs; they were listed in 60% of below bachelor's jobs, while they occurred in 70% of jobs that required a bachelor's degree.

[3] See Appendix 2 for detailed methodology.



Current Hiring & Training Practices / Offerings

Hiring Approaches

Employers use various approaches to identify candidates who possess some of the desired skills outlined above. Many use a combination of online job postings (e.g., on LinkedIn), references (e.g., from professional associates and colleagues), and career fairs.

Workshop participants debated the optimal language to use in these job postings; specifically, whether "quantum" should be included in the title or description. Some felt that the inclusion of "quantum" attracts candidates who are eager to get involved in a cutting-edge, disruptive industry. However, others were concerned that otherwise qualified candidates might self-select out of applying due to feeling intimidated by or uncertain about the technical requirements for a quantum role. The optimal descriptive framing of these positions may depend on the locality, funding source, and specific nature of the job.

Several participants mentioned that they frequently look at candidates' hobbies as an indicator of their potential success in the technician role. In the absence of quantum-specific education, trainable candidates who demonstrate passion, interest, and attention to detail while working with their hands are often a good fit. Example hobbies include robotics (e.g., developing systems with Arduinos, Raspberry Pi's), woodworking, automotive work (e.g., "hot rods"), audio / visual, cake decoration, knitting, jewelry making, and drone enthusiasts.

Employers are also looking to adjacent markets with similar skill requirements for recruiting purposes. Examples include:

- Microelectronics
- Semiconductor
- Photonics / optics (including lasers, telecom installers)
- Electrical and mechanical engineering
- HVAC
- Electrician
- Plumber
- Automotive assembly or mechanics
- Jewelers
- Audio technicians
- General machinists

Professionals in these fields are likely good candidates for reskilling. It may be beneficial to embed quantum-related content into existing training programs for these professions to build awareness and proficiency.

In addition to the technical qualifications, it is likely that there will be an increasing need for a subset of the technician workforce to either have or be able to obtain a security clearance. While one university, University of Colorado Boulder, is pursuing a program that could build a greater pipeline of students to address these needs, workshop participants recommended that additional programs be considered. University of Texas at San Antonio was also suggested as a potential school to benchmark given the large volume of secure work that they do with the intelligence community.

These programs should clearly communicate the unique requirements (e.g., US citizenship requirements, drug use policy, or limited opportunities to publish work / generate citations) and opportunities for work that requires security clearance to prospective program participants to maximize the share of enrollments that result in graduation, clearance procurement, and long-term career satisfaction. Emphasizing citizenship requirements is particularly important given the difficulty of obtaining clearance as a foreign national. To accelerate expansion of the clearance-holding, quantum ready talent pool, new quantum-focused programs may also focus marketing and recruiting efforts toward candidates who already have or previously had a clearance (e.g., veterans) to build awareness.

Training Approaches & Offerings

Most employers rely on in-house training for their technicians today, often based around shadowing scientists and engineers. Some internship and co-op opportunities exist to train future candidates, but these programs should be expanded to increase the number of students and employers participating and to maximize collaboration between industry, national labs, and academia).

Few external training programs specifically designed for quantum technicians exist today. However, workshop participants highlighted several options targeted at quantum professionals broadly, or technician roles for adjacent fields in optics, photonics, and nano / microelectronics.

The first program tailored to training quantum technicians will be piloted in Fall 2023 at Indian River State College in Fort Pierce, FL. Indian River State College's existing LASER-TEC program supports about 44 programs across the country, including many successful ones such as Pasadena City College in California and Monroe Community College in New York. New quantum curricula could be added to these programs to leverage the investment already in place and to speed up the process of adding new quantum technicians to the workforce.

Example Training Programs
Not Exhaustive

Quantum-Specific Programs

- EdQuantum – Indian River State College
- QuSTEAM partner universities and colleges – both 2-year and 4-year programs offered
- University of Waterloo Schrödinger's Class
- MIT xPro
- Chicago Quantum Exchange / University of Illinois programs
- Colorado School of Mines Quantum Engineering minor
- Purdue University quantum micro-masters (through EdX)
- "Quantum Mechanics for Everyone" – Jim Freericks course on EdX

Optics / Lasers Programs

- Optics Technician Program – Front Range Community College
- LASER-TEC Program – Indian River State College
- Optical Systems Technology and Optical Fabrication Programs – Monroe Community College
- Optics Technology Program – Sussex Community College

Nano / Microelectronics Programs

- Advanced Technological Education (ATE) Program – Pasadena City College / Micro-Nano Technology Education Center (MNT-EC)
- Microelectronic Technology Program – Portland Community College
- Semiconductor Manufacturing Program – Maricopa Community College
- Advanced Manufacturing Program – Onondaga Community College
- Vacuum and Thin Film Technology Program – Normandale Community College
- Electro-Mechanical Engineering Technology Program – Columbus State Community College
- Semiconductor Manufacturing Technology – Mohawk Valley Community College
- MEMS and Electronics Programs – Lorain Community College
- Advanced Manufacturing & Materials Engineering Technology Program – Edmonds College

Outstanding Gaps & Anticipated Challenges

In addition to describing and sharing current best practices, experts reflected on the desired future state for a quantum technician workforce to anticipate and identify gaps. Over a dozen related themes arose. At the workshop, participants voted on which gaps were most critical to address. The top 12 gaps spanned topics related to funding, access to hardware, structuring of training programs, DEI, and more. Funding was scored as most important, and the discussion focused on not only increasing the absolute amount of funding but also improving the specific allocation of existing quantum funding toward more education programs at a greater number of institutions of all sizes.

