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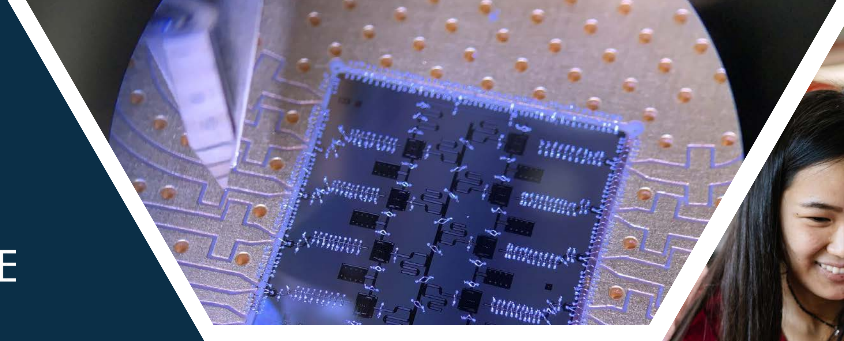

Navigating skills and talent development for quantum technology

Current insights and future horizons

Salil Gunashekar and
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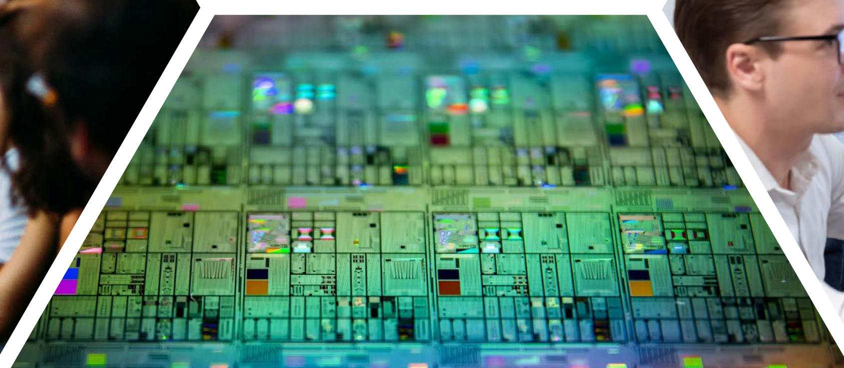

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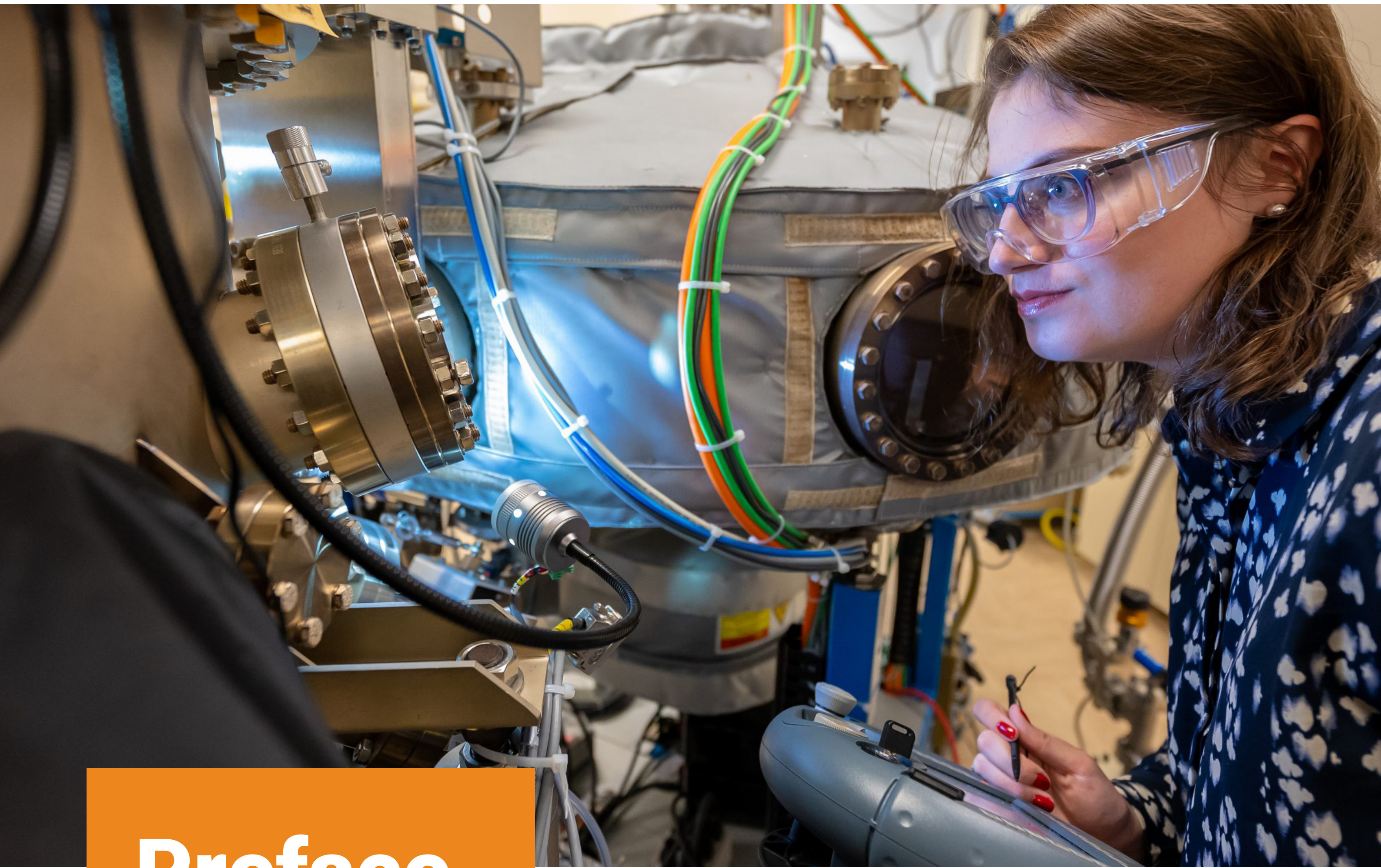

Preface

On 10 October 2024, RAND Europe and the Novo Nordisk Foundation co-hosted a roundtable discussion in Copenhagen to explore key aspects of the quantum technology ecosystem, given the rapid global advancements in cutting-edge research and innovation in the field. This was the second in a series of events aimed at bringing together thought leaders, researchers, industry experts and policymakers who are committed to helping responsibly shape the future of quantum technologies. The inaugural roundtable had taken place in London in November 2023, where discussions centred on ideas for promoting innovation while ensuring a safe and equitable future enabled by quantum technologies. The focus of this roundtable was on two critical issues that are likely to influence the direction of this rapidly progressing field: the development of skills and talent, and the strengthening of supply chains.

This short report provides a summary and overview of the discussions and insights from the skills and talent component of the roundtable. We find that the global quantum technology ecosystem is becoming increasingly diverse, integrating various expertise and disciplines, yet faces challenges to the availability and distribution of necessary skills. To build a sustainable talent pipeline, a coordinated, long-term approach involving enhanced educational programmes and multistakeholder collaboration was highlighted as essential to strategically improving quantum literacy and workforce readiness.

Drawing on the discussions, we propose a selection of policy considerations and associated enabling actions that stakeholders within the broader quantum technology ecosystem could take to address issues related to skills, talent and workforce development.

The policy considerations are organised into three clusters, each reflecting common themes: connecting, collaborating and community building; expanding and diversifying skills and perspectives; and approaching skills systems holistically with forward planning. Taken together, these policy considerations can be regarded as a set of cross-cutting principles intended to guide stakeholders in addressing challenges proactively and holistically, with the aim of developing a more resilient, equitable and future-ready quantum technology skills pipeline and workforce.

The analysis following the roundtable discussion reported here was internally funded by RAND Europe and has been peer-reviewed in accordance with RAND's quality assurance standards. This work is intended to inform the public good and should not be taken as a commercial endorsement of any product or service.

We extend our gratitude to the roundtable attendees for their participation and insightful contributions. Additionally, we wish to thank the quality assurance reviewers at RAND Europe, Hans Pung and Susan Guthrie, for their critical review of the report. Finally, we express our thanks to Jessica Plumridge and Georgina Melia for designing and laying out the report and Ruby Russell for her copyediting work.

RAND Europe is a not-for-profit research organisation that aims to improve policy and decision making in the public interest, through research and analysis. Our clients include European governments, institutions, non-governmental organisations and firms with a need for rigorous, independent, multidisciplinary analysis. This roundtable was delivered as part of RAND Europe's Frontiers of Technology Hub, where we pursue a proactive research agenda to anticipate and prepare stakeholders for emerging technologies and their impacts.

Novo Nordisk Foundation is a private, independent, philanthropic enterprise foundation. They provide grants and investment in the public sector for scientific, humanitarian, and social purposes. Their vision is to improve people's health and the sustainability of society and the planet. They have since 2019 been a key player in supporting and growing the Danish quantum ecosystem with grants, investments, partnerships and activities.

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Summary

In recent years, the capabilities of quantum technologies have advanced significantly, underscoring their potential applications across diverse fields, including the life sciences, finance, aerospace, defence, energy and telecommunications. In recognition of the centennial year of the development of quantum mechanics, the United Nations (UN) has designated 2025 as the International Year of Quantum Science and Technology, seeking to raise global awareness and understanding of quantum applications across various sectors. **Against this backdrop, on 10 October 2024, RAND Europe and the Novo Nordisk Foundation co-hosted a roundtable discussion in Copenhagen to explore key aspects of the quantum technology ecosystem, given the rapid global advancements in cutting-edge research and innovation in the field.** This was the second in a series of events aimed at bringing together thought leaders, researchers, industry experts and policymakers who are committed to helping responsibly shape the future of quantum technologies. The inaugural roundtable had taken place in London in November 2023, where discussions centred on ideas for promoting innovation while ensuring a safe and equitable future enabled by quantum technologies. The focus of this roundtable was on two critical issues that are likely to influence the direction of this rapidly progressing field: the development of skills and talent, and the strengthening of supply chains.

This report captures the perspectives and insights of participants at the roundtable, serving as a concise guide to inform and contribute to the broader stakeholder discourse on quantum technology skills

The main **cross-cutting themes** that emerged during the discussion are as follows:

The global quantum technology ecosystem is evolving to become increasingly heterogeneous, encompassing a range of expertise and disciplines.

There are key challenges concerning the availability, types and distribution of skills pertinent to advancing the quantum technology ecosystem.

Universities worldwide are expanding quantum-related degree programmes and research opportunities, while industry players are also increasingly developing educational content and tools, collectively enhancing quantum literacy and workforce readiness.

The development of a robust, sustainable quantum technology talent pipeline will require adopting a patient, long-term approach that targets different learning levels across the education and skills development journey.

Addressing the quantum technology workforce development challenge necessitates coordination, community building and common standards.

and talent, as policy on these key issues develops over the coming months.[1] **It is widely recognised that skills, talent and competencies are crucial to advancing economies in general; however, they are particularly vital to constructing resilient workforces and maintaining progress in advanced technology domains like quantum technology.** Alongside other structural factors such as funding, infrastructure, collaboration and oversight, skills development can be considered one of the essential enablers of the broader quantum technology ecosystem. We discussed that **the quantum technology ecosystem is facing a skills gap**, which stakeholders are actively striving to bridge. Ultimately, strategically investing in skills and talent development is essential to cultivating robust ecosystems capable of supporting the ongoing evolution and expected impact of quantum technologies.

Drawing on the roundtable discussions, we offer a selection of **high-level policy considerations** and associated **enabling actions** that stakeholders within the broader quantum technology ecosystem could take to address issues related to skills, talent and workforce development. Figure 1 provides a visual representation of the policy considerations. Taken together, these eight policy considerations can be regarded as a set of **cross-cutting principles** intended to guide stakeholders in addressing challenges proactively and holistically, with the aim of developing a more **resilient, equitable and future-ready quantum technology skills pipeline and workforce**. We organise the eight policy considerations into three colour-coded clusters, each reflecting common themes across the respective policy considerations.

We believe that these principles could underpin a future '**Quantum Technology Skills Charter**', articulating a **collective statement of intent, ambition and commitment among stakeholders** including public, private and third sector (including civil society) entities. This charter could facilitate focused, coordinated efforts and actions to proactively address the key challenges related to quantum technology skills and the broader workforce.

