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# *Creating a Colorado Quantum-Ready Workforce in Service of the Nation*

## Introduction

The last several years have brought both definition and a sense of urgency to the development of the workforce needed to support Quantum Information Science and Technology (QIST) in the United States[1,2], both as an economic and a national security imperative. The recently released national strategic plan for QIST workforce development[3], outlines clear steps needed to develop a deeper understanding of QIST workforce needs, address QIST-specific gaps in education and training opportunities, increase the awareness and accessibility of careers in QIST and related fields, and introduce broader audiences to QIST through public outreach. In 2022, to support this national framing, the Quantum Economic Development Consortium (QED-C), the largest quantum industry consortium in the world, surveyed its members to better understand both the demand and the required skills on the QIST horizon, paying particular attention to the role of the professional technician in the QIST ecosystem. ***With these efforts as the backdrop, how can the State of Colorado, a national leader in QIST industry, research, and education, translate its expertise, assets, and infrastructure into a cohesive workforce pipeline for both the Mountain West and the nation? How can we design that pipeline that reaches students and workers where they are, professionally and geographically, to create a diverse and inclusive quantum-ready workforce?***

To start this conversation, the University of Colorado Boulder and Colorado's Office of Economic Development and International Trade (OEDIT) convened a workshop of higher education, industry, national laboratory, and government stakeholders in October 2023. The goal was to develop a statement of skills required, a picture of what a robust state and regional QIST workforce pipeline would look like, what assets and efforts stakeholders already had in place, and what they were interested in and capable of building together over the next 3-5 years. Building off of the work of the QED-C, the convening emphasized the role of non-PhD quantum workers, including professional technicians, and focused on the connections between K-12, community colleges, smaller four-year universities, and research-intensive universities.

QIST is a rapidly evolving field requiring a wide range of technical architectures. Intentional and functional connections between these institutions across Colorado, along with adequate financial resources from the State and elsewhere, is critical to ensuring that

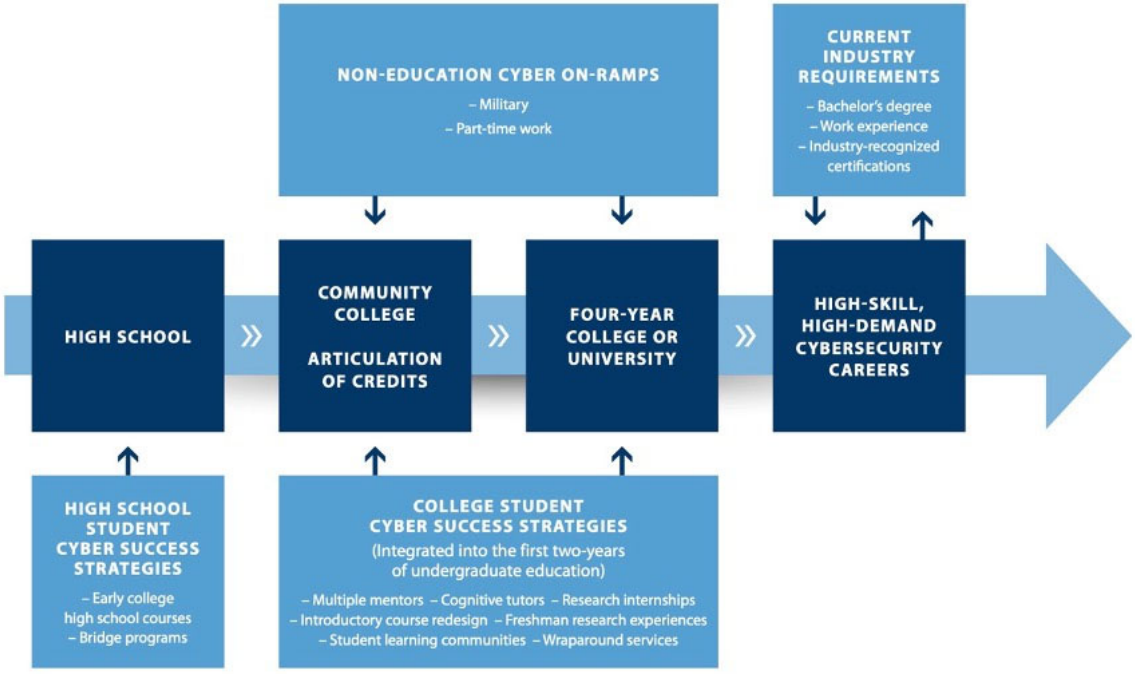
[1] https://www.quantum.gov/wp-content/uploads/2020/10/2018_NSTC_National_Strategic_Overview_QIS.pdf
[2] https://www.quantum.gov/wp-content/uploads/2020/10/QuantumFrontiers.pdf
[3] https://www.quantum.gov/wp-content/uploads/2022/02/QIST-Natl-Workforce-Plan.pdf