Top 12 Highest Priority Gaps

Gap	Share of Workshop Participants' Votes	Notes
Funding	14	More federal spending on quantum education (not just research); include more community engagement and outreach programs to reach more students and teachers
Assets	13	More distributed access to experimental setups to facilitate hands-on learning; identify what lower-cost demos could be used and / or options to share between institutions
Quantum Awareness / Communications	11	Clearer definition of skills that are needed and sufficient to overcome "quantum-phobia;" opportunity to expand marketing (e.g., podcasts, newsletters, centralized jobs database)
Expanding Workforce Pool	9	Improve diversity, equity, and inclusion; opportunity to recruit veterans for clearance-holding roles specifically; need to create asynchronous learning opportunities to reach more students
Programming & Credentialing	8	Expand options for micro-credentialing or certifications and improve accessibility to hybrid learning opportunities; limit number of pre-requisites
Teaching	7	More faculty training and support through additional funding and / or engagement with national lab and industry staff
Market Insight	6	Clearer quantification of workforce demand to motivate development of curricula and to recruit students; opportunity to establish co-located industry and community college programs
Standards & Accreditation	6	Standardize curricula and establish accreditation programs that would build confidence that new programs are aligned with industry needs
Culture Change	5	Improve acceptance of community college-trained technicians and other non-PhDs
Integration of Certificates & Degrees	5	Identify ways to integrate quantum courses into existing programs for adjacent industries (e.g., electricians, HVAC, plumbing, etc.)
More Internships & Co-Ops	4	Expand access to intereships and co-ops to build hands-on training experience; extend to non-PhD and non-Masters students
Lack of Clear Career Path	3	Need to present vision to students about the growth opportunities that are available; connection between quantum and other fields to de-risk any concerns about job stability

Recommended Solutions

The following actions will help to prepare a workforce of quantum technicians. While some of the most foundational activities are listed first, the recommendations are not listed in order of importance.

1. **Create framework to define the types of quantum technician roles and invest in marketing to build awareness about career trajectories**

   The quantum industry needs a clear framework delineating the specific types of technician roles it will employ (e.g., distinguishing between assembly, testing, and maintenance of different types of hardware). This clarification should come with a refined articulation of the KSAs that are pertinent to each role.

   The National Institute of Standards and Technology's (NIST) National Initiative for Cybersecurity Education (NICE) framework serves this purpose for the cybersecurity industry. NICE defines the range of relevant cybersecurity roles, tasks, knowledge areas, and competencies to provide a common language for discussing, understanding, developing, and managing the workforce.

   A similar framework could be developed for quantum to distinguish how a technician could support different activities, applications, and modalities. There are multiple potential benefits of creating such a framework:

   - Establish closer alignment between educators and industry to clarify what KSAs are most critical for each part of the ecosystem; educators can better tailor their programs accordingly.
   - Provide students and reskilling candidates with a clearer understanding of the breadth of roles available to them in the quantum industry, including opportunities for career growth and advancement.
   - Demystify job requirements by providing more specificity about the functional tasks a quantum technician would perform; help reskilling candidates more easily recognize that they have relevant expertise (e.g., "if you can turn wrenches, apply").
   - Make roles more tangible and therefore more easily marketed (e.g., via ad campaigns or day-in-the-life YouTube videos) to build awareness with current prospects as well as at the K-12 level.

2. **Map existing training programs versus defined KSAs**

   Many existing training programs in adjacent fields include KSAs relevant to quantum in their curricula; however, awareness of the current landscape of options is incomplete. Mapping existing associate, bachelor's, and certificate programs vs. the defined KSAs would illustrate where there is already strong coverage of the core skills. This could help the industry know where they can find qualified talent today (although they may still need to provide additional on-the-job training). Furthermore, this activity could surface opportunities to embed more quantum-specific content into existing programs to expand awareness across disciplines (e.g., optics, physics, or math).

3. **Build local partnerships between higher education, industry, and national labs**

   Co-location of community college training programs and industry / national labs jobs is critical given that many community college students generally will not choose to relocate for a job upon graduation. Closer partnerships between higher education and nearby employers can improve linkages between researchers, educators, and students, and clarify specific local skill requirements. These partnerships also improve insight into market demand so that academic institutions can confidently establish programs knowing that there is a local and immediate workforce need. Many examples of this kind of close collaboration between community colleges and industry exist in adjacent fields like semiconductors and photonics.

4. **Establish an accreditation program for quantum technology curricula**

   An accreditation program would further formalize skill requirements and ensure the quality and effectiveness of programs aimed at training quantum technicians. While there are a diverse range of skills that a quantum technician may employ, the accreditation program should aim to define the ~80% of skills that are common across the industry. Curricula should focus on skills that are unique to quantum – e.g., combination of vacuum, optics, and cryogenics systems – but further cross-industry discussion is warranted to define specific topics for inclusion. The accreditation program development process should also closely scrutinize what pre-requisites are truly required to ensure that the most difficult courses (for many students, e.g., math, programming) are only included if needed, to avoid arbitrarily cutting out otherwise qualified candidates. It may also be advantageous to establish programs with “micro credentials” where students can progressively gain skills over a shorter time period. This approach could expand the workforce pool by allowing students whose academic careers are interrupted to get a credential for the courses they did complete (e.g., soldering). Programs would ideally provide flexibility for students to enter the workforce immediately (with a terminal degree) or to go on to pursue bachelor’s, master’s or PhD programs.

5. **Expand teacher training programs across disciplines**

   In addition to standardizing curricula, providing further professional development for educators can better equip them to integrate quantum concepts into their courses. Outreach efforts should focus on a broad set of disciplines, including math, physics, chemistry, computer science, engineering, and others. Providing access to interactive training programs and / or hands-on research opportunities will build competency and excitement about introducing new quantum-related modules or programs.

   One possibility is to build on the National Science Foundation’s Research Experience for Teachers (RET) program. Research placements could occur at the quantum technology research labs at both universities and in industry.

   Programs should build off existing programs. The following summarizes example activities that fall into this area:

- Federally funded and private sector teacher professional development for K-12: This includes TeachQuantum (Midwest), Quantum Academy (Chicago), QuantumforAll (multiple states with IQC), QCaMP (southwest & west coast), QuEST (NYC), QubitXQubit, and more. Some of these programs offer on-site research experiences akin to RETs, and others are modeled from successful (non-research) professional development in the teacher community.
- Federally funded and industry-sponsored programs for expanding capacity at the undergraduate educator level: QuSTEAM aims to offer undergraduate educators course modules and professional development. The IBM HBCU program offers opportunities for undergraduate educators at historically black colleges and universities (HBCUs) and minority serving institutions (MSIs) to develop individual or institutional capacity for quantum science.
- The National Q-12 Education Partnership has developed a framework as the basis of formal curriculum development at the K-12 level. At the undergraduate level, a paper covering the design of future quantum engineering degree programs was published in IEEE Transactions in Education following a large-scale workshop.[4]

6. **Increase access to assets to enable hands-on learning opportunities**

   Employers and educators alike highlighted the importance of hands-on learning opportunities to build the requisite skills for most quantum technician roles; however, access to the appropriate experimental equipment and other assets was cited as a critical challenge for educational institutions primarily focusing on career and technical programs at the bachelor's level and below. Creative approaches are needed to expand access to equipment outside of the large research institutions. Options include:

- Further industry and academic collaboration could define what lower-cost experimental setups could be used to demonstrate quantum concepts. An estimated 80% of the critical hardware needed for education could represent approximately 20% of the cost of a fully equipped quantum lab. Ensuring that more institutions have access to this basic hardware will help facilitate hands-on learning.
- For the remaining ~20% of equipment, which may include high-cost items like dilution refrigerators, alternative access models should be considered. For example, in the past, the nanotechnology field established programs and partnerships between local community colleges and research institutions with state-of-the-art equipment.[5] While students at the community college learned on more basic experimental setups locally, they would complete a capstone project at the research institutions to gain hands-on experience. A similar hub-and-spoke model should be considered for quantum.
- Create an asset library, potentially at the state- level, to build awareness about what equipment exists. Better connectivity and understanding of what resource-constrained institutions need and what comparatively resource-rich research institutions have could create opportunities for collaboration or even loaner models. QED-C's connections with major universities and its active volunteer base could facilitate such a project.

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[4]A. Asfaw et al., "Building a Quantum Engineering Undergraduate Program," in IEEE Transactions on Education, vol. 65, no. 2, pp. 220-242, May 2022, doi: 10.1109/TE.2022.3144943.
[5]For example, see the Nanotechnology Applications and Career Knowledge (NACK) Resource Center, information available at https://www.cneu.psu.edu/nano4me/

7. **Expand co-ops and internship opportunities to non-graduate degree students, with greater emphasis on diversity, equity, and inclusion**

   Internships and co-ops are another great option to provide hands-on learning; however, most positions are filled by master's and PhD level students today. Most employers / sponsors are currently incented to hire these students because employers are focused on research, which is typically associated with more advanced degrees. Additional funding intentionally earmarked for education at other levels is needed, and should ideally encourage creation of internship opportunities across degree levels (associate, bachelor, master, and PhD). Close attention should also be paid to improving diversity, equity, and inclusion through these programs.

8. **Allocate more funding for institutions focused on training and education rather than research requirements**

   While there is a significant amount of funding for quantum research, most of that work is being completed at research institutions in advanced degree programs. Additional funding should be specifically allocated for education and training, and may be tailored to institutions such as community colleges or technical schools that are more likely to train the local quantum workforce, including technicians. One particular constraint is lack of administrative support to help secure grant funding (e.g., assistance with submitting proposals, other paperwork). Enabling access to such a resource – whether through state funding or the development of a program specifically targeting this need – could reduce one barrier for these institutions. Programs should also include some allocation of funding for marketing these quantum programs to prospective students in the local area to build awareness.

Conclusion

The quantum industry, while still nascent, is advancing rapidly. Given the time that it takes to develop new curricula and train the workforce, it is imperative to start planning for solutions to build the quantum technician workforce now. The recommendations of this report are intended to serve as a guide for program managers and policymakers who are shaping future public-private initiatives, as well as for educators in two-year and four-year educational institutions. QED-C hopes to continue to facilitate the dialogue among employers and educators to facilitate action on the proposed recommendations outlined above and to further advance workforce development efforts.

Appendix 1: Report Methodology

This report summarizes inputs from a QED-C workshop, a 2022 survey of QED-C members, stakeholder interviews, independent research, and community recommendations. It details perspectives and recommendations shared by a broad set of stakeholders in a two-day QED-C workshop that occurred on August 17 – 18, 2023 in Albuquerque, NM. Over 50 individuals from industry, academia, national labs, and other sectors of the quantum ecosystem contributed their expertise and views in the workshop or via 1:1 interviews.

The workshop began with two panel discussions that included representatives from the demand side (i.e., those hiring quantum technicians) and the supply side (i.e., those training the workforce who could fill quantum technician roles). The remainder of the workshop included a series of collaborative brainstorming sessions in breakout groups to populate a quantum technician workforce planning map. Each breakout group included 10 – 15 participants, including a mix of industry, academia, and national labs.

Facilitation Roadmap

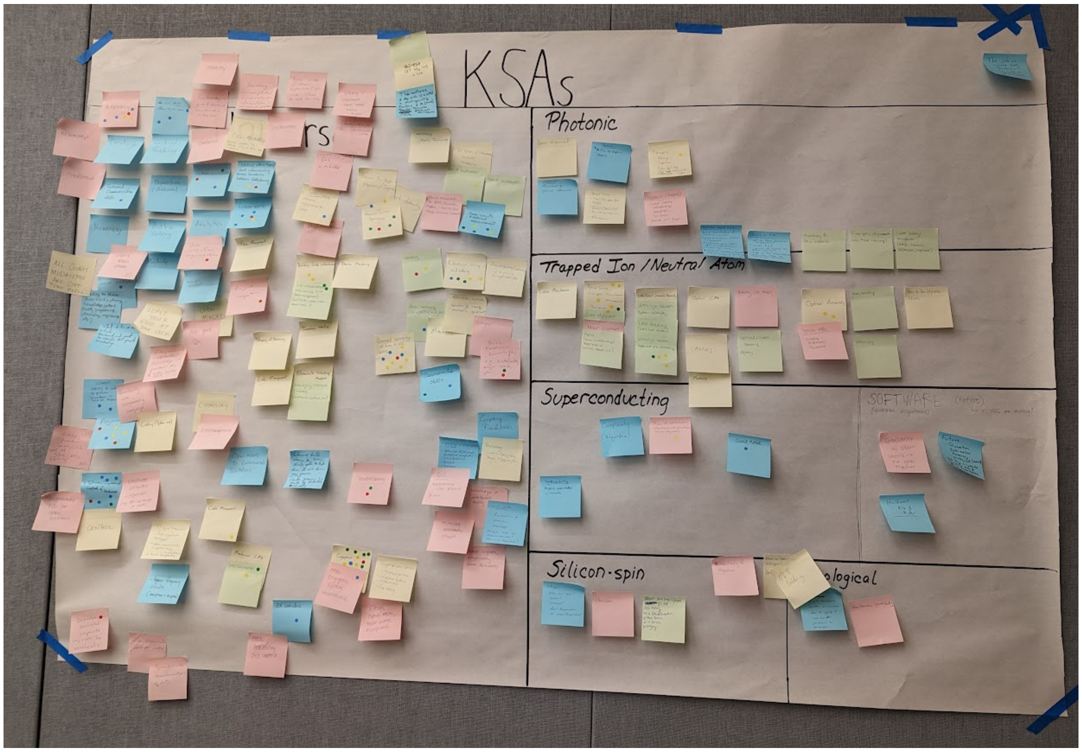
	Dimension	Current State	Desired / Future State	Gap	Recommendations
Demand *Finding the Ideal Candidate*	Demand for Quantum Technicians				
	Quantum Technician Roles & Responsibilities	Day 1 – Table 1			
	Hiring / Recruiting Process for Technicians				
Outcome *The Ideal Candidate*	Knowledge, Skills, and Abilities Needed for Quantum Technicians	Day 1 – Table 2			Day 2
Supply *Training the Ideal Candidate*	Training Programs for Upskilling Quantum Technicians	Day 1 – Table 3			
	Adjacent Industries and Targets for Reskilling Quantum Technicians				