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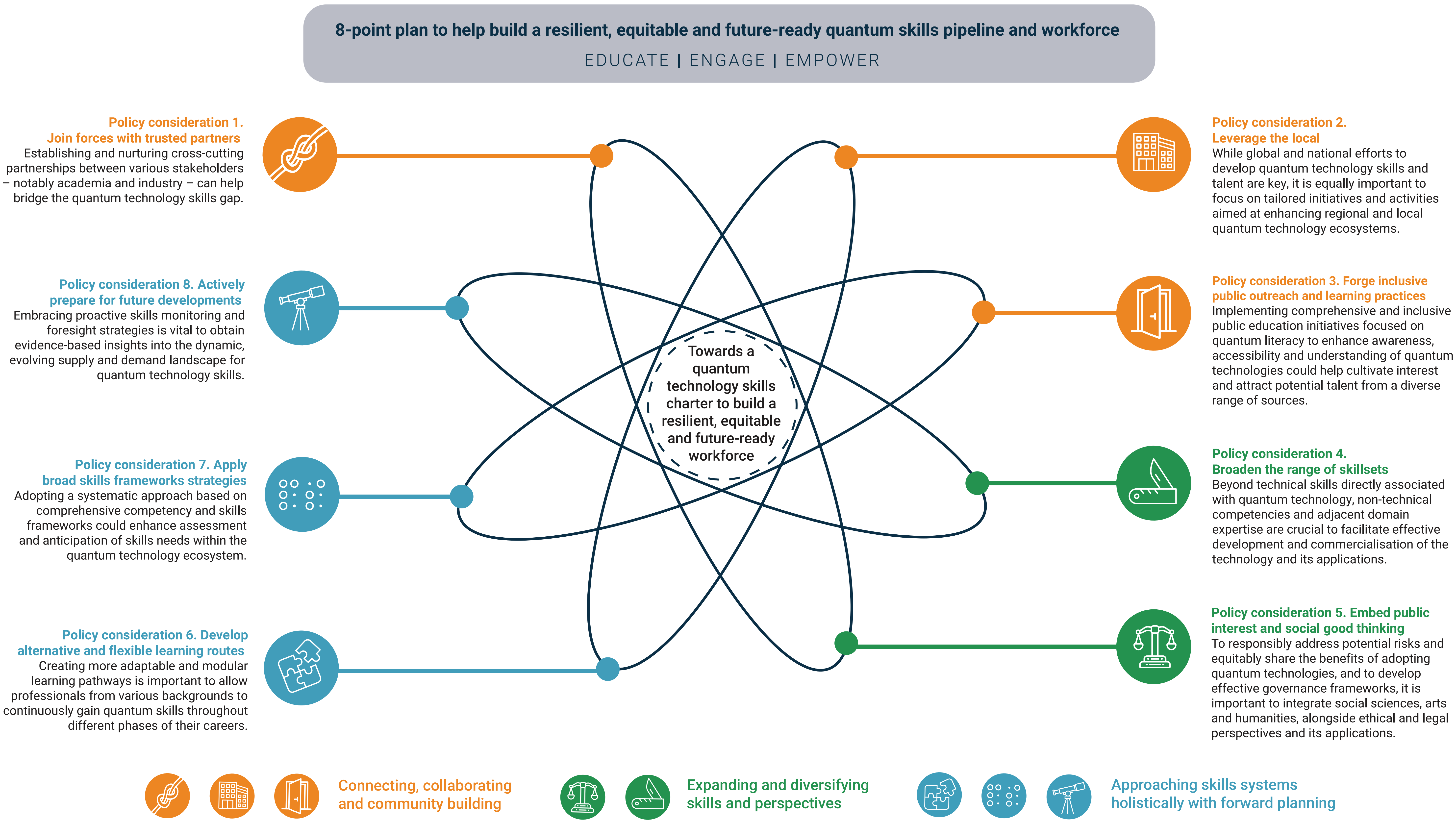
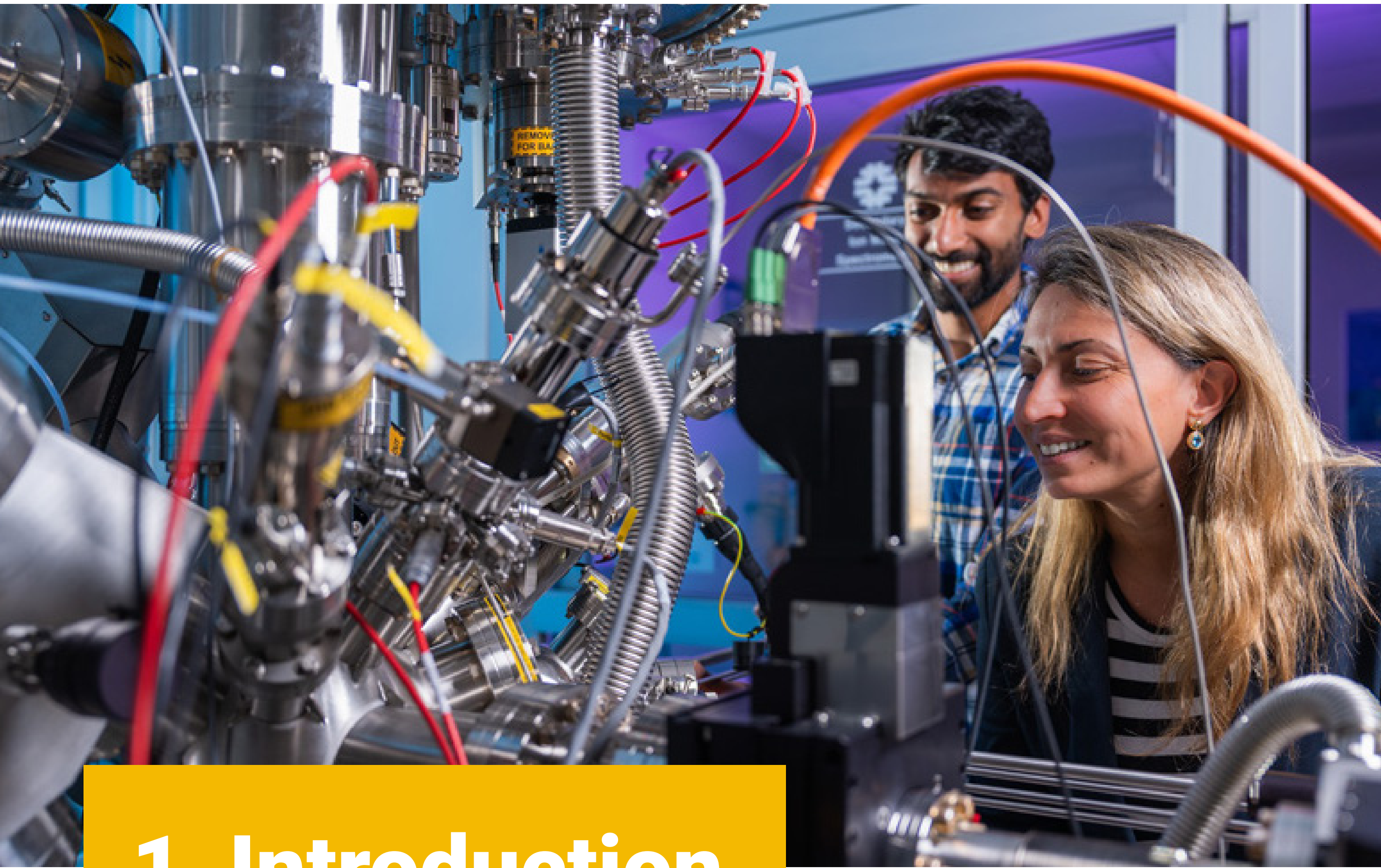
1 A forthcoming companion report will provide a summary of the discussions related to the supply chains component of the roundtable.

Figure 1: Eight policy considerations for stakeholders within the quantum technology ecosystem to address issues related to skills, talent and workforce development (note: policy considerations are organised into three colour-coded clusters, each reflecting common themes: connecting, collaborating and community building; expanding and diversifying skills and perspectives; and approaching skills systems holistically with forward planning)



Source: RAND Europe analysis



1. Introduction

In recent years, the capabilities of quantum technologies have advanced significantly, underscoring their potential applications across diverse fields, including the life sciences, finance, aerospace, defence, energy and telecommunications. While many quantum technologies seem poised for breakthroughs over the next few years, several bottlenecks persist. These challenges include technical issues such as scalability and error correction, lack of standardisation, complexities associated with advancements in hardware, algorithms and software for quantum systems, and cybersecurity risks. Crucially, broader ecosystem barriers must be addressed to fully realise the benefits of quantum technologies. These encompass longer-term issues such as funding and investment challenges, governance uncertainty, interdisciplinary collaboration, supply chain development, international competition and skills and talent development (Gunashekar et al. 2022).

On 10 October 2024, RAND Europe and the Novo Nordisk Foundation co-hosted an in-person roundtable discussion in Copenhagen to explore key aspects of the quantum technology ecosystem, given the rapid global advancements in cutting-edge research and innovation in the field. This was the second in a series of events aimed at bringing together thought leaders, researchers, industry experts and policymakers who are committed to shaping the future of quantum technologies.[2] The inaugural roundtable had taken place in London in

2 Annex A contains a more detailed account of the types of participants present at the roundtable.

November 2023, where discussions centred on ideas for promoting innovation while ensuring a safe and equitable future enabled by quantum technologies. **The focus of this roundtable was on two critical issues that are likely to shape the direction of this rapidly progressing field: development of skills and talent, and the strengthening of supply chains** (see Box 1 for an overview of the broad topics discussed at the roundtable and Box 2 for definitions of key terms).

This short report provides a summary of the roundtable discussions concerning the skills and talent component (Chapter 2), incorporating findings and reflections from different activities undertaken at the roundtable.[3] Based on an analysis of discussions, we also propose a selection of policy considerations and related enabling actions that stakeholders within the wider quantum technology ecosystem might take to resolve challenges related to skills, talent and workforce development (Chapter 3). In Annex A, we outline the approach adopted to design and conduct the roundtable, along with the limitations of the analysis.

It is widely recognised that skills, talent and competencies are crucial to advancing economies in general; however, they are particularly vital to constructing resilient workforces and maintaining progress in advanced technology domains like quantum technology. **Ultimately, investing in skills and talent development and promoting capacity-building efforts are essential to cultivate robust ecosystems capable of supporting the ongoing evolution and expected impact of quantum technologies.**

The quantum technology development 'roadmap' poses several challenges to developing human capital. Roundtable participants highlighted some of the unique challenges and features associated with the current state of development of quantum technology (see Box 3 for a selection of these key features). Despite not having yet achieved widespread, scalable error correction or the development of fault-tolerant quantum computers, the technology currently demonstrates a limited – but meaningful – level of 'utility' in solving problems.

Box 1: Overview of main topics discussed at the roundtable

Skills and talent: Building the quantum workforce of tomorrow (Roundtable session 1)
The rapid development of quantum technologies requires a skilled workforce to drive innovation and convert theoretical advancements into practical applications. However, there is a growing acknowledgement that the current talent pool is inadequate to satisfy the expanding demands of the broader quantum research and innovation ecosystem. The roundtable explored ideas to cultivate and sustain a robust quantum workforce, focusing on issues such as education and training, talent pipelines, diversity and inclusion, and collaboration.

Supply chains: Ensuring resilience and sustainability (Roundtable session 2)
The development and deployment of quantum technologies relies on complex and often fragile global supply chains. From the procurement of rare materials to the manufacture of sophisticated components, ensuring the resilience and sustainability of these supply chains is paramount. The roundtable addressed issues such as supply chain mapping, risk assessment, innovation and localisation, and sustainability and ethics.

3 An accompanying report (forthcoming) will encapsulate discussions concerning the supply chains aspect of the roundtable The two reports should be read in conjunction with each other to obtain a more holistic snapshot of the discussions at the roundtable.

Box 2: Definitions of key terms

Quantum technology refers to a range of technologies that harness the principles of quantum mechanics, the fundamental theory in physics that describes nature at the smallest scales (i.e. at the atomic or subatomic levels, using the properties of electrons, photons, atoms or molecules) (Gunashekar et al. 2022). These technologies leverage unique quantum phenomena to perform tasks in ways that classical technology cannot. Quantum technologies currently encompass several emerging fields, such as quantum computing, quantum communication, quantum sensing and metrology, and quantum simulation. Experts increasingly acknowledge that quantum technology holds promise to transform multiple industries by enabling novel capabilities and enhancing current technologies – for example, delivering significant improvements in computing power, communication security and measurement precision.

A **qubit** refers to a 'quantum bit', the fundamental unit of quantum information. A qubit is equivalent to the classical digital bit in traditional computing. While classical bits are binary (i.e. they can be in one of two states, 0 *or* 1), a qubit can exist in a superposition of both states simultaneously (i.e. they can be in 0 *and* 1 states), with different probabilities attached to each state (Gunashekar et al. 2022; Kasirajan 2021). The development and manipulation of qubits is fundamental to advancing quantum computing and other quantum technologies.

Qubit modalities refer to the various physical systems or methods used to fabricate, store or manipulate qubits. While digital bits use a single technology – semiconductors – different systems are being researched and developed in parallel for qubits, including trapped ion qubits, superconducting qubits, photonic qubits, topological qubits, spin qubits and neutral atom qubits (Kasirajan 2021). Each modality presents distinct advantages and challenges, determined by its underlying quantum properties and technological considerations.

Quantum computers today are characterised by high error rates. **Quantum error correction** refers to the processes of counteracting the errors and noise inherent within quantum systems to help enable more reliable (and scalable) quantum computations (see Box 3 for further information). It has been noted that the full potential of quantum computers (including building practical and scalable quantum computers) may not be realised until quantum error correction is effectively implemented to mitigate the noise and errors arising from the inherent fragility of quantum systems (Gunashekar et al. 2022).

A **supply chain** is a linked set of resources and processes involved in the development, production, distribution and delivery of a final product or service to a customer (NIST 2025). It includes all stages, from the initial concept and design through to the final deployment and maintenance of technological solutions. Supply chains are often complex and global in scope, involving numerous stakeholders and requiring detailed coordination across different regions, sectors and organisations. In the case of quantum technologies, supply chains can encompass the initial sourcing of raw materials and critical components, through research and development, to manufacturing and distribution.

Dual-use technology refers to technologies that can be used for both beneficial and harmful purposes. Recently, this term has been applied in the context of potential weaponisation and exploitation of technology and applications by malicious actors. Historically, it has been used to denote technologies with both civilian (i.e. commercial or industrial) and military applications. Examples of dual-use technology include certain types of biotechnology, artificial intelligence (AI), quantum technologies, drones, advanced materials and manufacturing, space technologies and nuclear power technologies. The dual-use nature of these technologies presents specific challenges and considerations, especially concerning regulation, export control and ethical implications.

Roundtable participants acknowledged that the current stage in the development trajectory of quantum computing is characterised by rapid change and uncertainty, with important implications for skills and workforce development – specifically: *What skills are needed now and in the future, and how can a skilled and resilient workforce be built?* Participants cautioned that stakeholders should approach policy and broader strategy development with care, striving to achieve a level of agility that matches the rapid pace of technological advancement, while avoiding the pitfalls of succumbing to 'hype' or taking potentially premature actions.

Box 3: Selected features highlighted by roundtable participants regarding the current development stage of the quantum technology ecosystem

Persistent noise and error correction. Quantum computers today are subject to noise and have high error rates that significantly impact their accuracy and reliability (see Box 2). Error correction remains one of the most challenging aspects of building stable, practical quantum technology applications. Although quantum error correction is an active area of research, it remains unresolved and must be overcome to address the many and significant data errors that hinder the reliability and scalability of current quantum computers.

Use case relevance. Although not reliable enough to currently solve real-world problems, quantum computers have reached a stage in their development trajectory that allows users to identify problem domains and scientific questions to test their utility[4] (for example, through simulations and experimental applications). It was noted that the capacity to demonstrate tangible, practical applications over time will enhance credibility, attract investment and promote the growth of the quantum technology ecosystem.

Perceived 'competition' between multiple hardware modalities. When it comes to quantum technology hardware, the challenge of how to create qubits is still open, and researchers globally are exploring several modalities, including photonic qubits, superconducting qubits, topological qubits, neutral atom qubits and trapped ion qubits (see Box 2). There are differing views, along with uncertainty and scepticism, regarding which modalities are likely to prove most effective in the long term.[5]

Emergent business models. As the development of quantum technology continues to extend beyond academic research and the domain of large technology firms into the startup sector, new business models for quantum computers are also emerging, encompassing both application-focused and hardware-focused approaches. Although these may generate a variety of economic opportunities over time, the path to commercialising quantum technology is considered to be uncertain and risky.

4 Some researchers have used the term 'quantum utility' to refer to the ability of quantum computers 'to perform reliable computations at a scale beyond brute force classical computing methods that provide exact solutions to computational problems' (IBM 2023). Quantum utility is defined in contrast to 'quantum advantage', which refers to the ability of quantum computers to achieve better performance compared to a classical computer – i.e. the development trajectory phase at which substantial progress has occurred in relation to quantum computers completing useful tasks considerably faster or more accurately than known classical alternatives (IBM 2023). Others have referred to quantum utility as an ability to produce more accurate results with less computing time and power than a classical computer of any size, weight and cost (Hermann et al. 2023).

5 As exemplified by the varied reactions to Microsoft's February 2025 announcement claiming the creation of the first topological qubit (Ball 2025).

2. Trends and insights related to the development of skills and talent in quantum technology

Key takeaways

- The global quantum technology ecosystem is evolving to become increasingly heterogeneous, encompassing a range of expertise and disciplines.
- There are key challenges concerning the availability, types and distribution of skills pertinent to advancing the quantum technology ecosystem.
- Universities worldwide are expanding quantum-related degree programmes and research opportunities, while industry players are also increasingly developing educational content and tools, collectively enhancing quantum literacy and workforce readiness.
- The development of a robust, sustainable quantum technology talent pipeline will require adopting a patient, long-term approach that targets different learning levels across the education and skills development journey.
- Addressing the quantum technology workforce development challenge necessitates coordination, community building and common standards.

Source: RAND Europe analysis

The advancement of quantum technologies requires a strategic focus on developing a skilled workforce capable of driving innovation to address fundamental technological challenges and translating theoretical breakthroughs into practical applications. Alongside other structural factors such as funding, infrastructure, collaboration and oversight, skills development can be considered one of the essential enablers of the broader quantum technology ecosystem. Roundtable participants explored the challenges and opportunities related to building a robust talent pipeline, highlighting a series of good practice examples and key developments in this space (specific examples are included in boxes throughout the report).[6] Given that these topics were discussed and debated at various times during the roundtable, we have organised them by theme rather than providing a chronological account of the discussions. We explore these key themes below.

2.1. The global quantum technology ecosystem is evolving to become increasingly heterogeneous, encompassing a range of expertise and disciplines

Participants noted that the evolving quantum technology ecosystem is marked by **growing interdisciplinarity**, drawing on expertise and skills from a **wide range of disciplines and sectors**. This includes fields like physics, engineering (and design),[7] mathematics, computer science (applied and theoretical) and materials science, as well as **sectoral knowledge** pertinent to application areas such as finance, the life sciences, energy and communications, all contributing to its progression. Participants highlighted the importance of drawing on expertise and techniques from related 'classical technical fields', for example, both hardware and software engineering that offer **many transferable and 'problem-solving' skills**. Participants stressed that **having a specialised background or training in quantum computing is not essential to join the quantum workforce** (see the following section for further details); individuals with diverse educational backgrounds and training can also pursue careers in quantum technology. Participants noted that technical experts, despite not possessing deep 'quantum knowledge', can contribute significantly with knowledge and expertise from their own domains (e.g. engineers designing and developing components for quantum computers, software developers creating algorithms and software for quantum computing platforms, or professionals specialising in drug development with extensive expertise in the natural sciences). Furthermore, according to some participants, the **broadening capabilities of AI** (along with growing technical expertise in the area) **offer numerous opportunities** to advance quantum technology (and vice versa), with potential benefits for both research and practical applications.