Colorado's QIST leadership in research and development can be translated into a robust workforce that supports not only Colorado industries, but the nation's QIST economy. With the designation of *ElevateQuantum!* as an EDA TechHub[4], Colorado has a unique opportunity to integrate its QIST workforce pipeline development into the national QIST infrastructure.

**Emerging Themes**

Throughout the discussion, several themes emerged that, together, begin to identify what a successful quantum workforce pipeline could look like. These themes are not unique to Colorado, but rather (reassuringly) align with national trends and QED-C findings for QIST workforce development. They also mirror successful state-level coordinated workforce efforts from other sectors, such as Maryland's partnership with BHEF to build a cohesive workforce pipeline in cybersecurity[5]. These themes presented here start with higher-level ideas and gradually work down through more specific (not necessarily less important) ideas and keys for success in creating a diverse, accessible workforce pipeline in the state.

***Figure 1. Maryland's Integrated Workforce Development Model for Cybersecurity[5]***




***Theme 1: Creating cohesiveness and connection***

A successful and functioning QIST workforce ecosystem in Colorado requires an intentional and supported effort to align, develop and help implement a cogent QIST educational framework, based on a common set of Knowledge, Skills, and Abilities (KSAs). Key aspects of this effort could include:

- A distributed leadership team empowered with a collaboration model for non-competitive coordination, along with key stakeholders from participating institutions, as well as industry subject matter experts.

[4] https://www.denverpost.com/2023/10/20/colorado-designated-as-tech-hub-quantum-chips/
[5] https://www.bhef.com/sites/default/files/BHEF_2014_maryland%281%29.pdf

- A focal point of exchange, ensuring that Colorado's quantum efforts extend beyond the borders to adjacent states and the Mountain West and allows straightforward migration of other states' successful models into Colorado.
- Quantum Community Coalition of educators and other stakeholders across the state with cohorts 'owning' specific pieces of the ecosystem, as well as creating collaboration opportunities for their constituents. The Coalition worked to create a shared set of goals and language around QIST workforce development.
- Intentional pathways of development for QIST that starts with community colleges and leads to Colorado School of Mines, CSU and CU Boulder.
- Common curricula aligned with identified, industry-driven KSAs (both technical and durable skills) (see Theme 2). Key courses have shared syllabus, learning goals, labs, etc., sharing the workload across the stakeholders and creating a degree of uniformity (e.g., hands-on cryogenics training at one college has the same basic structure and learning goals as that taught at another.) Includes a Quantum Concepts course at all community colleges in Colorado. These efforts could be exported to other parts of the country.
- Coordinated system for sharing industry engagement across K-12, 2- and 4-yr, and research-intensive universities.
- Identify how the KSAs for quantum could be used in adjacent industries (e.g., semiconductors), broadening the opportunities for students and workers participating.

***The Portfolio of Quantum Education and Training Ideas***

Beyond traditional Bachelors, Masters and PhD in quantum-related/adjacent fields, workforce development encompasses a broad range of alternative credentialing that should be considered as part of Colorado's approach, including:

• Quantum minors, based on the needs of QIST jobs
• Critical and Emerging Technology minor
• Badging, certificates, micro- and stackable credentials, digital wallet of verifiable credentials
• Industry-focused/designed capstones for all levels of student
• Quantum certificates and micro-Masters for business majors, law students, program management
• End-to-end quantum business pipeline education, from idea to market
• Bring quantum into University 101 courses
• Concurrent enrollment options for high school students that can be stacked from certificate to AAs to BAs, with ultimate flexibility for both on-ramps and off-ramps