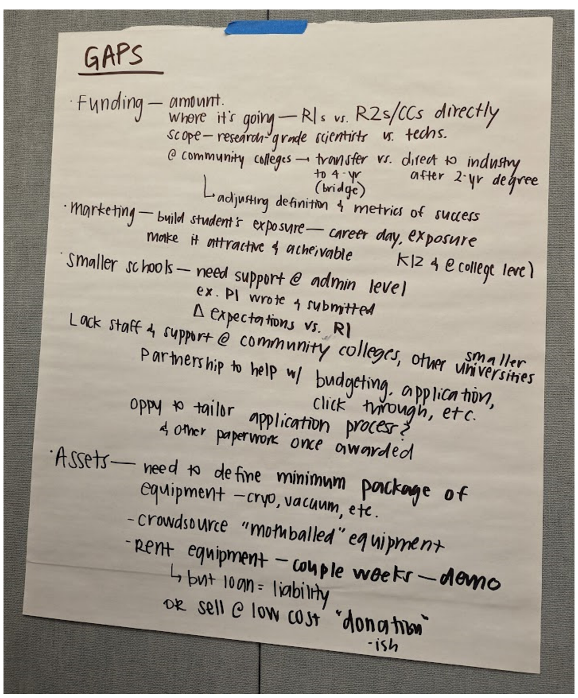
In the breakout groups, participants were asked to reflect on a series of questions:

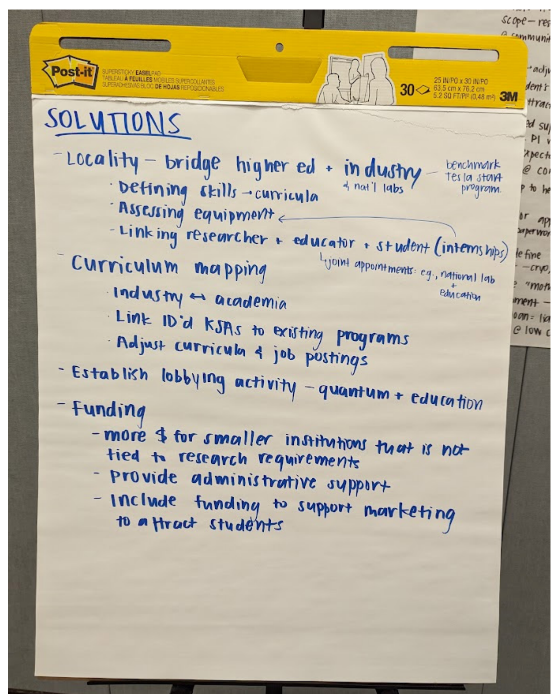
Demand: Finding the Ideal Candidate	• What trends are driving growth in the quantum landscape? What will technician jobs look like in 2025 vs. 2035? • What roles do technicians play? What functional tasks are they responsible for? • How do organizations seeking skilled technicians identify and recruit candidates? Are there specific programs or resources that are useful? • What are examples of successful industry-academic partnerships in other fields? • What industries have similar skill requirements that could be targeted for reskilling?
Outcome: The Ideal Candidate	• What knowledge, skills, and abilities would a skilled quantum technician have to help meet your current / emerging workforce needs? How might the requisite skills vary by modality (e.g., atom / ion vs. superconducting vs. photonic) and application? • Which skills are most critical? • Which skills could be learned on the job? How could you assess aptitude?
Supply: Training the Ideal Candidate	• What approaches have been used to train quantum technicians? • What elements of in-house trainings have been successful? • What specific external / academic programs are available? • If you were going to design the ideal curriculum, what would you include?

Participants shared and debated their views in a series of facilitated discussions. Individuals contributed their own ideas via post-it notes, and then summary recommendations were developed by the group.

Example Raw Workshop Output







Workshop participants were asked to propose solutions to address the identified gaps. Eight recommendations emerged, spanning a variety of topics and implementation timescales.

Appendix 2: CISP Methodology

To conduct this analysis, SRI leveraged the National Labor Exchange (NLx) database, a data repository maintained by the National Association of State Workforce Agencies that contains job postings collected by state workforce agencies and scraped from the web. SRI analyzed job postings from the database covering the period from January 2019 to May 2023 for all 50 states and the District of Columbia. SRI conducted two rounds of analysis, the first to prepare the pre-read materials and the second to incorporate feedback from the workshop.

For the first analysis, SRI identified jobs relating to the quantum workforce by filtering to jobs that contained the word "quantum" in the job title or several times in the job description. SRI then classified job postings by their education requirements and limited the dataset to those jobs that did not require a graduate degree. The full NLx dataset for this time period contains more than 50 million job postings, so the initial approach used a conservative definition of quantum jobs to minimize inclusion of unrelated postings that would create noise in the data. The dataset of quantum jobs used in this analysis included 1,958 job postings from 180 companies, before filtering by required education level to look only at job postings for quantum technicians.

Following the workshop, SRI expanded the criteria in the updated analysis by including jobs from any company with "quantum" or "qubit" in the company title and by adding any job that used both the words "qubit" and "quantum" at least once each. This update added 874 jobs from 94 companies, before filtering by required education level and relevance to the quantum workforce.

Our sample coverage was limited in the overlap between firms present in the job postings dataset, QED-C members, and workshop attendees. Of firms that participated in the workshop, only 14% were represented in the jobs postings dataset. There were also only 14% of QED-C members represented in the dataset. Finally, 74% of firms in the job postings dataset were neither workshop attendees nor QED-C members. A contributing factor to the limited overlap is that our dataset contains no federal government jobs, though jobs at national labs are well-represented in the data.