Several participants recognised the importance of **quantum scientists and technical experts 'building bridges' with experts in social sciences, arts and humanities as well as with policymakers** (and vice versa), especially considering the potential long-term and far-reaching societal impacts of quantum technology. These experts can offer valuable insights into the **ethical, legal, societal and policy implications of quantum advancements**, ensuring that technologies and applications are developed in alignment with societal values and needs, and could, for example, play key roles in government,[8] academia[9] or industry[10]. As one participant remarked, beyond specialised quantum-specific qualifications and training, 'we need a lot of different people and skills in quantum technology – diversity is so important.'

6 Many of the examples we feature in the report were mentioned during the roundtable. However, assessing the overall effectiveness of each of these initiatives, developments, organisations, etc., falls outside the scope of this research.

7 E.g. electronics engineering, optical communications, photonics, signal processing, etc.

8 E.g. policymaker/civil servant/advisor in a government department focussing on quantum technology strategy development; industry and academic engagement specialist in a government department.

9 E.g. technology transfer office professional at a research institution; coordinator/researcher at a university examining the societal and ethical aspects of quantum technology.

10 E.g. chief commercial/business officer of a quantum technology startup; government relations and policy manager in a quantum technology company.

> Embracing interdisciplinarity can allow the quantum technology sector to drive more effective solutions and enable the conversion of scientific breakthroughs into practical applications.

It was noted that this **blending of disciplines and talent across the globe is vital** to tackling the complex challenges inherent to quantum technology, **requiring collaboration** among theorists, experimentalists and practitioners from diverse fields and backgrounds. Interdisciplinary approaches allow for the **integration of various perspectives, methods and approaches**, helping to foster innovation and potentially accelerate the discovery and application of quantum technology innovations. Moreover, as highlighted by some participants, this fusion of fields and disciplines **could help support the development of comprehensive educational programmes** that equip the next generation of 'quantum professionals' with a more holistic understanding of the ecosystem. Embracing interdisciplinarity can allow the quantum technology sector to drive more effective solutions and enable the **conversion of scientific breakthroughs into practical applications**. Overall, there was consensus among participants that by **incorporating diverse perspectives**, the quantum ecosystem can foster inclusive, equitable and sustainable growth, ultimately leading to **broader societal benefits and responsible technological development**.

2.2. There are key challenges concerning the availability, types and distribution of skills pertinent to advancing the quantum technology ecosystem

As noted in the previous section, the progression of quantum technologies calls for a highly skilled and diverse workforce capable of **driving innovation and transforming theoretical breakthroughs into practical, commercial applications**. This need has been acknowledged across academia, industry and government – **building a robust talent pipeline has become a critical priority**. Developing a qualified workforce features as a priority in several national quantum strategies– including those of the United Kingdom (UK) (DSIT 2023), Denmark (The Danish Government 2023) (see Box 4), France (Government of France 2021), and the United States (US) (NSTC 2022), as well as in pan-European initiatives such as the European Commission's Quantum Flagship programme (European Quantum Flagship 2020) – and has been recognised as a key enabler by several industry players (Greinert et al. 2024).[11] However, participants noted that there is **increasing recognition that the current talent pool for this relatively nascent field is insufficient to meet the growing demands** of the wider quantum research and innovation ecosystem. The field requires highly specialised and technical expertise (often with extensive academic training), and it was felt that the **current supply of deep quantum technology skills does not appear to be meeting demand** as large technology companies, startups and research institutions compete for this limited pool of talent, often to the detriment of smaller players.

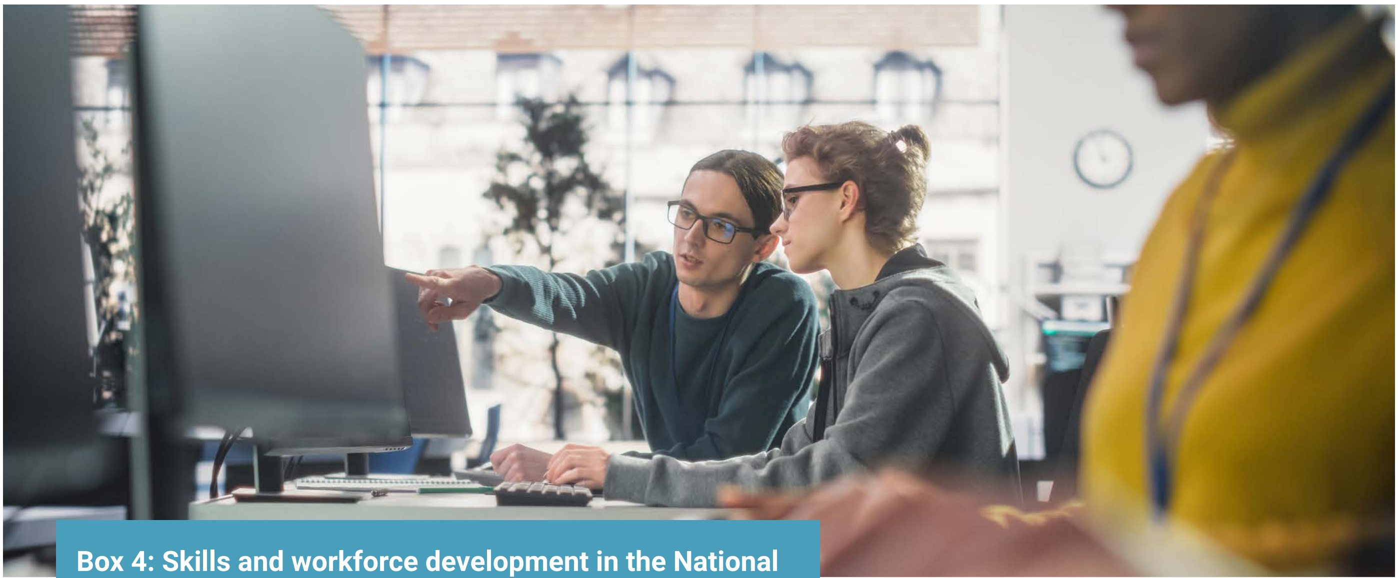
Participants pointed out that the **rapid expansion of quantum technology companies across the globe is outpacing the influx of researchers and engineers** – often requiring advanced degrees – into the job market. They noted that for regions like Europe, the increased appeal of other international 'markets' such as the US – perceived to have a more mature and dynamic quantum technology environment with development opportunities for quantum experts – can draw away skilled experts.

> There is increasing recognition that the current talent pool for this relatively nascent field is insufficient to meet the growing demands of the wider quantum research and innovation ecosystem.

11 More broadly, national governments are crucial in steering the direction and progress of quantum technology research and innovation ecosystems (Gunashekar et al. 2022).

Even though many countries and organisations have launched educational initiatives and workforce development programmes focused on quantum technologies, **the shortage of qualified personnel – the so-called 'quantum skills gap' – was cited as a major obstacle to scaling up** the development and commercialisation of quantum technology.

In this context, **international recruitment** was identified as essential to bridge the talent gap. Participants emphasised the need for policies and structural measures (e.g. research grants and competitive salaries) coupled with 'favourable visa regulations' to facilitate the recruitment of global talent. Streamlined visa processes and supportive immigration policies could attract skilled professionals worldwide, **enhancing the mobility, diversity and capability of the quantum technology workforce**. However, it was also recognised that the **rise of 'quantum nationalism'** in certain regions and countries, characterised by efforts to 'dominate the technology' could potentially affect the accessibility and mobility of quantum talent and skills.



Box 4: Skills and workforce development in the National Quantum Strategies of the UK and Denmark

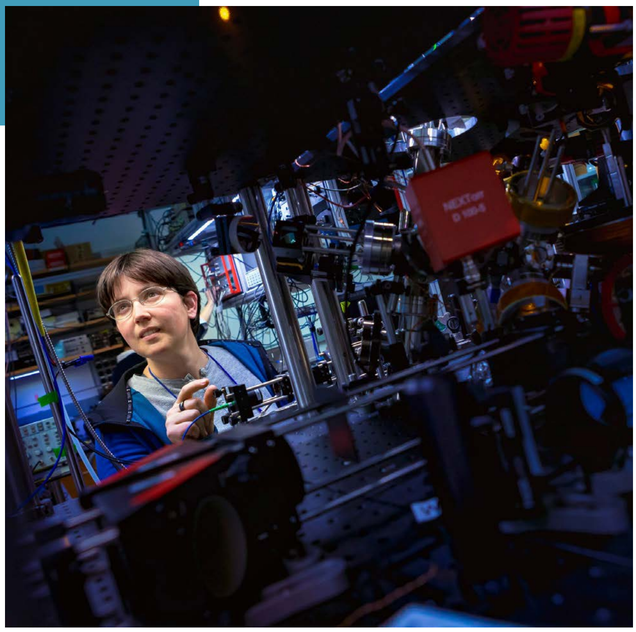
The UK National Quantum Strategy (DSIT 2023) recognises the development of skills as an area crucial to advancing the UK's quantum sector, emphasising the need to build a quantum-literate workforce that extends beyond traditional doctoral training. Doing so requires creating pathways from schools to professional roles through technical and vocational training, professionalising quantum engineering skills, facilitating transitions from adjacent sectors, and increasing quantum literacy across the economy, particularly in key end-user sectors. Intervention points laid out in the Strategy include: updating visa routes to facilitate the entry of highly skilled international talent; establishing a Quantum Skills Taskforce to align the skills system with industry needs; increasing the number of Centres for Doctoral Training; investing in fellowship programmes, as well as initiatives aimed at the 'next generation', such as outreach programmes in schools (e.g. the Quantum Ambassadors Programme (STEM Learning 2025)), summer schools and research exchanges; and creating industry placement and apprenticeship schemes.

The Danish government also includes a set of priority initiatives for workforce development in its National Strategy for Quantum Technology (The Danish Government 2023). The Strategy recognises that attracting and maintaining quantum talent in Denmark is essential to accelerating the commercialisation of quantum technologies, especially in the context of global competition for talent. The Danish government's approach includes funding to enable higher education institutions to develop their educational offers in quantum, as well as summer schools and measures to attract more international students.

Furthermore, although deep quantum expertise and skills are in high demand, **participants cautioned against the narrow perspective that these skills** – typically available at the PhD+ level – **are either sufficient or necessary for an individual to participate in the quantum technology workforce**. While specialised quantum expertise is undoubtedly important, participants noted that there is **growing demand in the ecosystem for other key skills** as well. These skills include:

- **Complementary engineering and technical expertise** – for instance in areas such as high-performance computing, materials science and hybrid algorithms.[12]
- **Specialised knowledge and expertise in the specific domains** to which quantum technology is applied, such as the life sciences, energy, climate science and finance.
- **Transversal competencies (and attitudes)** such as organisational skills, management skills, entrepreneurial/innovative thinking, communication skills and 'problem-solving'.
- **Business development and commercialisation skills** – for example, to help understand market needs, develop business strategies, build relationships with potential clients or help translate technology and ideas into products and services.

Despite the need for alternative and additional skills, some participants noted a **perception that companies often struggle to justify investment in skills development below the PhD level**, as their revenue models do not tend to support investment in 'junior-level skills.' Participants emphasised that the benefits of such investment may not yield immediate returns for companies, exacerbated by the widely acknowledged observation that 'a quantum future remains far away'. Therefore, a primary challenge involves addressing the question posed by one participant: **'How can quantum companies be incentivised to support training?'** (see Section 2.3 for further discussion on this).



Another significant shortcoming of the current quantum talent pool is **relatively low levels of gender diversity.** Participants observed that the quantum technology ecosystem is predominantly male dominated, **mirroring a broader systemic trend in science, technology, engineering and mathematics (STEM) fields** (Feijao et al. 2021). While up-to-date quantitative data on diversity within the quantum technology sector is limited, qualitative evidence suggests that the distribution of quantum skills aligns with general patterns observed in STEM subjects, where diversity is lacking (Heidt 2024). The AI industry could serve as a relevant comparative example, especially as certain types of quantum expertise stem from similar disciplines, including computer science.[13] While quantum computing faces a similar – if not more pronounced – dearth of diversity data, some reported figures suggest that only 2 per cent of applicants for quantum roles were female (Josten et al. 2023), hinting at a potential trajectory mirroring that of AI (and other STEM-related domains) unless action is taken. Participants stressed the importance of **proactively fostering greater involvement of women in the development of the broader quantum technology ecosystem**.

12 This is further complicated by the emergent nature of quantum technology – for instance, uncertainty around the 'winning' hardware modality could potentially have implications for specific areas of quantum skills development.

13 While the data on the diversity of the sector is sparse (Young et al. 2021), The Organisation for Economic Co-operation and Development (OECD) analysis suggests that only 35 per cent of the AI workforce in OECD countries is female; with more than half of UK AI firms having no female employees doing AI-related work (Green & Lamby 2021).

Box 5: Girls in Quantum

Girls in Quantum is a student-led, non-profit initiative dedicated to advancing efforts in quantum education globally, and 'inspiring and empowering girls' and students more broadly to 'get involved' in quantum computing by providing free educational content and resources (e.g. webinars and videos, courses, games, textbooks, etc.) (Girls in Quantum 2025). At the time of writing, the organisation's activities have reached roughly 5,000 students from 27 countries globally, and include learning seminars, community and network-building activities, and a series of collaborations with organisations and companies to provide students with a variety of opportunities in quantum technology.

2.3. Universities worldwide are expanding quantum-related degree programmes and research opportunities, while industry players are also increasingly developing educational content and tools, collectively enhancing quantum literacy and workforce readiness

To address the skills shortage, different stakeholders are actively employing a mix of strategies to increase the number and accessibility of people with expertise in quantum technologies and related areas. Roundtable participants noted that researchers with **doctoral experience** are in 'high demand', but it is **unlikely they will be sufficient to plug the talent gap**. Furthermore, the **number and range of specialised master's programmes focusing on quantum technologies has significantly increased** over the past decade, with joint master's programmes[14] often deployed as part of national strategies (Goorney et al. 2025).

Some roundtable participants reflected positively on such developments but stressed that **industry should complement the efforts happening within academia**. Participants recognised several examples of industry-developed programme content and educational tools with potential to offer accessible learning resources to a broader audience and by doing so, **democratising quantum education** and **reaching learners beyond traditional academic environments**. Examples include **open-source tools** such as IBM's Qiskit (IBM 2024) software stack, which allows individuals to experiment with quantum computing applications, and its modular learning platform. Another example is NVIDIA's CUDA-Q Academic programme (NVIDIA 2025a) which was also flagged as an example of **industry-academia collaboration**, as NVIDIA partners with universities to provide students and researchers with **online, self-guided learning resources** for using the CUDA-Q software development platform (NVIDIA 2025b).

Participants emphasised the **importance of such 'hands-on experiences'** in learning about quantum technologies, highlighting that **practical engagement with 'building quantum computers' is invaluable**. This could provide learners with the opportunity to understand real-world challenges and develop important problem-solving skills.

> By incorporating practical industry insights into academic curricula, students can gain hands-on experience and a deeper understanding of real-world applications.

14 In this context, joint programmes refer to programmes developed and delivered jointly by different faculties – reflecting the growing interdisciplinarity of the field of quantum technology.