***Theme 2: Industry-driven learning objectives that lead to credentialing equivalents across institutions***

Throughout the discussion, the idea of industry-driven, skills-based education that connects training (upskilling and reskilling) to industry needs resonated strongly. This connection is particularly critical, given how quickly the field (and therefore industry needs) are changing. Additionally, there is a strong sense that, if this industry-academic partnership can be effectively functionalized, there are significant workforce-related federal and foundational resources available to support it. The ideas generated fell into two categories:

- ***Industry partners work with educators on the development of curriculum KSAs:*** The Community Coalition (or its equivalent) and industry stakeholders together identify critical KSAs and career-relevant learning objectives and how best to incorporate them into a curricular sequence. Define with clarity what distinguishes the quantum workforce from traditional/related workforce. And consider reverse engineering courses, starting with the needed skills.
- ***Industry as a center of training, particularly for fast-fuse industry-focused credentialing:*** Given the specialization of the instrumentation and facilities, industry partners can be more than the driver of KSAs, they can serve as an important center of gravity for professional training. Ideas included:
    - One-off/light touch professional development (e.g., hackathons, quantum industry seminars)
    - Short-term/intensive hands-on experiences (e.g., Quantum summer camps, short courses)
    - Industry-led credentials/certifications (like electricians) emphasizing project-based learning
    - Industry-centered 4-course professional master's program
    - Work-based learning, including internships, apprenticeships, industry-sponsored projects

Inherent in this notion will be a novel financial model that allows revenue sharing between academic and industry partners to enable industry participation.

***Theme 3: Accessing Hands-On Laboratory Infrastructure….and when you can't***

A serious challenge of QIST workforce development is that it requires hands-on training with infrastructure and instrumentation that can be expensive and is changing rapidly. How do we implement hands-on practices in program development with appropriate infrastructure across the state? Developing dedicated teaching spaces with sufficient technology and knowledgeable supervision will be key to Colorado's success in building an effective QIST workforce pipeline. Several approaches could be considered:

- Industry-centered training (See Theme 2)
- State-supported/industry-invested Quantum Training Centers, including nano-fabrication facilities and other hardware platforms. This could include augmentation of advanced manufacturing training centers in the state. Shared user facilities that could be used for training but could also be used by quantum start-ups in the state.

- Shared equipment networks, whereby decommissioned instrumentation from industry could be re-purposed for education and training.

While it is clear there is a need to invest significant resources into hardware platforms for training purposes and that these platforms are more useful than less-costly simulation platforms, there is a role for virtual platforms and simulations in training in a wide-range of quantum-related labs. This is a particularly important idea when connecting quantum research expertise, which is concentrated in the Front Range, to students and workers located in other parts of the state.

***Theme 4: The Criticality of Effective Training of Instructors across Colorado***

The success of the Colorado quantum workforce pipeline hinges on having instructors that are effectively trained and updated in quantum-related technologies. This is a steep hill to climb, particularly for community colleges and small institutions sitting outside the Front Range. Additionally, it should be recognized that these efforts will require intentional and dedicated funding and support to achieve. There is a need for state-level quantum educator pipelines, which could include:

- Pipeline programs and credentialing for quantum instructors, specifically designed to support Colorado's community colleges
- A system for sharing and/or sourcing faculty and part-time instructors, including offering incentives for industry partners to provide their employees as instructors
- Mini-sabbaticals in industry for instructors
- An annual conference for quantum educators

***Big Idea:*** Cohort training, state-wide: Bring quantum researchers, educators and industry from Front Range out to centers of gravity around the state (think Greeley, Durango, Grand Junction, etc.). Training quantum adjacent fields instructors and faculty (e.g., math, chem, etc.) about the WHY of quantum and how to embed quantum into their curriculum. Add side meetings with local govt and industry to support and engage.

***Theme 5: How to Inspire and Raise Awareness – The Power of the Story***

Time and again, during workforce discussions at the national level, within QED-C efforts and again in Colorado, the challenges of the story, messaging, and awareness of quantum – what it is and what it means in our day-to-day life – is a consistent theme. Intangible and not currently part of our collective experience, quantum and its importance has been difficult to convey to diverse communities, students and workers needed to support the quantum economy. Several targeted efforts were identified to the transition to the quantum economy.