Jobs that listed accepting candidates with either a bachelor's degree or a master's degree were included. In total, there were 872 quantum technician job postings included in SRI's first analysis. Because the updated analysis had more relaxed inclusion criteria, SRI performed an additional relevance check where an analyst manually labeled jobs as related to the quantum workforce. Filtering for relevancy reduced the newly identified jobs to 405, of which 172 did not require a graduate degree. Our full dataset therefore consisted of 1,044 jobs from 199 companies.

Skills were obtained by first classifying job posting sections using a machine learning tool called bidirectional encoder representations from transformers (BERT) and filtering to sentences predicted to be from the required skills portions of job postings. SRI conducted topic modeling using BERTopic on the predicted skills-related sentences from postings. The identified topics were used to create skill clusters, and additional frequency analysis was conducted to identify specific skills within modeled topics, such as particular programming languages.

Appendix 3: QED-C Workforce and Education Survey Results

QED-C conducted a survey of its member organizations in November 2022 to understand workforce and education needs. Forty-two organizations responded. Respondents primarily represented:

- Hardware system developer for quantum computers (24%)
- Algorithm / software provider (15%)
- Education (12%)
- Enabling hardware components (e.g., lasers) (10%)
- Professional services (10%)

Survey Questions

1. Do you currently employ technicians with quantum knowledge in your research labs or production facilities?
    - Yes
    - No
2. Do you anticipate need for your organization to employ technicians with quantum skills?
    - Yes, immediately needed
    - Yes, in a few years
    - No
3. Currently, how much work do your researchers (engineers) perform that could otherwise be done by technicians (tasks that do not require advanced degrees at Bachelor level and above)?
    - Below 25%
    - 25-50%
    - Above 50%
4. Would you be interested in the upskilling of your current technician workforce (or other employees) with new quantum skills and competencies?
    - Yes
    - No
5. How much time per week could the currently employed technicians invest in the quantum upskilling during regular working hours?
    - None
    - 2 hours
    - 4 hours
    - Only outside work (evening, weekend)

6. What format of quantum training would your organization be interested to provide to the currently employed technicians? (check all that apply)
    - None
    - One-week on-site workshop
    - One-semester course at a local community college
    - Four course quantum technician certificate (includes non-calculus courses such as quantum fundamentals, hardware, computing, or similar)
7. What financial structure would your organization support to cover expenses of such quantum training? (check all that apply)
    - Through corporate tuition reimbursement or similar
    - Employees covering on their own
    - Other means of support