Box 6: Examples of industry-led quantum technology learning in action

Several industry players have contributed to efforts to enhance the skills base for quantum technology. Some examples highlighted during the roundtable include:

Qiskit, developed by IBM, is an open-source software development kit (SDK) that helps people learn about quantum computing by allowing them to create and experiment with quantum circuits (IBM 2024). It supports both IBM's quantum computers and other hardware, giving learners the chance to explore various quantum computing concepts. IBM also offers Qiskit tutorials and other educational resources to help users learn about quantum computing through the IBM Quantum Learning platform (IBM Quantum Learning 2025).

CUDA-Q, developed by NVIDIA, is an open-source, hardware-agnostic platform designed to facilitate the development of hybrid quantum-classical applications (NVIDIA 2025a). It integrates several elements – including quantum processing units, quantum emulation, graphics processing units (GPUs), and central processing units (CPUs) – within a unified programming model. This is aimed to be accessible to domain scientists transitioning into quantum application development. As part of the CUDA-Q Academic initiative, NVIDIA also collaborates with several academic institutions, providing resources such as self-paced online modules, interactive coding exercises and videos (NVIDIA 2025b).

Emerging industry players have also been involved in developing learning initiatives (although roundtable participants noted that this is more challenging given their limited time and resources compared to larger organisations). For instance, Finnish startup IQM has developed IQM Academy, an online curriculum covering a range of quantum computing topics for beginners as well as advanced learners (IQM Academy 2025). QURECA (Qureca 2025) provides an online quantum learning platform aggregating courses on a range of topics and is collaborating with several European universities as part of the European Flagship-funded QTIndu (Quantum Technology Courses for Industry) Project, to develop industry-oriented quantum technology training programmes (QTIndu 2025).

Participants remarked that **cooperation between academia and industry** ensures that quantum educational programmes **stay relevant and aligned with current technological advancements and market needs**. By incorporating practical industry insights into academic curricula, students can gain hands-on experience and a deeper understanding of real-world applications (potentially also making them more competitive in the job market, according to some participants). This holistic approach not only equips a skilled workforce to meet the demands of the expanding quantum technology sector but also helps foster a culture of continuous learning and innovation, which is crucial to sustaining long-term growth in this rapidly evolving field.

However, as noted in Section 2.2, some participants also cautioned that some **industry players might lack the motivation to invest in skills-building programmes and educational initiatives** if they do not see an immediate return on investment. They highlighted the importance of **collaborative models**, such as **apprenticeship programmes, public-private partnerships**, and **financial incentives or grants**, which can facilitate industry involvement in education.

2.4. The development of a robust, sustainable quantum technology talent pipeline will require adopting a patient, long-term approach that targets different learning levels across the education and skills development journey

While the increase in educational initiatives within academia and industry is an important step towards strengthening the quantum skills base, participants

Box 7: QTEdu

The Coordination and Support Action (CSA) for Quantum Technology Education (QTEdu) project is a part of the European Quantum Flagship initiative and is dedicated to creating 'the learning ecosystem necessary to inform and educate society about quantum technologies' (Quantum Technology Education 2025). QTEdu brings together a network of over 440 members (including researchers, educators and science communicators) across 50 countries. It seeks to achieve its goal by compiling a set of learning and communication tools and resources and supporting pilot projects across a range of themes, including school education outreach, higher education, lifelong learning and retraining, education research, and equity and inclusion (Quantum Technology Education 2025).

argued that a **'whole pipeline' approach is needed**. This entails understanding not only the current job roles and their associated skill requirements, but also **anticipating future needs and developing comprehensive strategies to cultivate the talent** required for the evolving landscape of quantum technologies, from early academic – including school – levels to advanced research stages. Participants highlighted that it is **crucial to engage children more effectively at an early age** in understanding various aspects of quantum technology and in envisioning potential careers in this field, to help ensure a greater number of individuals enter the talent pipeline. By fostering interest in STEM subjects from a young age, educational systems **can lay the groundwork for future 'quantum specialists'.** As one participant remarked, 'Today's school students will be building the quantum computers of tomorrow.'

Participants discussed a range of approaches that could be deployed beyond traditional educational settings to support skills development at different levels. These include **local outreach programmes** to reach individuals who typically do not benefit from quantum technology education activities; **support for informal groups**, such as students' study groups; dedicated events such as **hackathons**, which can increase engagement through hands-on, competitive activities; **open repositories of learning resources; online forums and tutorials**; and **'teach the teacher' training programmes** aimed at increasing primary and secondary school teacher knowledge of different aspects of quantum technologies.

Participants noted that **developing a strong skills pipeline will require 'patience' and long-term commitment from key stakeholders** (including government and industry) to **'stay the course'**, acknowledging the time required to cultivate relevant and sufficient expertise and innovations that could help shape future quantum capabilities. This will require **long-term, sustained funding for educational activities offered across the whole education and skills pipeline**. Additionally, certain participants underscored the significance of **avoiding excessive dependence on industry demand** to guide the development of quantum skills programmes and initiatives. They cautioned that **such reliance could potentially prioritise short-term needs** – possibly driven by hype – over broader and longer-term educational objectives.

Developing a strong skills pipeline will require 'patience' and long-term commitment from key stakeholders (including government and industry) to 'stay the course', acknowledging the time required to cultivate relevant and sufficient expertise and innovations that could help shape future quantum capabilities.

Box 8: Qubit by Qubit

Qubit by Qubit is an initiative of The Coding School, a nonprofit organisation dedicated to equipping the future workforce with skills in emerging technologies (Qubit by Qubit 2025). It has educated over 22,500 students and professionals in quantum computing across 130 countries. Qubit by Qubit provides various educational activities, including bootcamps, courses, workshops, research projects and internships, for students in primary and secondary education. It also trains high school teachers to deliver quantum education. The organisation works in partnership with several universities and companies, and is guided by an academic board of advisors.

2.5. Addressing the quantum technology workforce development challenge necessitates coordination, community building and common standards

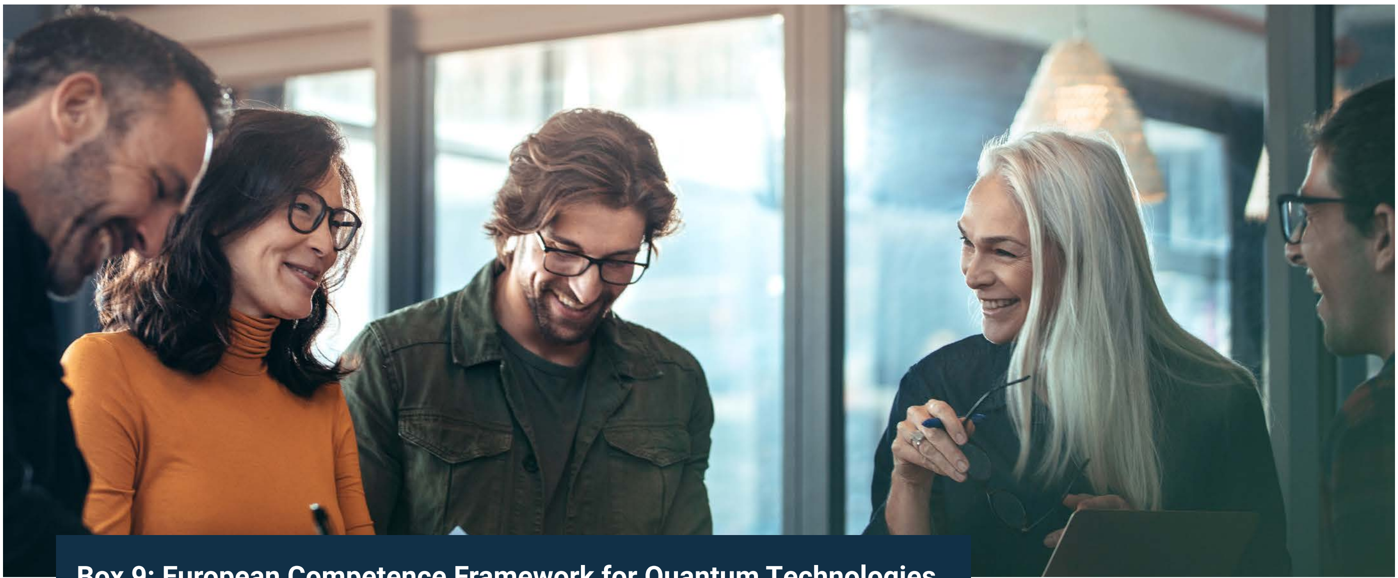
Participants emphasised the **importance of standardised, concerted action** as another key ingredient in developing the necessary quantum technology skills base, particularly in Europe. They observed that the **current skills development landscape is fragmented** – partly because of the novel, emergent nature of the ecosystem itself – and that 'people often lack a common language, talking about the same concept in different ways.'

Participants concurred that an initial positive step towards **establishing a 'common language' involves creating a taxonomy of skills**, pointing to the **European Competence Framework for Quantum Technologies** as a significant development in this area (Greinert & Müller 2024) (see Box 9). Most participants agreed on the general **value of competency framework approaches**, noting that standardisation is needed to **ensure that the teaching of quantum (and ancillary) skills is 'up to standard, relevant and transferable'** across different settings. They noted that adopting a competency framework approach can also **help increase quantum skills intelligence**[15] by providing a consistent framework for reporting skills demand (e.g. employers reporting skills gaps they are experiencing) and supply (e.g. education providers reporting on competencies developed). This can, in turn, **potentially foster alignment between different stakeholders**, allowing industry to **better signal skills needs to training providers and policymakers**. Participants noted that industry can further support the standardisation of skills development efforts through the provision of industry certificates.

Finally, participants reiterated the **value of collaboration platforms and initiatives** like the European Quantum Flagship programme (Quantum Flagship 2025), and other similar national-level initiatives, highlighting the **benefits of tightly knit local quantum ecosystems**, such as increased awareness and improved communication channels. Participants noted that it was **important to both continue and expand community-building activities at the local level**, drawing inspiration from examples such as Denmark's growing quantum technology ecosystem, (Ministry of Foreign Affairs of Denmark 2021) as a means to bring together a wide range of experts and stakeholders with shared objectives.

We summarise some of the key themes and insights discussed above in the form of a mind map (Figure 2). Although the mind map does not contain an exhaustive list of the concepts that emerged during the roundtable discussion, we hope it offers an overarching visual snapshot of the key dimensions related to the challenges and opportunities involved in strengthening the quantum technology skills ecosystem and workforce.

15 Skills intelligence activities aim to assess and anticipate 'current and future skill needs in the labour market in a strategic way by using consistent and systematic methods' (Cedefop 2024).



Box 9: European Competence Framework for Quantum Technologies

The European Competence Framework for Quantum Technologies (released in September 2021 (version 1.0) and updated in April 2023 (version 2.0) and April 2024 (version 2.5)) is a taxonomy of quantum technology-related knowledge and skills (Greinert & Müller 2024). The Framework was developed by the QTEdu CSA. It aims to standardise and provide structure for various education and qualification processes associated with quantum technologies. It does so by providing a unified language for planning, mapping and comparing educational activities, personal qualifications and job requirements.

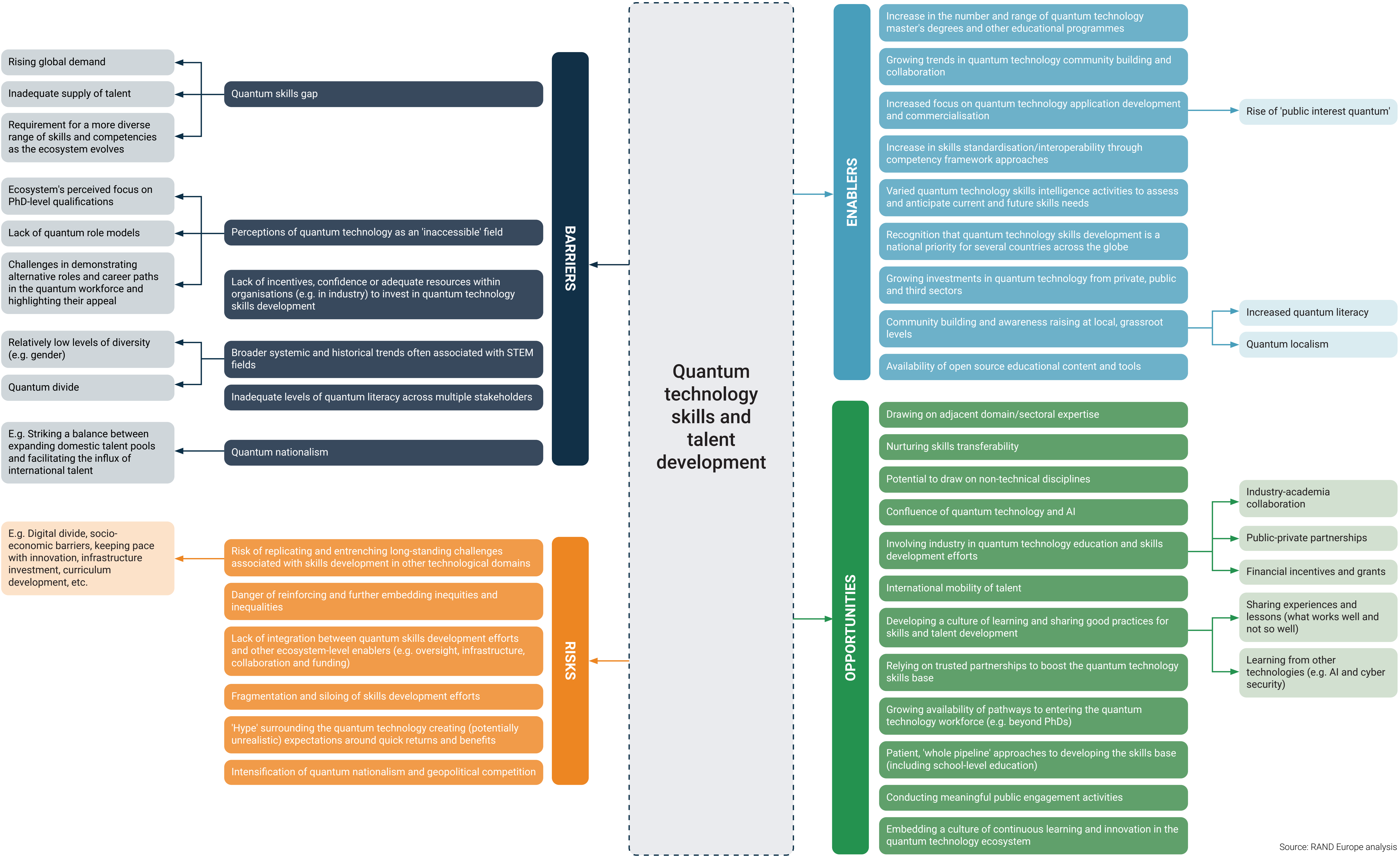
The key components of the European Competence Framework for Quantum Technologies include:

- A proficiency triangle that provides a multidimensional approach to assessing proficiency relating to three key dimensions: quantum concepts (e.g. mathematical foundations, quantum physics), quantum technology hardware and software engineering (e.g. qubit realisation, quantum programming languages), and applications and strategies (e.g. knowledge of specific application areas such as quantum for logistics optimisation, understanding impacts and ethical implications of quantum technologies).
- A set of associated proficiency levels inspired by language qualification labels, ranging from awareness to innovation.
- Several qualifications reflecting different combinations of skills – including profiles such as quantum engineering professionals, quantum technology product strategists and core innovators.

The Framework is expected to serve a series of functions, including planning educational activities (from workshops to full study programmes), helping individuals articulate their qualifications and goals and identify training needs, and helping companies articulate qualifications needed and identify gaps. It also plays a broader standardisation function (for instance, by providing alignment with proficiency descriptors that are aligned with other common frameworks such as the European Qualification Framework (EQF) (Cedefop 2025a) or the European Credit Transfer and Accumulation System (ECTS) (European Education Area 2022).