- **K-12 awareness/inspiration:** The quantum pipeline starts with K-12 students and educators. Illuminating quantum career pathways early, using research-based best practices, through stories, examples of success and diverse experiences starts to articulate social capital in terms of the values for learners. Building on those stories to create career-aligned learning activities for K-12 students, aligned with state and national education standards, will provide critical scaffolding for students' understanding of quantum and its practical applications. Providing, through national

and state quantum education clearinghouses, K-12 quantum education materials, quantum-to-go lectures, access to in-person demos for students and field trips to quantum laboratories and companies, and ideas for harnessing school robotics and machine shops will begin to build K-12 capacity for quantum awareness and inspiration. Lastly, tying the awareness of quantum and quantum careers to offerings at community colleges and 4-year colleges and universities gives students an actionable pathway into the quantum economy.

- **Beyond the classroom: Quantum everywhere, all the time -- and hands-on wherever possible**: Education is never restricted to the classroom. Informal education venues offer critical opportunities for raising awareness and elucidating career pathways for students. Museums (e.g., Denver Museum of Nature and Science, Discovery Museum, Children's Museum, Denver Museum of Art) and libraries with access to books, AV, and programming) are valued and trusted community centers of knowledge where quantum messages and information can be put forward. One could get even more creative:
    - A Quantum Festival
    - The Quantum Bus with pop-up labs that travel to various underserved communities as an introduction
    - A quantum version of CSU's Little Shop of Physics
    - A Quantum Roadshow with quantum-themed events/activities for youngsters at local libraries elementary/middle schools, etc.
    - Ready-made mailable quantum learning kits
    - Qubit x Qubit = early quantum career immersion opportunity
    - Quantum gaming
    - Quantum Barbie, Oppen-Ken – Quantum toys

- **For the general population:** Key to becoming quantum-forward is making quantum easily understood by mainstream population to help convey the excitement and awe of quantum. To do this, it requires developing a cadre of communicators with an understanding of QIST, along with a set of quantum communication assets (e.g., slides, videos, content, tools) that spark interest, dispel myths, and show the value of QIST.
    - Professional development experiences for media
    - Professional development workshops for policy makers, with the goal of education but also communicating the value proposition and common goals of QIST to the state and the nation
    - Community outreach supported by industry – dedicate one day a month go outside and talk to students and community groups, with prepared/vetted decks to support

**Systemic Solutions**

To build an effective, state-level, coordinated quantum education pipeline means novel approaches for overcoming the historical competition both within and between higher education institutions. The Quantum Community Coalition has to have the ability, messages and resources to incentivize participation and buy in of higher education administration. The case for quantum is compelling for students and for the state, but it will require intentional engagement by QIST researchers, higher education, industry, and state officials of the stakeholders across the ecosystem to motivate participation and flexibility to create a functional quantum workforce network.

Beyond well documented concerns about student financial stability, wrap around services, and the challenges of a traditional academic calendar and work week can pose for some students, quantum workforce ecosystem in the state would benefit from:

- Consider adding skills-based transcripts that connects assessment to specific skills into the mix, including learning & education record (LER) attributes
- Consider creating a clearinghouse that provides a 'One Stop Shop' for students interested in QIST, including list of academic programs for prospective students, career network that connects students to companies hiring,
- Look at a single application process for high school students that feed into all of the Stat's quantum options; support these pathways with quantum mentors who act as ambassadors
- Remove focus of long-term 'completion' (2-yr degree, 4-yr degree, etc.), and create more off-ramps and clearer iteration of degree progressions
- Guarantee transfer courses from community colleges/programs to 4-year partners.
- Consider a Quantum Education Investment Corps to incubate student venture ideas, educational advances, including private equity, banks, govt, foundations

**Next Steps**

The summary of ideas here emerged over the course of the October 2023 workforce convening. The next stage of this effort is to bring together a group of empowered stakeholders to build a roadmap that, once implemented, will lead to an effective and coordinated QIST workforce pipeline for Colorado and the Mountain West. The road mapping work will begin in the spring of 2024 and is anticipated to be presented to the State by Fall of 2024 for further consideration.

We, signing below, agree to support the vision outlined in this document.

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