Summary of Survey Responses

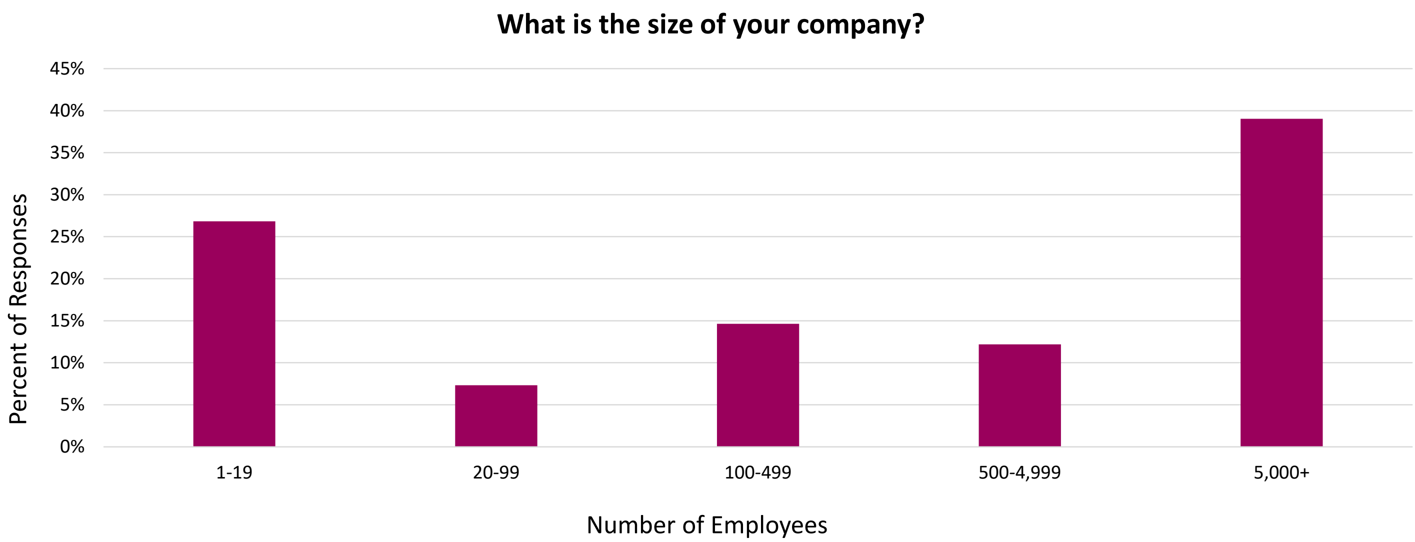
Current Technician Workforce

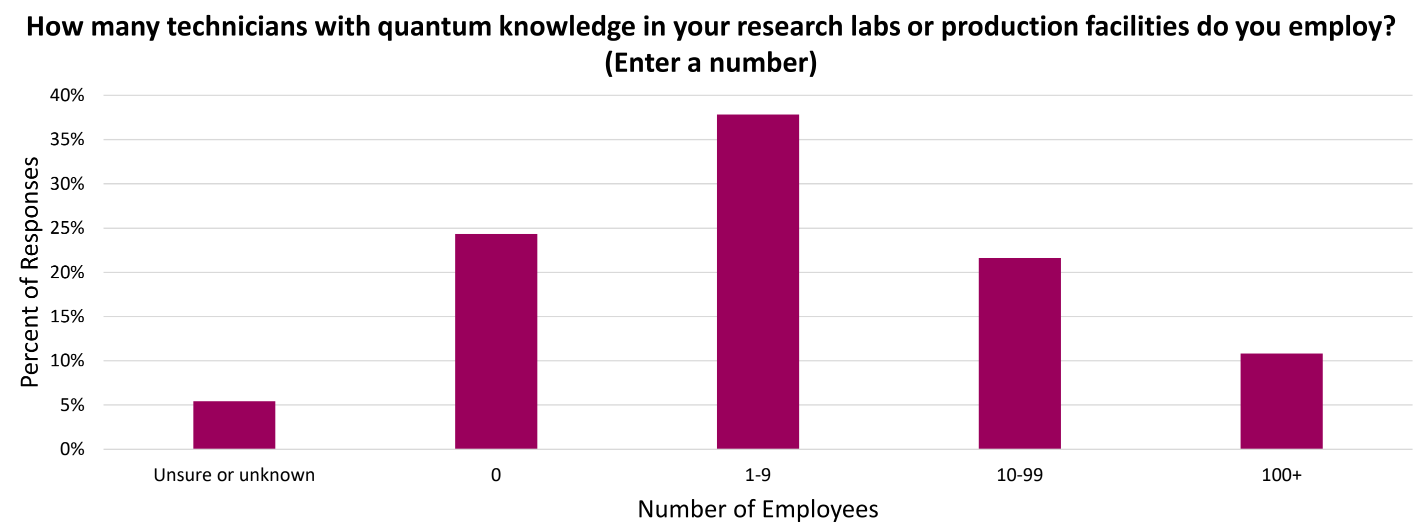
- Quantum knowledge is important to respondents; 95% reported they employ at least one technician with quantum knowledge
- Most respondents anticipate needing to hire more technicians with quantum skills, either immediately (46%) or in a few years (43%)
- Almost half of respondents say at least 25% of the work currently performed by engineers can be done by technicians

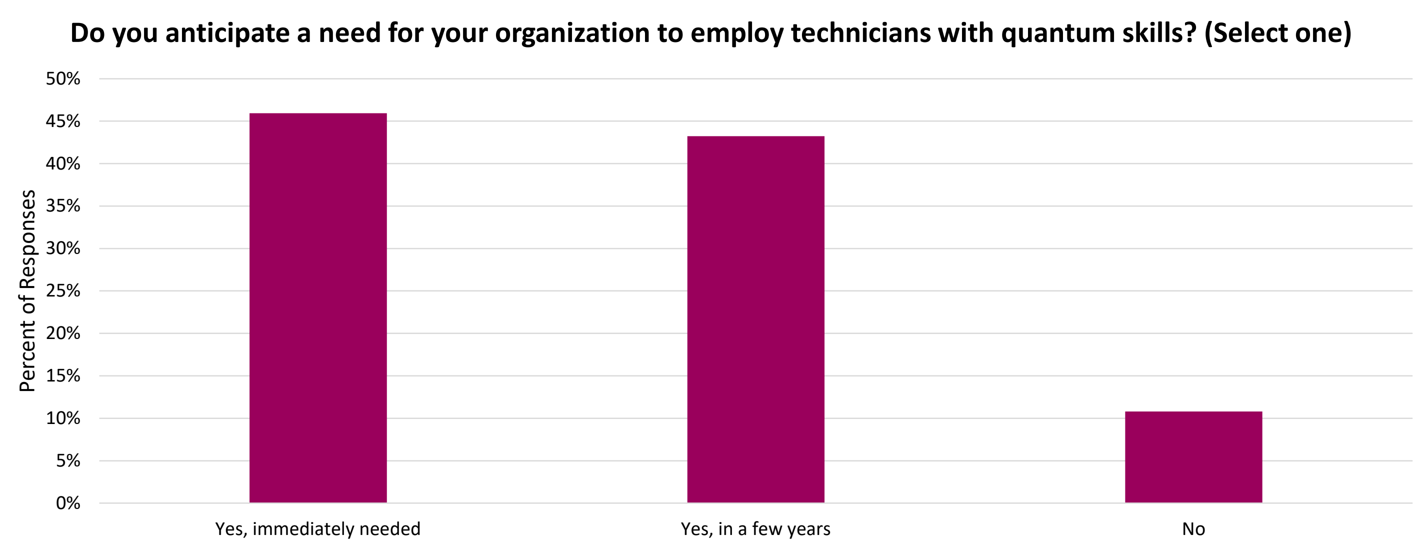
Training and Workforce Development

- 84% of respondents report interest in upskilling their current technician workforce with new quantum skills and competencies
- Over 80% of respondents believe they can structure quantum upskilling during regular work hours for their current and future technicians
- Given multi-select options, respondents prefer offering one-week on-site workshops (55%) or four-course quantum technician certificates (55%) to upskill their current and future workforce
- Only 21% of respondents anticipate employees covering their own quantum training expenses. The majority selected corporate tuition reimbursement structures or other means of support to cover training expenses
- Over two-thirds of respondents (64%) report they're interested in working with community colleges and university partners to stand up new technician programs, and 70% of those respondents shared their contact information for future communication