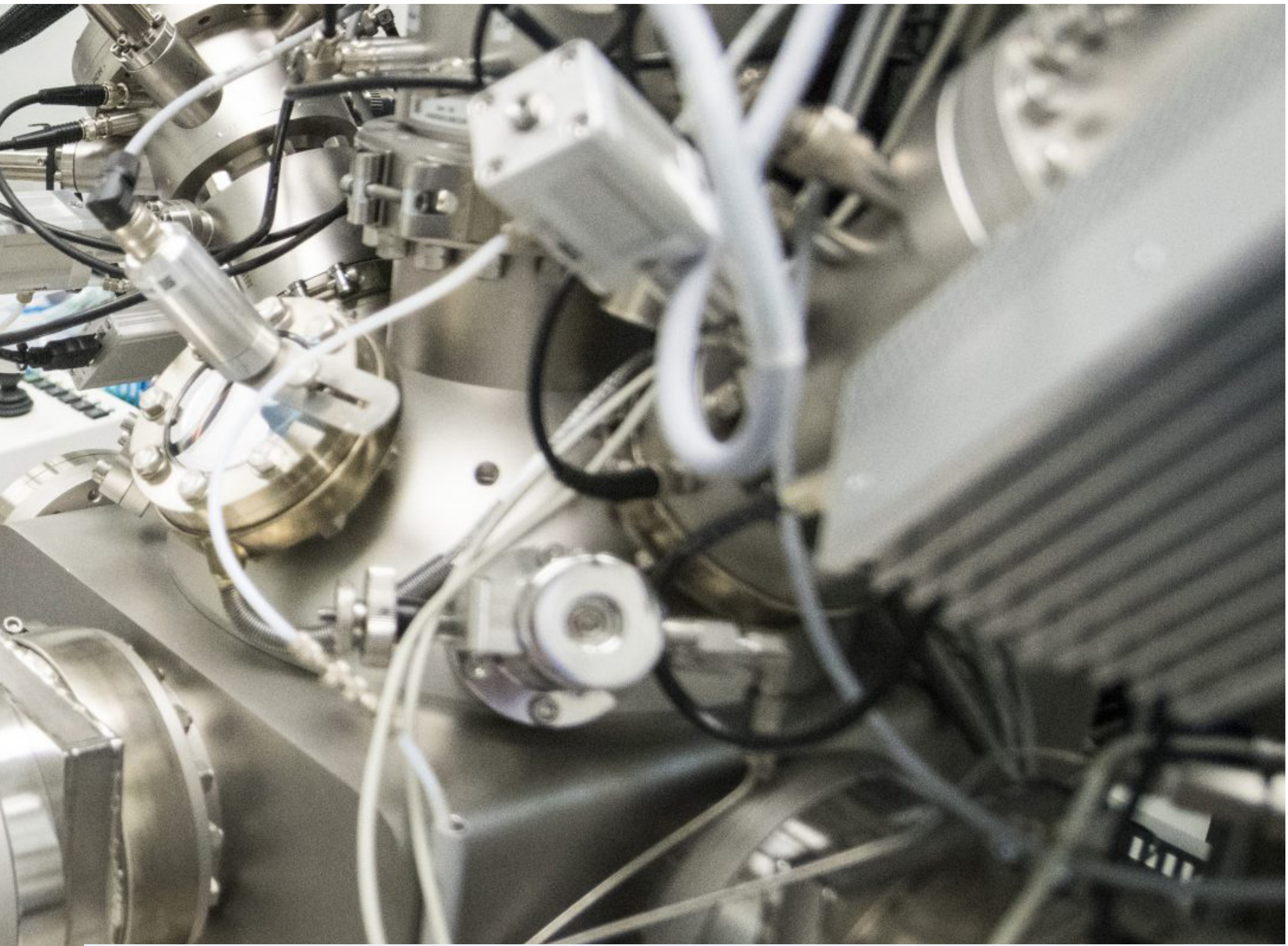
The development of the European Competence Framework for Quantum Technologies was informed by extensive industry input to ensure its alignment with real-world needs. This input was gathered through a series of interviews with representatives from various quantum technology companies, ranging from startups to large corporations across Europe.

Figure 2: Mind map illustrating a selection of key dimensions associated with the challenges and opportunities to strengthen the quantum technology skills ecosystem (based on discussions at the roundtable)



Source: RAND Europe analysis

3. Looking to the future: Cross-cutting policy considerations and actions to enable the responsible development of skills and talent for quantum technology



Key takeaways

Policy considerations to address issues related to quantum technology skills, talent and workforce development:

CONNECTING, COLLABORATING AND COMMUNITY BUILDING

Policy consideration 1: Join forces with trusted partners
Establishing and nurturing cross-cutting partnerships between various stakeholders – notably academia and industry – can help bridge the quantum technology skills gap.

Policy consideration 2: Leverage the local
While global and national efforts to develop quantum technology skills and talent are key, it is equally important to focus on tailored initiatives and activities aimed at enhancing regional and local quantum technology ecosystems.

Policy consideration 3: Forge inclusive public outreach and learning practices
Implementing comprehensive and inclusive public education initiatives focused on quantum literacy to enhance awareness, accessibility and understanding of quantum technologies could help cultivate interest and attract potential talent from a diverse range of sources.

EXPANDING AND DIVERSIFYING SKILLS AND PERSPECTIVES

Policy consideration 4: Broaden the range of skillsets
Beyond technical skills directly associated with quantum technology, non-technical competencies and adjacent domain expertise are crucial to facilitate the effective development and commercialisation of the technology and its applications.

Policy consideration 5: Embed public interest and social-good thinking
To responsibly address potential risks and equitably share the benefits of adopting quantum technologies, and to develop effective governance frameworks, it is important to integrate social sciences, arts and humanities, alongside ethical and legal perspectives.

APPROACHING SKILLS SYSTEMS HOLISTICALLY WITH FORWARD PLANNING

Policy consideration 6: Develop alternative and flexible learning routes
Creating more adaptable and modular learning pathways is important to allow professionals from various backgrounds to continuously gain quantum skills throughout different phases of their careers.

Policy consideration 7: Apply broad skills frameworks strategies
Adopting a systematic approach based on comprehensive competency and skills frameworks could enhance assessment and anticipation of skills needs within the quantum technology ecosystem.

Policy consideration 8: Actively prepare for future developments
Embracing proactive skills monitoring and foresight strategies is vital to obtain evidence-based insights into the dynamic, evolving supply and demand landscape for quantum technology skills.

Source: RAND Europe analysis

Considering the breadth, pace and nature of cutting-edge research and innovation activities worldwide, 2025 could be a pivotal year for quantum technology. To commemorate 100 years since the development of quantum mechanics, **the UN has declared 2025 the International Year of Quantum Science and Technology** (IYQ 2025). As highlighted in this report, the challenges and opportunities related to the development and adoption of quantum technologies are numerous, diverse and complex. Addressing these evolving issues at this opportune moment will require a **proactive and coordinated approach involving dialogue and iteration among multiple stakeholders** from the public, private and third sectors across the globe (Gunashekar et al. 2022). Government and industry stakeholders are also contending with the challenge of **balancing investments in quantum technology with uncertainties** concerning its maturity and scalability.

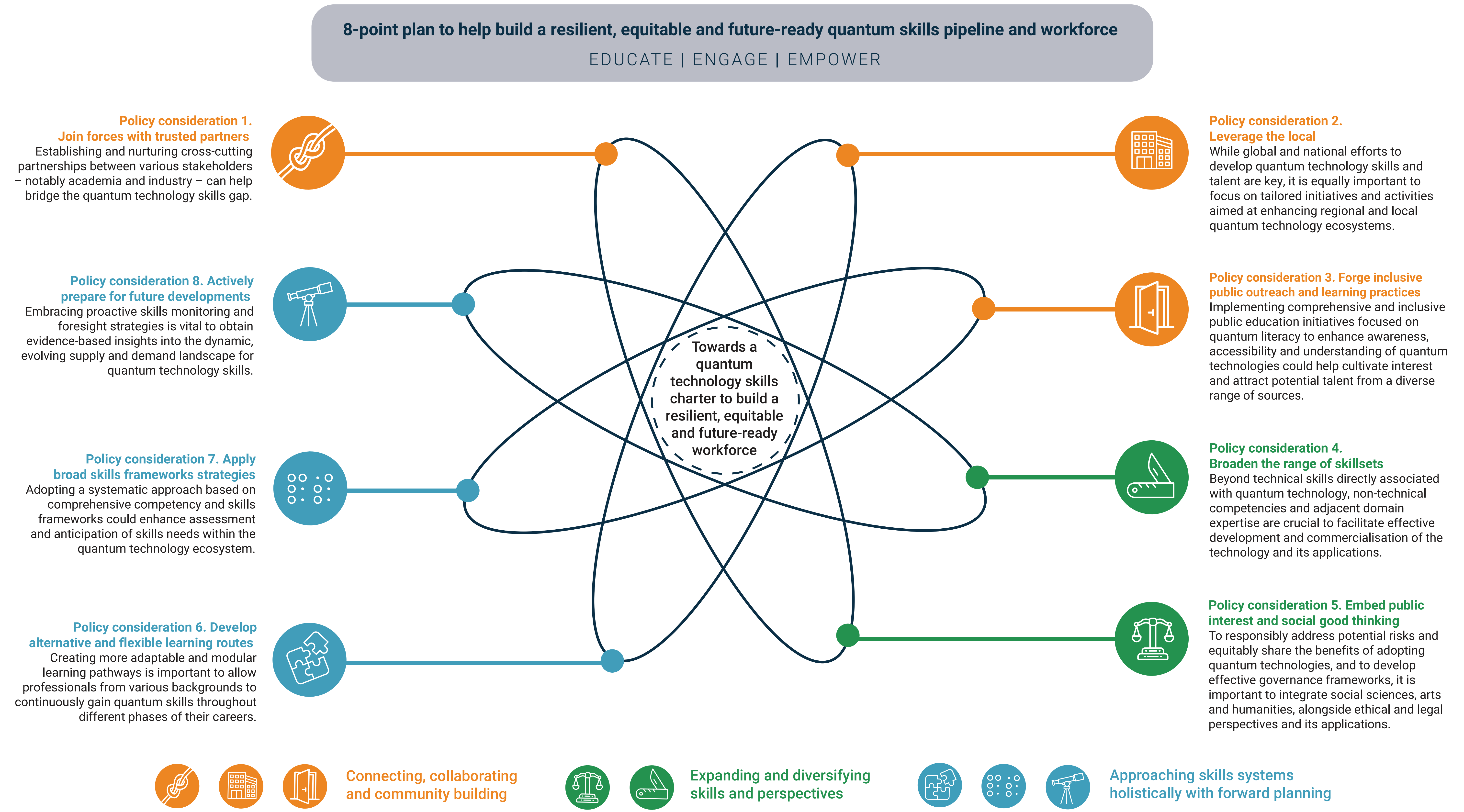
Based on the discussions at the roundtable, the sections below outline **eight high-level, cross-cutting policy considerations and exemplar enabling actions** that stakeholders within the broader quantum technology ecosystem could take to address issues associated with skills, talent and workforce development. We recognise that many of these ideas will require **careful planning and coordination, appropriate incentives** and **sustained long-term investment** involving **public and private sector and civil society entities** in the quantum technology educational and workforce landscape. As emphasised above, these policy considerations should be assessed together with **wider, system-level structural measures in countries, including, for example, immigration and visa policies** – particularly if establishing a **world-leading quantum workforce that also draws international talent** is a long-term goal.[16] Furthermore, it is vital that these proposed actions are not considered in isolation, but rather in conjunction with various activities and initiatives related to **broader quantum technology governance matters** that seek to responsibly develop the technology while balancing opportunities and risks. Concurrently, it is important that the **effectiveness of the various strategies is regularly assessed and revised**, and that **experiences, good practice and lessons learned (including, where relevant from other technological domains like AI and cyber security) are shared** among relevant quantum technology stakeholders.

Taken together, these eight policy considerations can be regarded as a set of **cross-cutting principles intended to guide stakeholders** in proactively and comprehensively addressing issues, with the aim of developing a more **resilient, equitable and future-ready quantum technology skills pipeline and workforce**. We believe that these principles could underpin a future '**Quantum Technology Skills Charter**', articulating a **collective statement of intent, ambition and commitment among stakeholders** including public, private and third sector entities. This charter could facilitate focused and coordinated efforts and actions to actively address the key challenges related to quantum technology skills and the broader workforce.

In the following sections, each of these policy considerations and examples of associated enabling actions – summarised in the infographic below (Figure 3) – is discussed in turn. We organise the eight policy considerations into **three colour-coded clusters**, each reflecting common themes across the respective policy considerations. Policy considerations 1, 2 and 3 (**in orange**) primarily focus on actions related to **connecting, collaborating and community building** concerning the development of the quantum technology skills pipeline and workforce. Policy considerations 4 and 5 (**in green**) pertain to actions aimed at **expanding and diversifying skills and perspectives**. Lastly, policy considerations 6, 7 and 8 (**in blue**) are associated **approaching skills systems holistically with forward planning** within the broader quantum technology ecosystem.

16 E.g. to address the quantum skills gap, how can countries, if at all, strike a balance between expanding (and upskilling/reskilling) their domestic talent pool and facilitating the influx of international talent?

Figure 3: Eight policy considerations for stakeholders within the quantum technology ecosystem to address issues related to skills, talent and workforce development (note: policy considerations are organised into three colour-coded clusters, each reflecting common themes: connecting, collaborating and community building; expanding and diversifying skills and perspectives; and approaching skills systems holistically with forward planning)



Source: RAND Europe analysis

3.1. Connecting, collaborating and community building

3.1.1. Policy consideration 1: Join forces with trusted partners

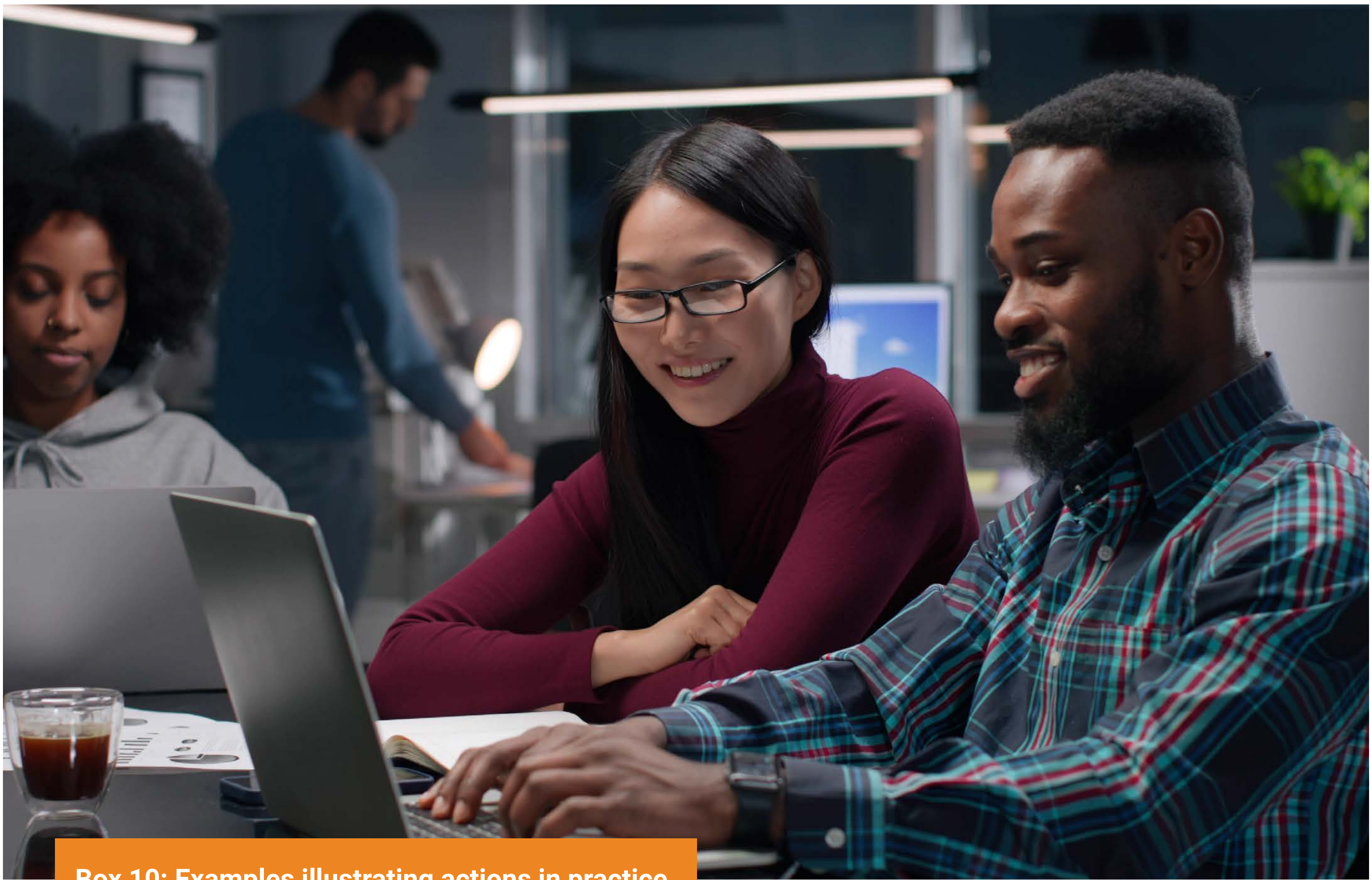
Establishing and nurturing cross-cutting partnerships between various stakeholders – notably academia and industry – can help bridge the quantum technology skills gap.