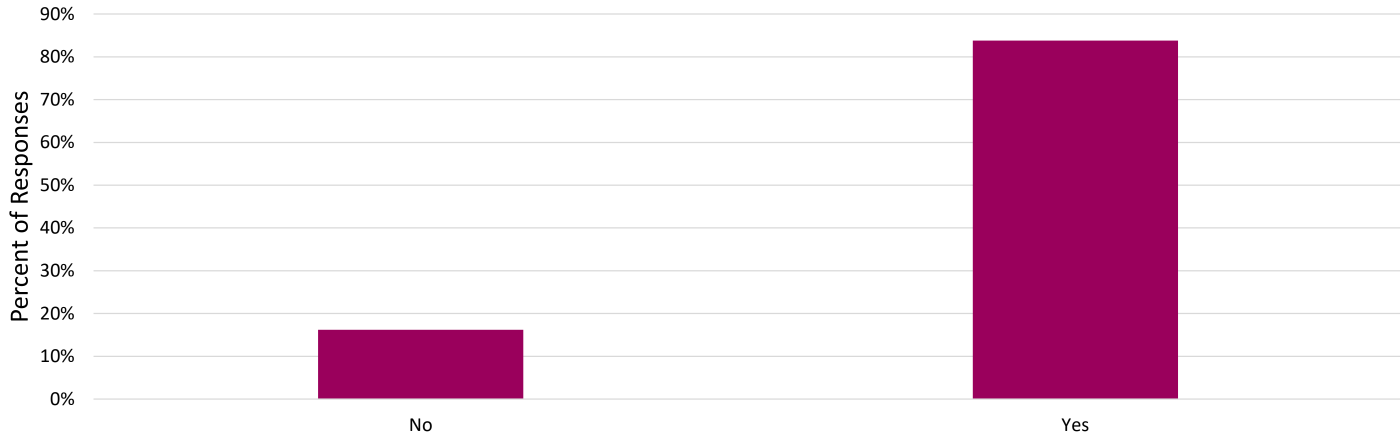
Survey Exhibits



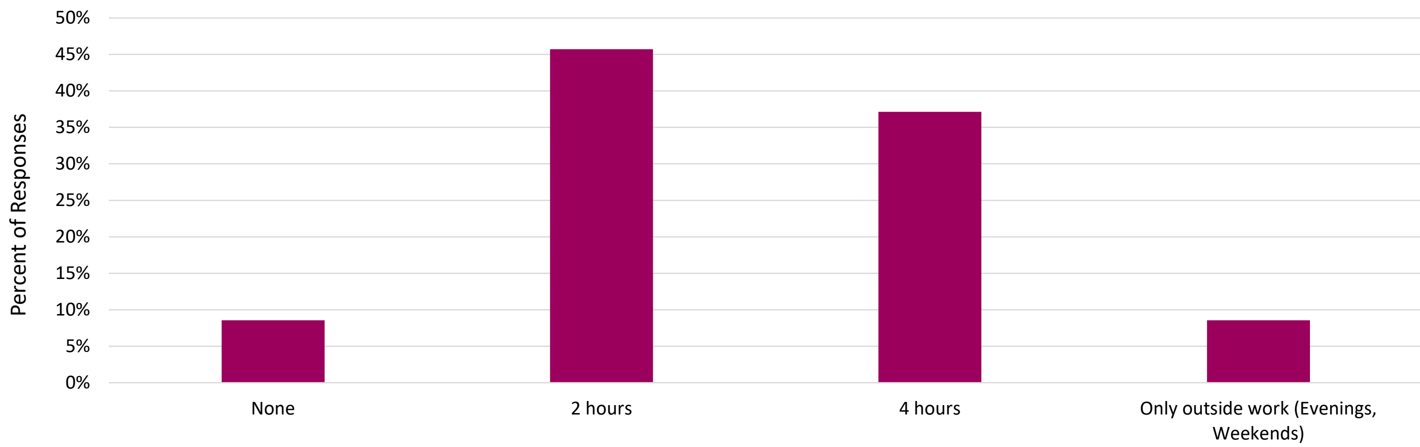




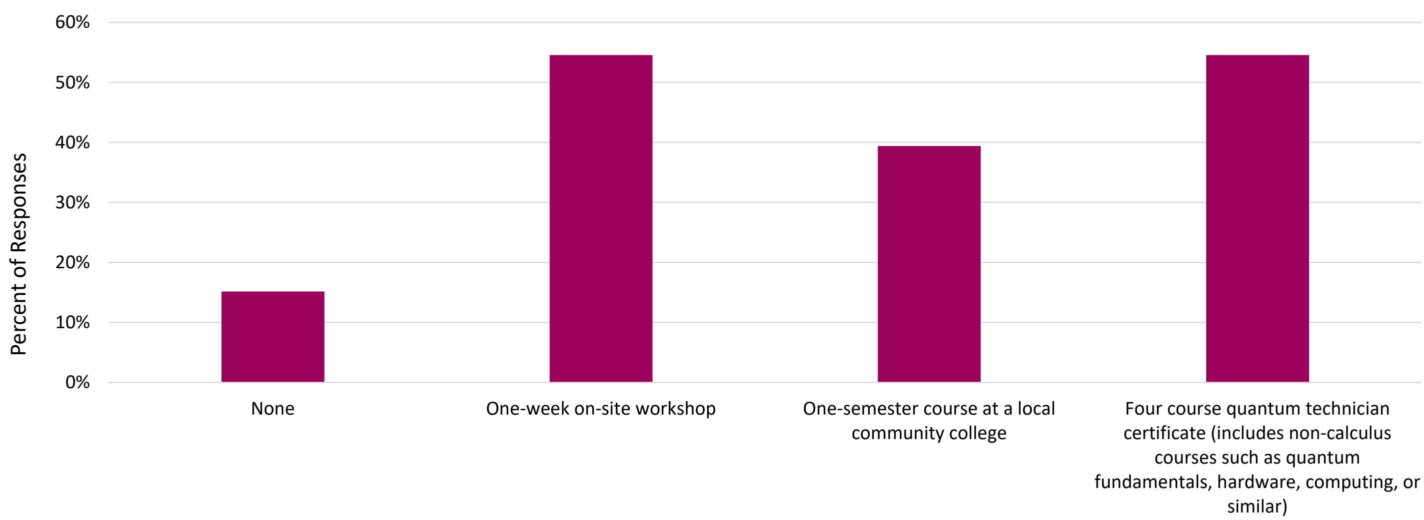
Would you be interested in the upskilling of your current technician workforce (or other employees) with new quantum skills and competencies? (Select one)

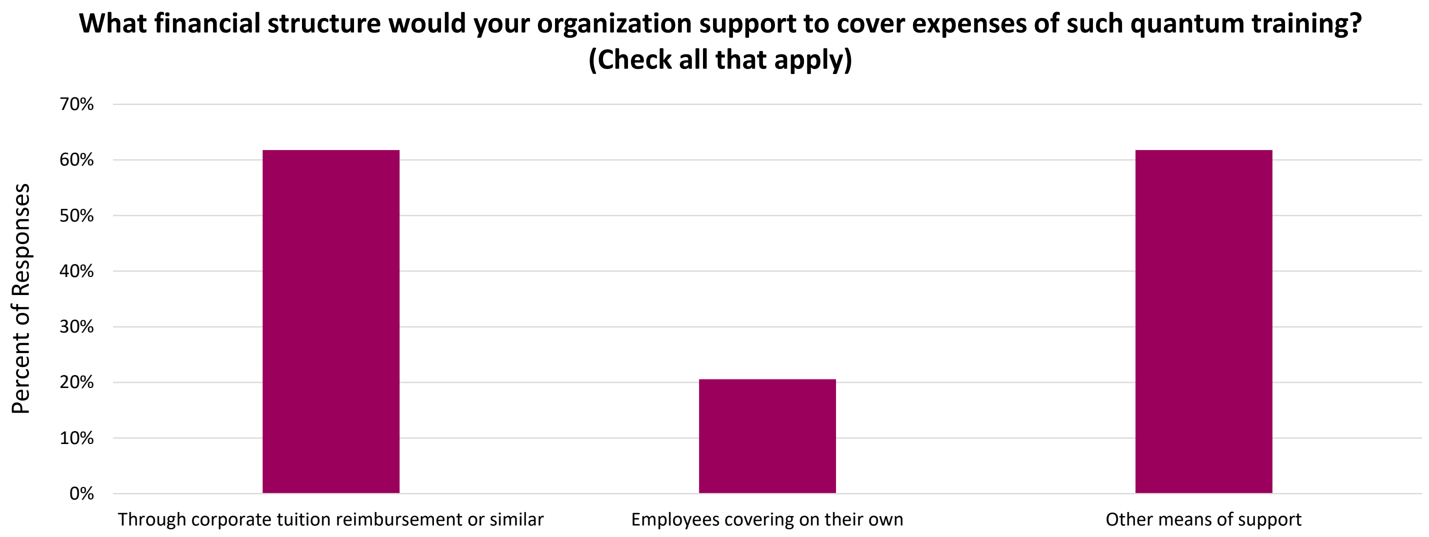


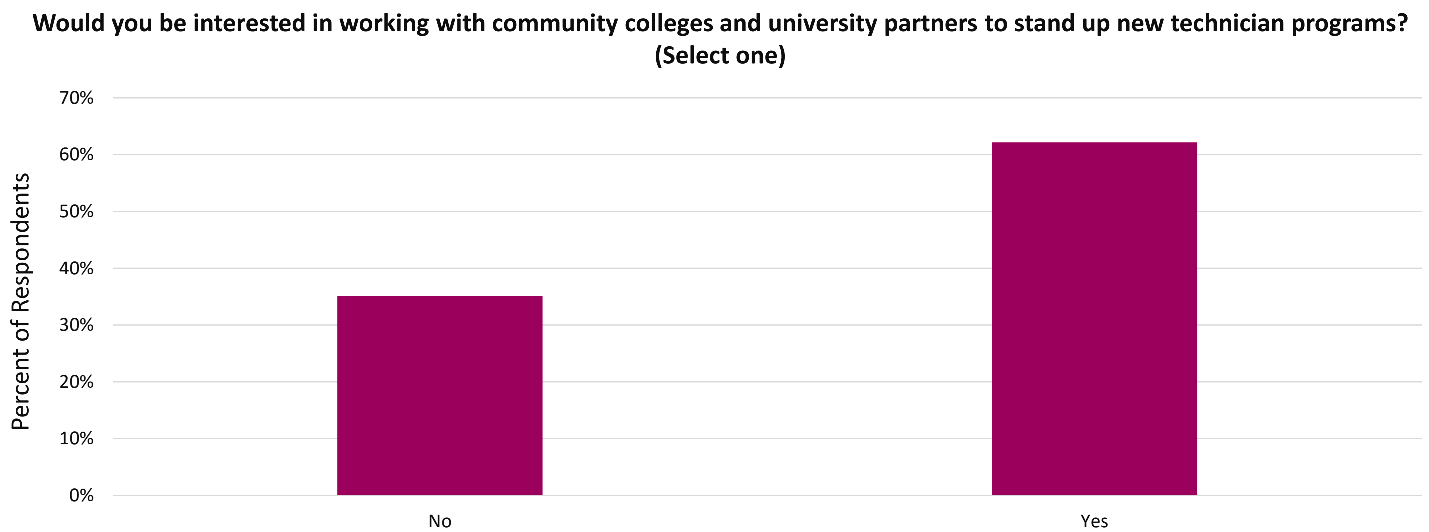
How much time per week could the currently employed or future technicians invest in the quantum upskilling during regular working hours?



What format of quantum training would your organization be interested to provide to the currently employed or future technicians? (Check all that apply)




What financial structure would your organization support to cover expenses of such quantum training? (Check all that apply)
Percent of Responses
70%
60%
50%
40%
30%
20%
10%
0%
Through corporate tuition reimbursement or similar
Employees covering on their own
Other means of support


Would you be interested in working with community colleges and university partners to stand up new technician programs? (Select one)
Percent of Respondents
70%
60%
50%
40%
30%
20%
10%
0%
No
Yes

Appendix 4: Workshop Participant and Interviewee List

Thank you to the following participants at the August 2023 workshop and interviewees for sharing their time and perspectives:

- Jared Ashcroft, Pasadena City College
- Boris Blinov, University of Washington
- Peter Bordow, Wells Fargo
- Reese Brown, Quantinuum
- Bennett Brown, QuSTEAM
- Wojtek Chodzko-Zajko, University of Illinois
- Emily CoBabe-Ammann, CU Boulder
- Kasey Correnti, Newry Corp
- Zheng Cui, Boston Consulting Group
- Bert de Jong, Lawrence Berkeley National Laboratory
- Ivan Deutsch, University of New Mexico
- Jake Douglass, Sandia National Laboratories
- Charlotte Evans, Sandia National Laboratories
- Amy Fritz, Newry Corp
- Andrew Gartley, Newry Corp
- Adrian German, University of Indiana
- Jeff Hall, New Mexico Economic Development Dept.
- Mo Hasanovic, Indian River State College
- Travis Humble, Oak Ridge National Laboratory
- Megan Ivory, Sandia National Laboratories
- Brian Kasch, U.S. Space Force
- Boris Kiefer, New Mexico State University
- Michelle Lampa, Riverlane
- Phil Lister, Central New Mexico Community College
- Anjul Loiacono, Infleqtion
- Chris Lynberg, Centers for Disease Control & Prevention
- Celia Merzbacher, QED-C | SRI International
- Ines Montano, Northern Arizona University
- Rick Muller, Sandia National Laboratories
- Humberto Munoz Barona, Southern University and A&M College-Baton Rouge
- Kiera Peltz, Qubit by Qubit
- Justin Perron, Cal State - San Marcos
- Mike Rabin, Los Alamos National Laboratory
- Tim Rambo, Quantum Opus
- Brian Rashap, CNM Ingenuity
- Scott Rommel, Vescent Photonics
- Samuel Serna Otalvaro, Bridgewater State University
- Christian Servin, El Paso Community College
- Daniel Stack, Atom Computing
- Jeff Stapleton, Wells Fargo
- David Stewart, Purdue University
- Corban Tillemann-Dick, Maybell Quantum
- Erin Weeks, QED-C | SRI International
- Laura Wessing, AFRL
- Steven Wignall, University of Nebrasksa - Lincoln
- Evangeline Williams, CJW Quantum