Context: The global quantum technology landscape encompasses a growing array of initiatives (e.g. government strategies, industry roadmaps, grassroot activities) designed to enhance quantum technology research and innovation across national, regional and international dimensions. Strengthening trusted and long-term collaborations between academic institutions and industry is crucial to ensure that quantum technology educational programmes remain relevant and aligned with practical requirements in the evolving and advancing ecosystem. These partnerships also provide the industry with a skilled talent pool, helping drive innovation and growth. While industry-academia cooperation appears to be growing, bolstering new sustainable and mutually beneficial forms of collaboration will play an important role in supporting and growing the quantum technology ecosystem. In addition, in the long run, these partnerships and alliances could potentially help and improve employment pathways for individuals considering a move from academia to industry – for example, by equipping them with skills that align more directly with industry needs.

Enabling actions: For this policy consideration, we offer a range of **enabling actions** for stakeholders to consider in their ongoing skills, education and workforce-related initiatives and planning, to prepare for – and positively shape – the rapidly evolving landscape of quantum technology:

- Work together to **align educational curricula with current and future industry needs**,[17] ensuring that the skills taught and learned in academic settings are directly applicable to practical applications.
- Co-design **joint initiatives and activities** – including **collaborative training/degree programmes, internships/placements, apprenticeships, vocational courses, scholarships** and **research fellowships** – that provide students and professionals with hands-on experience and exposure to cutting-edge quantum technology topics (e.g. in a business/research/laboratory setting).
- Explore collaboration formats that enable **theoretical research from academia to be combined with practical insights and resources from industry**, potentially accelerating the development and commercialisation of new quantum solutions.
- More generally, nurture **interdisciplinary research teams**, drawing on diverse expertise that transcends traditional disciplinary boundaries to tackle complex challenges and ultimately strengthen the entire quantum technology ecosystem.

17 As previously noted, achieving a balance is crucial. While aligning educational curricula with industry needs is important, it is equally vital to avoid an overreliance on industry demand to steer the development of quantum skills programmes and initiatives. Such dependence could potentially prioritise relatively short-term needs at the expense of longer-term educational goals.



Box 10: Examples illustrating actions in practice

- The NVIDIA **CUDA-Q Academic** programme was developed in collaboration with several academic institutions and is designed to support student learning (NVIDIA 2024). More information about CUDA-Q Academy is provided in Box 6.
- The **QTIndu Project** brings together several academic institutions and aims to develop industry-targeted training materials (QTIndu 2025).
- **Japan's New Energy and Industrial Technology Development Organization (NEDO)** launched a ¥200m challenge prize competition looking for use cases where quantum computing can help solve societal challenges (NEDO 2025). The NEDO Challenge is designed to be inclusive of diverse participant profiles and to foster interdisciplinarity. It is open to individuals without prior quantum expertise (who will be offered free preparatory courses), or who come from various fields, such as 'corporate researchers and International Mathematical Olympiad participants' (NEDO 2025).

3.1.2. Policy consideration 2: Leverage the local

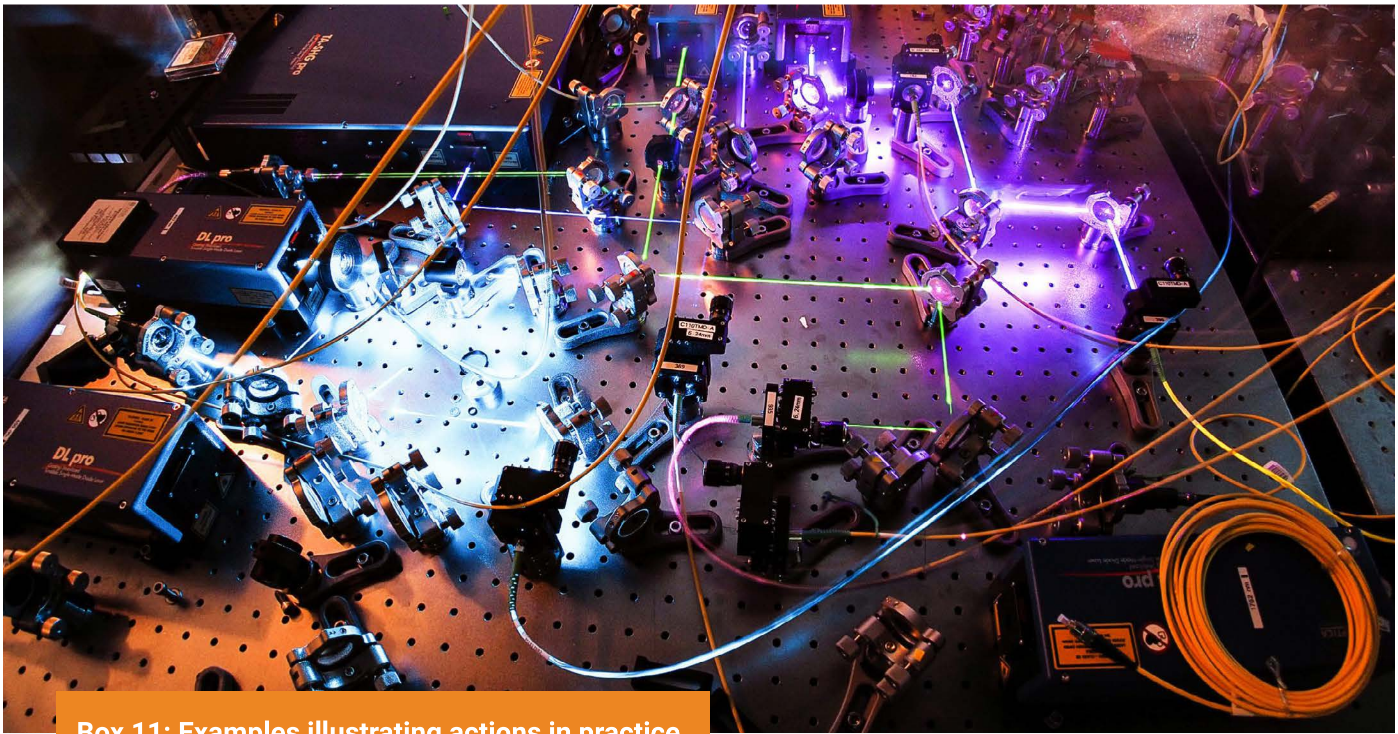
While global and national efforts to develop quantum technology skills and talent are key, it is equally important to focus on tailored initiatives and activities aimed at enhancing regional and local quantum technology ecosystems.

Context: While global and national initiatives are essential to advancing quantum technology skills, these alone will not be sufficient. Mobilising local ecosystems is crucial to address the skills gap by tapping into the pools of potential talent. Lessons from other fields suggest that rapid development occurs where talent, infrastructure and educational and employment opportunities intersect – for instance, the advanced manufacturing cluster in Singapore (EDB Singapore 2021), or the various life sciences clusters in cities such as Boston (City of Boston 2025), Basel (Basel Area 2025), Cambridge (Fell 2023) and Copenhagen (Innovation District Copenhagen 2024). Participants pointed out that Europe and local regions across the continent have potential to replicate this success for quantum technology. An approach centred on 'quantum technology localism' could encompass initiatives by local decision makers aimed at managing the use and integration of quantum technology developments within their local or regional communities. Overall, these localised efforts can help ensure that the benefits of advances in quantum technology are distributed across different communities, as well as being aligned with regional economic priorities and opportunities. Furthermore, any local or regional innovation quantum technology 'hubs' that develop could, over time, also function as magnets attracting international talent.

Enabling actions: For this policy consideration, we offer a range of **enabling actions** for stakeholders to consider in their ongoing skills, education and workforce-related initiatives and planning, to prepare for – and positively shape – the rapidly evolving landscape of quantum technology:

- Adopt a strategic approach to **investing in (physical) quantum infrastructure and facilities at the local level**, with a focus on areas that show potential to nurture further development of quantum technology activities, opportunities – and thus talent.[18]
- **Support local startups and small and medium-sized enterprises (SMEs)** (including local branches of quantum technology companies) **in the quantum technology** sector, along with **research institutes/ universities**, to attract investment, stimulate economic activity and help create jobs.
- **Customise educational programmes in regional quantum technology ecosystems to address the specific needs of local industries and research institutions**, thereby enhancing the relevance and applicability of training.
- **Engage with local communities at a grassroots level**, to not only help raise awareness but also make quantum technology a more attractive and attainable potential career path (also see policy consideration 3). This could involve, for instance, utilising initiatives such as industry fairs, science festivals, careers fairs, public talks and interactive workshops to engage local communities.
- **Develop and leverage local expertise**, encompassing innovation hubs, incubators and clusters, and community-based organisations, networks and related initiatives (including career support activities).

18 This can potentially be paired with targeted regional strategies and policies.



Box 11: Examples illustrating actions in practice

- Founded in 2021, the **Danish Quantum Community** is a multistakeholder initiative dedicated to building a cohesive quantum ecosystem in Denmark and enhancing Denmark's capabilities and efforts in quantum research and technologies. Its mission is to 'increase knowledge about quantum technology, improve conditions for research and innovation and illustrate applications of quantum technology' (Danish Quantum Community 2025). It consists of over 50 partners from the wider Danish quantum ecosystem, encompassing startups, established firms, universities, funding bodies, industry associations, quantum end users and others. Education and talent are key focus areas of this initiative.

- Funded by the Department of Science, Technology, and Innovation in South Africa, the **South African Quantum Technology Initiative (SA QuTI)** aims to 'create the conditions for a globally competitive research environment in quantum technology and grow a local quantum technology industry in South Africa' (SA QuTI 2025).

- Several **Scottish academic institutions and industry bodies** have partnered to build on Scotland's photonics cluster (key to certain quantum technology hardware) and develop local skills and capacity in quantum applications (Technology Scotland and Photonics Scotland 2023).

- The **Harwell Quantum Cluster** (Harwell Campus 2025) hosts the National Quantum Computing Centre (NQCC), a national laboratory opened in the UK in October 2024 (Harwell Campus 2024) with a £93m investment. NQCC will house 12 quantum computers currently in development. The Harwell Campus aims to host a broader quantum community, integrating expertise in communications, sensing and imaging, and enabling multidisciplinary collaboration with the other clusters housed in application areas such as space, energy and health technology.

3.1.3. Policy consideration 3: Forge inclusive public outreach and learning practices

Implementing comprehensive and inclusive public education initiatives focused on quantum literacy to enhance awareness, accessibility and understanding of quantum technologies could help cultivate interest and attract potential talent from a diverse range of sources.

Context: As quantum technologies continue to develop and impact various aspects of society and industry, ensuring widespread literacy in this field is vital to foster inclusivity and innovation. The emergence of the quantum workforce presents a crucial juncture where historic patterns that have often resulted in entrenched inequalities and imbalances within STEM fields can either be perpetuated or overcome.[19] Ensuring that quantum technology education initiatives are accessible to a broader cross-section of society, irrespective of socio-economic background, is crucial to democratise access and reduce barriers to entry. By designing initiatives and learning pathways that accommodate diverse backgrounds and interests, quantum technology education initiatives can potentially draw talent from a wide range of fields. This approach will not only enrich the quantum technology sector with diverse perspectives and ideas but could also promote social equity by providing opportunities for under-represented communities. By creating and sustaining a more inclusive environment, the field of quantum technology could set a precedent for other STEM areas by avoiding a potential 'quantum divide'[20] and leading to a more equitable and innovative future ecosystem.

Enabling actions: For this policy consideration, we offer a range of **enabling actions** for stakeholders to consider in their ongoing skills, education and workforce-related initiatives and planning, to prepare for – and positively shape – the rapidly evolving landscape of quantum technology:

- **Develop a holistic understanding of the specific barriers to participation different groups face in the quantum workforce** – this could be achieved through dedicated engagement and research activities that explore potential factors at various levels, ranging from **individual**[21] to **institutional**[22] and **systemic**.[23]
- **Create accessible learning opportunities**, for example:
  - » **Providing free or affordable, self-paced (online) resources or community workshops** to help bridge the gap for groups who are under-represented in the quantum workforce.
  - » **Actively considering the needs of different individuals** when designing learning activities.[24]

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19 This has been highlighted previously in convenings such as that reported by Aiello et al (2021).

20 E.g. a digital divide in terms of emerging disparities and inequalities among different countries, research communities, and organisations regarding access to, understanding of, and ability to leverage quantum technologies. This divide could manifest in various forms, reflecting differences in technological capabilities, research advancements, workforce readiness and wider economic benefits.

21 E.g. awareness, accessibility, time, interest.

22 E.g. curriculum design, affordability of training.

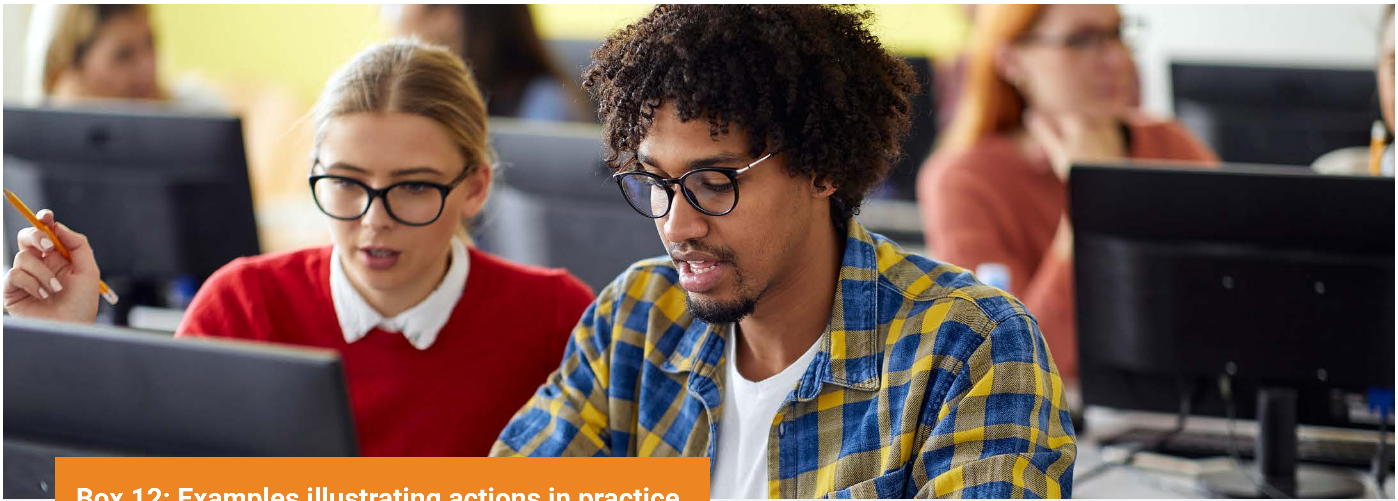
23 E.g. biases based on factors such as gender, race, nationality, disability, neurodiversity, etc., or low levels of public funding for lifelong learning.

24 Factors that might affect individuals' access might include caring responsibilities, transportation and opportunity costs, different learning styles, etc.

  - » Where appropriate, **delivering specialised programmes** targeting groups who are under-represented in STEM, while also ensuring these groups have access to mainstream learning opportunities.

- **Invest appropriate time and resources in developing skills for, and supporting, public awareness and engagement activities related to quantum technologies. This could include leveraging (local) initiatives such as public lectures and seminars, science fairs, interactive workshops, mentoring schemes[25] and outreach programmes** to engage broader audiences and demystify quantum technology, highlighting its real-world applications and benefits, while also explaining potential risks (also see policy consideration 2).
- **Integrate relevant quantum technology concepts into educational curricula across various levels** – from primary schools to universities – to stimulate curiosity and interest among students. **Interactive** and **hands-on approaches** – such as games-based approaches, practical demonstrations, online tutorials, interactive visualisations, hackathons and competitions – can help make complex quantum topics more tangible and appealing. If interest is ignited early, students are more likely to pursue further studies and careers in quantum technology-related fields.
- **Develop viable alternative career entry points into the quantum technology industry** – for instance through internship and apprenticeship programmes (also see policy consideration 6).
- Draw on **recent good practices and lessons from the career guidance/advisory domain in similarly fast-evolving fields** (e.g. AI, cyber security, green energy, etc.) and engage with organisations that have effectively created sustainable career opportunities for different groups in these fields.
- At the international level, work towards **bridging the gap in quantum skills and access to skills between low- and middle-income (LMICs) and high-income countries (HICs),** through scientific cooperation initiatives including funding opportunities for LMIC researchers, investing in collaboration and network-building programmes, and providing shared access to research infrastructure.

25 Mentors can offer aspiring 'quantum professionals' and students guidance and support in navigating the complexities of quantum technology, providing practical insights and sharing their expertise. More broadly, role models and 'quantum champions' can provide inspiration by demonstrating successful career paths and achievements in quantum technology, thereby motivating potential new entrants to pursue careers in this field.



Box 12: Examples illustrating actions in practice

- **Girls in Quantum** (see Box 5 in Section 2.2 for more information) is a student-led initiative dedicated to inspiring and empowering girls to get involved in quantum computing (Girls in Quantum 2025).

- **Women in Quantum Development (WIQD)** is a professional network operating in the Netherlands' quantum technology sector. Its mission is to 'connect and retain underrepresented groups in the quantum sector in the Netherlands through support, networking, and community growth' (WIQD 2025). It regularly organises activities and events such as hackathons, symposia, talks and mentoring programmes.

- **Science Melting Pot** is a grassroots initiative based in Denmark that focuses on providing training and consulting to improve equity, diversity and inclusion in STEM and medicine fields. It also supports science communication efforts, helping researchers engage with the public and disseminate their work more broadly (Science Melting Pot 2025). The organisation's project portfolio encompasses several quantum science and technology-focused initiatives such as game design, workshops and videos (Science Melting Pot 2025).

- **High5Girls** is a Denmark-based organisation that encourages women into science and technology through a variety of activities such as facilitating connections with role models working in STEM, organising camps, mother/daughter evenings, and community building activities (High5Girls 2025).

- **The UK Quantum Ambassadors Programme** is an example of a programme focused on engaging secondary education students. The initiative aims to inspire students aged 16 to 19 by engaging them in the latest science and technology developments. It supports teachers in leading quantum physics activities with STEM Ambassadors, covering advancements from the 'first quantum revolution' to future technologies (STEM Learning 2025).

- The UK's **National Physical Laboratory** runs an **apprenticeship scheme** that complements traditional routes into physics careers; this includes a quantum technology-focused apprenticeship programme (National Physical Laboratory 2023).

- The Open Quantum Institute (OQI) developed an **OQI Hackathon in a Box guide** (OQI 2025). The 'quantathon' approach aims to 'mitigate the quantum digital divide' and help 'develop applications for the benefit of humanity' by focusing ideation efforts on addressing the UN Sustainable Development Goals (UN 2015) through quantum computing, particularly in low resource settings.

3.2. Expanding and diversifying skills and perspectives

3.2.1. Policy consideration 4: Broaden the range of skillsets

Beyond technical skills directly associated with quantum technology, non-technical competencies and adjacent domain expertise are crucial to facilitate the effective development and commercialisation of the technology and its applications.

Context: The quantum technology ecosystem is becoming increasingly interdisciplinary, drawing expertise from diverse fields and sectors to advance its development and capacity-building efforts. In addition to hard technical (including quantum) skills, it is vital to broaden and diversify the skills base to encompass non-technical competencies as well as adjacent domain/sectoral expertise. Workforces increasingly require employees who possess not only the technical expertise to engage with new and emerging technologies, but also the soft skills and subject matter expertise necessary for collaboration and commercialisation in increasingly digitalised environments. By integrating non-technical skills with quantum expertise, organisations can enhance their ability to capitalise on emerging quantum technologies in a more holistic manner. Furthermore, it is important to highlight opportunities within the quantum technology ecosystem for 'non-quantum' experts who possess expertise in other domains, such as the life sciences, energy, finance or policymaking (see Section 2.1 for further information).

Enabling actions: For this policy consideration, we offer a range of **enabling actions** for stakeholders to consider in their ongoing skills, education and workforce-related initiatives and planning, to prepare for – and positively shape – the rapidly evolving landscape of quantum technology:

- Support the **development and integration of transversal skills**, including:
  - **Business and management expertise, and entrepreneurial skills**, enabling individuals and organisations to navigate market dynamics and identify viable pathways to bring quantum innovations to market.
  - **Commercial knowledge**, which is essential to understanding areas such as complex regulatory environments, intellectual property management and effective marketing strategies, all of which are important factors in potentially scaling quantum technologies over time.
  - **Leadership and mentoring skills**, which can play a pivotal role in guiding multi- and inter-disciplinary teams, fostering an environment of innovation and driving strategic decision making processes (including identifying areas where quantum technology could potentially be applied in the future (also see policy consideration 8)).
- Facilitate the recognition and leverage of 'soft', transversal skills by **including them as part of competence frameworks, certifications** and other **quantum ecosystem activities**.
- Create specific opportunities for **adjacent domain/sectoral experts (e.g. with knowledge of potential quantum application areas) to actively engage and collaborate within the quantum technology ecosystem** (see Section 2.1) – for example, by incentivising interdisciplinary employment opportunities and research projects (within quantum technology companies/research institutes), learning activities and other collaborative initiatives; and providing training/upskilling opportunities for stakeholders such as policymakers and civil servants.

Box 13: Examples illustrating actions in practice

- The **European Competence Framework for Quantum Technologies** recognises qualification profiles focused on quantum applications and strategies, which are presented as complementary to the science or engineering profiles traditionally associated with quantum technology roles (Greinert & Müller 2024) (see Box 9 for a more detailed description of the Framework).

- The UK Digital Catapult's **Quantum Technology Access Programme (QTAP)** is a programme aimed at industry leaders working in sectors relevant to quantum technology applications (Innovate UK 2025). The programme provides participants with the opportunity to develop use cases relevant to their business area, receive training, access cutting-edge software and hardware, and receive support from quantum industry partners.

- The **Novo Nordisk Foundation Quantum Computing Programme (NQCP) Education and Outreach Group** carries out a range of activities targeted at helping build a 'quantum-ready workforce' and 'creating quantum awareness' (NQCP 2024). For example, it is currently working on an initiative focused on teaching quantum technology concepts to non-specialists such as 'investors, IT professionals, lawyers, and state organisations,' with the goal of increasing the accessibility of quantum knowledge to a wider audience (NQCP 2024).

3.2.2. Policy consideration 5: Embed public interest and social good thinking

To responsibly address potential risks and equitably share the benefits of adopting quantum technologies, and to develop effective governance frameworks, it is important to integrate social sciences, arts and humanities, alongside ethical and legal perspectives.

Context: Quantum technologies present transformative potential, but also pose several societal challenges, with possible impacts on privacy, security, concentration of technological power, access to the technology and wider public trust. Given the rapid advancement of quantum technologies, it is increasingly important to examine the social sciences and humanities considerations associated with the technology and the overall responsible development of the ecosystem.[26] At a wider societal level, the availability of and access to quantum technologies, along with the education, skills and training required to develop and utilise the technologies, remains uncertain. Incorporating an ethical lens can ensure that quantum technologies are developed and applied in ways that foster fairness and do not exacerbate existing societal inequalities. In the long run, integrating these varied perspectives can enable policymakers and other interested stakeholders to establish comprehensive governance frameworks that both mitigate risks and leverage the benefits of quantum technologies for broader society.

Enabling actions: For this policy consideration, we offer a range of **enabling actions** for stakeholders to consider in their ongoing skills, education and workforce-related initiatives and planning, to prepare for – and positively shape – the rapidly evolving landscape of quantum technology:

- Support **interdisciplinary collaboration with social sciences, humanities and arts disciplines**, examining how quantum technologies affect social structures and issues such as privacy, security and public trust. More broadly, incorporating these perspectives into a technical field like quantum technology may **facilitate the delivery of insights and the development of methods** that ensure broader quantum technology policy – including governance – align with public interest.
- **Integrate ethics perspectives into quantum education programmes** (alongside broader scientific debate and governance efforts), allowing the ecosystem to address questions related to equity, justice and the broader human implications of quantum technologies. This could also include, for example, courses aimed at enhancing companies' and workers' understanding of the challenges posed by quantum technology, while equipping them with tools to address these challenges responsibly.
- Support the development of **quantum technology-focused legal expertise within the ecosystem**. Legal perspectives can form the foundation for development of more effective governance frameworks that balance innovation with safeguarding of public interests.
- Upskill and educate the quantum technology workforce in **responsible research and innovation practices and approaches** – for example, by providing practical tools to implement responsible quantum technology principles and by drawing on lessons and good practice from other emerging technology areas – both current and historic – that have encountered similar challenges and needs.[27]

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26 More broadly, SHAPE (social sciences, humanities and the arts for people and the economy) is a relatively new collective designation used by the British Academy and UK Research and Innovation (UKRI) for the social sciences, humanities and arts (The British Academy 2025).

27 See, for example, the historical analysis studies of technological development conducted by Gunashekar et al. (2019) and Vermeer (2024).

- **Support public awareness and engagement activities** for quantum technologies (see policy consideration 3) – this could also include **in-depth, deliberative approaches** aimed at enabling groups of individuals to explore consensus and surface uncertainties, risks, values and ethical implications related to quantum technologies.[28]

Box 14: Examples illustrating actions in practice

- Recognising the 100-year milestone since the inception of quantum mechanics, the **International Year of Quantum Science & Technology (IYQ) 2025** is a UN-endorsed initiative that aims to raise public awareness around quantum science and technology and its applications (IYQ 2025). During 2025, events of varying format and covering different topics will be delivered across the globe to celebrate IYQ. Participation in the initiative is guided by a set of principles for public engagement with quantum technologies – including 'recognise consensus, honour dissent, and admit ignorance' and 'help others find reliable quantum information,' among others – indicating commitment to a purposeful and inclusive approach to public engagement.

- The **World Economic Forum Quantum Computing Governance Principles** examine the broad implications of quantum computing for different sectors and industries, highlighting both risks and opportunities (World Economic Forum 2022). The principles outline a set of values that should inform the governance of quantum computing, including principles such as transparency, common good, non-maleficence, equitability, inclusiveness, accountability and accessibility. The principles were developed through a consensus-based decision-making method that involved multiple stakeholder groups.

- The **LIFE Foundation** in Denmark has a mission to 'to strengthen the interest and aspirations among children and adolescents to engage with and choose an education within natural sciences and technology regardless of their background' (LIFE 2025a). It aims to engage young audiences and promote STEM fields to address societal challenges, including the UN Sustainable Development Goals. It develops courses and teaching materials, and carries out other related activities, including, for example, in quantum communications (LIFE 2025b).

28 Evidence suggests that deliberative public engagement approaches, which frequently utilise structured processes and facilitated discussions to explore a topic in depth, extending beyond traditional consultation methods, are particularly well-suited to addressing complex topics and informing ethical and policy considerations (d'Angelo et al. 2021).

3.3. Approaching skills systems holistically with forward planning

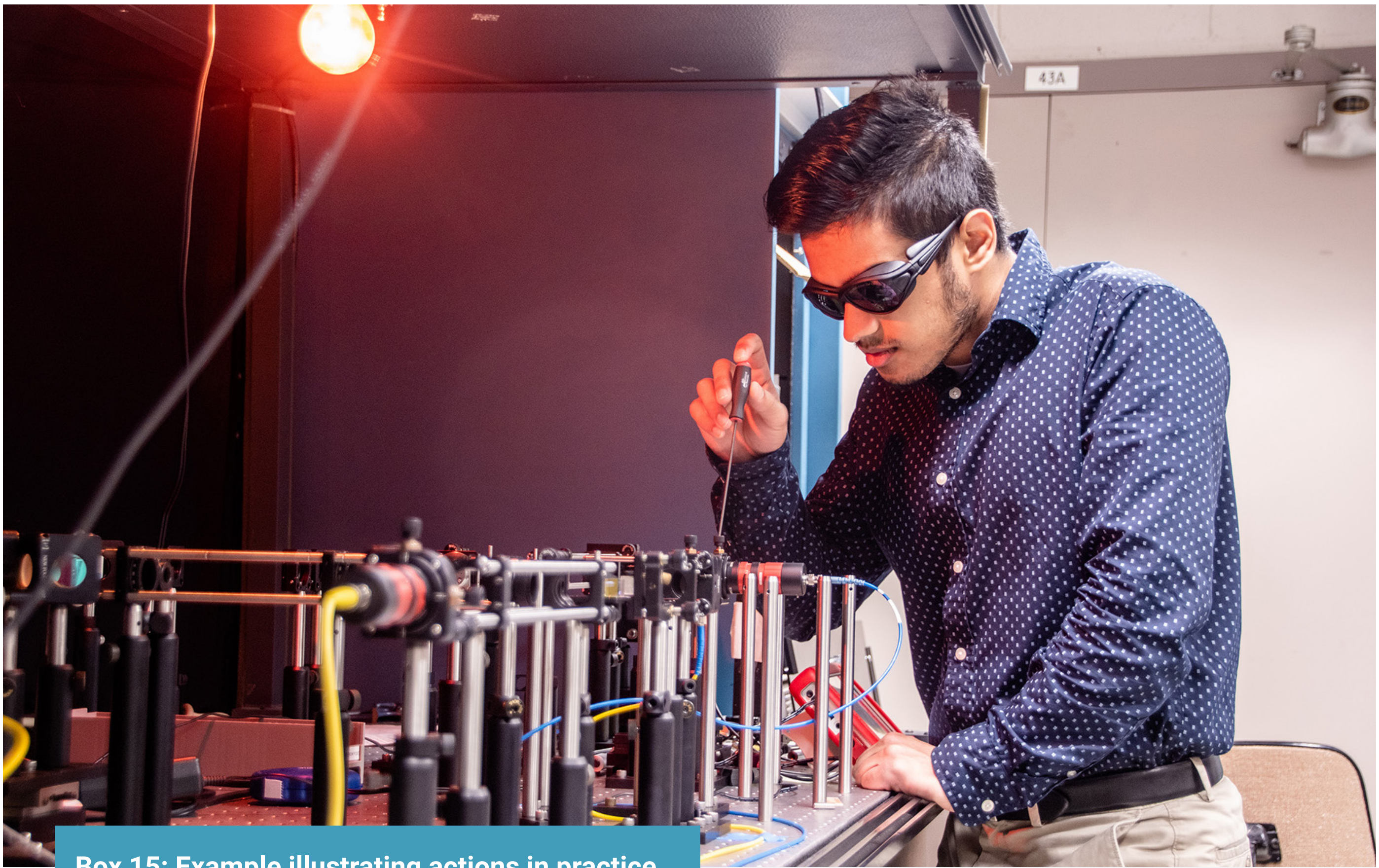
3.3.1. Policy consideration 6: Develop alternative and flexible learning routes

Creating more adaptable and modular learning pathways is important to allow professionals from various backgrounds to continuously gain quantum skills throughout different phases of their careers.

Context: As quantum technologies advance, the demand for new skill sets will rise. Furthermore, a persistent challenge with skills in advanced technological domains is the rapid pace of change, where the skills required today may become obsolete tomorrow. These are factors that both employers and employees in the wider quantum technology ecosystem must consider carefully. Flexible and modular learning pathways in quantum technology could enable continuous education, allowing professionals to regularly update their skills and keep pace with technological advancements. This model can help promote a culture of lifelong learning, enabling individuals to upskill or reskill as required throughout their careers. Overall, this approach recognises the dynamic nature of both quantum technology as a field and its workforce, and the need for continuous learning in a rapidly evolving technological landscape. It could help build a workforce that, in the medium to long term, is more resilient and capable of innovating and adapting to new challenges in the quantum technology domain.

Enabling actions: For this policy consideration, we offer a range of **enabling actions** for stakeholders to consider in their ongoing skills, education and workforce-related initiatives and planning, to prepare for – and positively shape – the rapidly evolving landscape of quantum technology:

- **Adopt a lifelong learning approach to quantum technology** – for example, through (tailored) workplace training programmes (including 'teach the teacher' or 'train the trainer' programmes), short courses, online tutorials, industry certifications or continuous self-directed learning. This has been well-documented in the literature as a crucial element to keeping digital skills current (Feijao et al. 2021).
- **Identify opportunities in the quantum workforce landscape for flexible learning pathways (as well as diverse and non-traditional career paths) that can allow for both vertical and lateral moves around one's learning journey** – for example, facilitating employees to develop deep (technical) expertise in one or more areas, or enabling employees to develop complementary skills such as commercialisation or leadership skills – and **invest in tailored educational workforce development initiatives that can enable such transitions**. It will also be important to create opportunities for technical specialists and researchers in related fields such as physics, computer science and engineering to acquire the specialised skills and expertise required to work in quantum technology companies.
- **Customise learning experiences to align with specific career goals and help boost employee engagement and motivation** – enabling quantum professionals to choose 'modules' that correspond to their individual interests and professional needs can result in more pertinent and effective learning outcomes.



Box 15: Example illustrating actions in practice

- Funded by the European Union, **DigiQ** is a project that aims to develop 16 specialised master's degree programmes in quantum technology across Europe to provide a 'personalised route' for students into the quantum workforce (DigiQ 2025.). It aims to design and distribute a range of multilingual educational resources across Europe and contribute to developing the quantum ecosystem through a 'pan European mobility programme.' The DigiQ project consortium consists of 24 organisations spanning ten countries across Europe.

- The **Quantum Information Research Support Center** in South Korea aims to engender a 'leap of capacity' in the local quantum ecosystem (QCenter 2025). It does so through a range of initiatives, including training and support at various levels (both within and outside of academia), the provision of a 'Quantum Fab' allowing users to access equipment and facilities, and community engagement activities.

- The European Commission's recent **Union of Skills** initiative is designed to tackle the European Union's skill and labour gap challenge (European Commission 2025). The initiative aims to achieve this through a range of actions across the skill development pipeline, from supporting basic skills development, to regular upskilling and reskilling and lifelong learning, facilitating the free movement of working within the Single Market, and attracting, developing and retaining talent, including from outside of the European Union.

3.3.2. Policy consideration 7: Apply broad skills frameworks strategies

Adopting a systematic approach based on comprehensive competency and skills frameworks could enhance assessment and anticipation of skills needs within the quantum technology ecosystem.

Context: Fast developing fields like quantum technology require the active involvement of several stakeholder groups, including industry, academia, policymakers and third sector organisations. These groups operate in different contexts, serving as providers of education and training, primary recipients of skills, and coordinators and conveners of the system. Managing such skills systems is a complex, multistakeholder process that requires integrated information systems incorporating multiple data sources and catering to several end users (OECD 2020). Understanding the dynamics of the quantum skills market and identifying appropriate intervention points is a key challenge for stakeholders to address current skill gaps. By implementing skills frameworks, stakeholders can help ensure that educational programmes, workforce training and policymaking are aligned with future trends and industry needs in the quantum technology ecosystem. Such frameworks can also offer clear and consistent language for articulating skills and competencies, thereby enhancing communication between educators, employers and policymakers.[29]

Enabling actions: For this policy consideration, we offer a range of **enabling actions** for stakeholders to consider in their ongoing skills, education and workforce-related initiatives and planning, to prepare for – and positively shape – the rapidly evolving landscape of quantum technology:

- **Design and adopt aligned skills and competency frameworks** to support the coordination of skills systems, providing a systematic, structured and standardised approach to mapping, assessing and anticipating quantum skills needs. This approach could enable more accurate identification and mapping of both current and emerging skills needed within the quantum technology ecosystem.[30]
- To maximise the effectiveness of such frameworks, it is important that stakeholders **actively integrate them into their skills development and workforce planning strategies**. This could involve, for example, embedding the framework standards in educational curricula, training programmes and workforce development initiatives across various sectors.
- **Continue to regularly assess and update existing frameworks** so that they remain relevant and keep pace with the rapid advancements in quantum technology, as well as emerging needs.

29 One of the main reasons for establishing a common skills framework or language is to potentially facilitate a shift towards a more skills-based labour system, allowing employers to select and hire talent based on individuals' skills and competencies rather than conventional qualifications like college degrees and job titles (Feijao et al. 2021).

30 If designed effectively, a unified skills framework could serve as a tool to align and match talent with the skills demands of businesses (Feijao et al. 2021). Leveraging these frameworks could also potentially enable organisations to more effectively create standardised job profiles and career pathways in quantum technologies.

- **Ensure that the standardisation offered by competency framework approaches does not come at the expense of maintaining an inclusive and flexible view of skills and learning pathways** (see policy considerations 3, 4 and 6).[31]
- In addition to recognising the wide range of roles available, **consider potential areas of complementary and transferable knowledge** that could allow individuals with qualifications gained in other industries to transitions into quantum roles.

Box 16: Example illustrating actions in practice

- Participants at the roundtable noted that the development of, and regular updates to, the **European Competence Framework for Quantum Technologies** were welcome developments for the European quantum technology ecosystem. Box 9 in Section 2.5. provides a detailed overview of the Competence Framework and its role in facilitating alignment between skills development initiatives in Europe (Greinert & Müller 2024).

31 For example, the European Competence Framework for Quantum Technologies includes a set of valorisation-related competencies, such as business strategy, entrepreneurship and management of quantum technologies, and responsibility and awareness. It also proposes several qualification profiles reflecting the diversity of potential job roles beyond those accessible to PhD level technical experts – such as quantum technology informed decision makers, or quantum technology business analysts (Greinert & Müller 2024).

3.3.3. Policy consideration 8: Actively prepare for future developments

Embracing proactive skills monitoring and foresight strategies is vital to obtain evidence-based insights into the evolving and dynamic landscape of supply and demand for quantum technology skills.

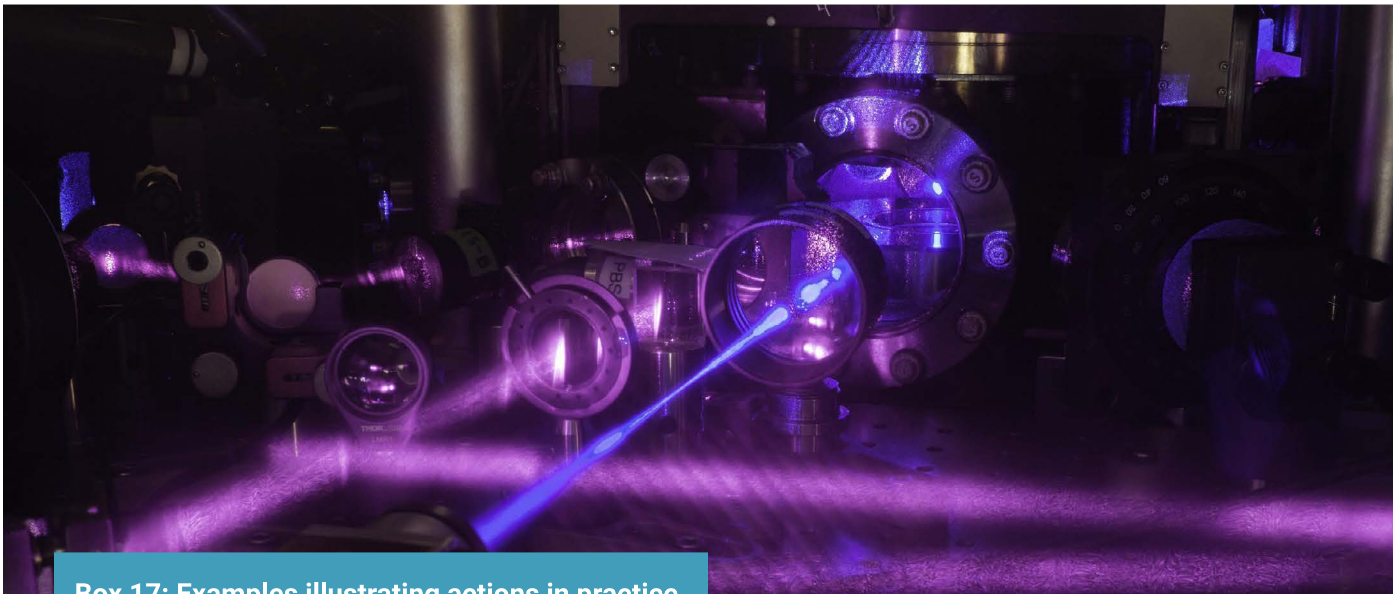
Context: Understanding the supply and demand for quantum technology skills and competencies is challenging because of the rapidly evolving nature of the scientific field itself, as well as the uncertainty associated with the direction and pace of growth of the industry. Competing qubit modalities, 'tipping points' within the technological development roadmap (such as potential breakthroughs in error correction), and external factors like supply chain disruptions or geopolitical issues (including changes in export control regimes and immigration policies) can significantly complicate the determination of specific quantum technology skills required. Traditional approaches to anticipating skills demand to inform policy at national and regional levels include forecast approaches based on econometric models extrapolating from historic trends. However, such approaches are limited by their reliance on past data, which can be unreliable in contexts characterised by high levels of uncertainty (Cedefop 2024). It is important for stakeholders to develop a dynamic, future-focused approach to collecting, compiling, analysing and disseminating insights related to quantum technology skills needs. Overall, this underscores the significance of collaboratively embedding a forward-looking, evidence-based approach to workforce and education development strategies in quantum technologies.

Enabling actions: For this policy consideration, we offer a range of **enabling actions** for stakeholders to consider in their ongoing skills, education and workforce-related initiatives and planning, to prepare for – and positively shape – the rapidly evolving landscape of quantum technology:

- **Consider developing tailored, practical tools such as skills monitors and observatories** to help understand the complexities and development of quantum technology skills supply and demand. These platforms could provide periodic, 'real-time' data and insights into emerging trends and skill requirements[32] within the quantum technology ecosystem. By systematically and proactively tracking and monitoring developments in the quantum technology landscape (e.g. via dashboards, case studies, etc.), and disseminating information and analysis tailored to the needs – both current and future – of various stakeholders, skills monitors and observatories can enhance the ability of policymakers, industry leaders and educators to make informed decisions.
- **Employ skills foresight approaches**, such as those grounded in the principles of technology foresight, and integrate horizon scanning practices and scenario planning. This will enable decision makers to proactively understand and potentially anticipate future trends (as well as envision multiple possible futures) and their implications for the demand and supply of quantum technology skills. Specifically, an anticipatory, foresight-driven approach could assist in examining and assessing uncertainties surrounding the evolution of quantum technologies skills landscape over time, facilitating better understanding of, and response to, diverse factors influencing its development.

32 E.g. identifying current and growing quantum technology skills sets; job postings; educational/training programmes; regional/national/international variations; industry/sector distributions; etc.

- **Tailor skills intelligence collection and dissemination to specific user needs** – for instance, providing real-time or regular updates, at relevant levels of granularity, could significantly increase the likelihood of skills intelligence/foresight insights achieving their intended impact.
- **Ensure that skills intelligence and foresight analysis is readily accessible and useful to relevant decision makers who would use the information** – including, for example, policymakers and industry leaders using these insights to inform skills and workforce development policies; funders/providers of training and education programmes from different sectors; and universities, other learning providers and career support services looking to understand how they can best support the development of the quantum technology skills base.



Box 17: Examples illustrating actions in practice

- As a long-running decentralised EU agency, **Cedefop** facilitates the advancement, development and execution of EU policies concerning vocational education and training (VET), alongside skills and qualifications policies (Cedefop 2025b). As part of its responsibilities, Cedefop designs and curates an array of online tools, such as databases, dashboards, scoreboards, surveys and forecasts (Cedefop 2025c).
- **Quantum Computing Report** serves as a source for regular quantum industry developments, offering news and analysis of various technical advancements, as well as information about funding, partnerships, jobs and other relevant updates worldwide (Quantum Computing Report 2025).
- The **OECD AI Policy Observatory** functions as a global point of reference for AI-related policy developments and data, offering an online platform that regularly monitors AI policies and various other data on a global scale (OECD AI Policy Observatory 2025).
- The **Green Jobs Explorer** compiles several insights on 'green' roles and the skills required to occupy them, broken down by region (Nesta 2024). The results are based on analysis of large-scale job advertisement data.

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Annex A: Description of roundtable approach

The in-person roundtable was conducted under the Chatham House Rule[33] to encourage open conversations. The views expressed during the roundtable discussions have not been attributed to specific individuals in this report. The roundtable was structured as a series of facilitated discussions and activities in both plenary and breakout groups. The structure aimed to provide a balanced mix of presentations, interactive discussions and collaborative problem-solving. The roundtable convened a wide range of participants from academia, industry, government, non-governmental organisations and charities.[34] In total, 36 participants attended.

The roundtable was structured around two key topics relevant to current development of the quantum ecosystem in Europe (as well as globally). These were: the development of skills and talent, which was addressed during *Session 1 - Skills and talent: Building the quantum workforce of tomorrow* (the findings of which are described in this report), and the strengthening of supply chains, which was the subject of *Session 2 - Supply chains: Ensuring resilience and sustainability* (the findings of which will be described in a forthcoming companion report).

Representatives of RAND Europe and the Novo Nordisk Foundation kicked off the roundtable, providing some context and a general framing for subsequent discussions on the two topics. This was followed by keynote addresses from senior quantum technology experts working as practitioners in the areas of skills and talent development and supply chain management.

Each of the two sessions began with a series of concise presentations delivered by experts from policy, industry and academia, followed by a moderated panel discussion. The discussions covered aspects related to barriers and enablers to achieving the desired outcomes for skills development and supply chain resilience; ideas for potential actions by different stakeholder groups in the quantum technology ecosystem; and the exchange of initial insights and reflections based on current implementations and practices. The panel discussions were followed by a Q&A session with the wider group of roundtable participants.

In addition to the panel discussions, each session featured a set of small breakout group discussions where participants were invited to primarily reflect on the two main topics. First, participants were asked to discuss current and future aspects of the quantum technology ecosystem (including barriers and enablers) relating to skills and talent, and supply chains, respectively. Second, participants, were asked to consider the range of potential strategies that stakeholders from policy, industry, academia and the third sector could implement to help develop the ecosystem. Each breakout group comprised a diverse mix of experts from various stakeholder groups, promoting the exchange of ideas across different areas of expertise. These sessions were

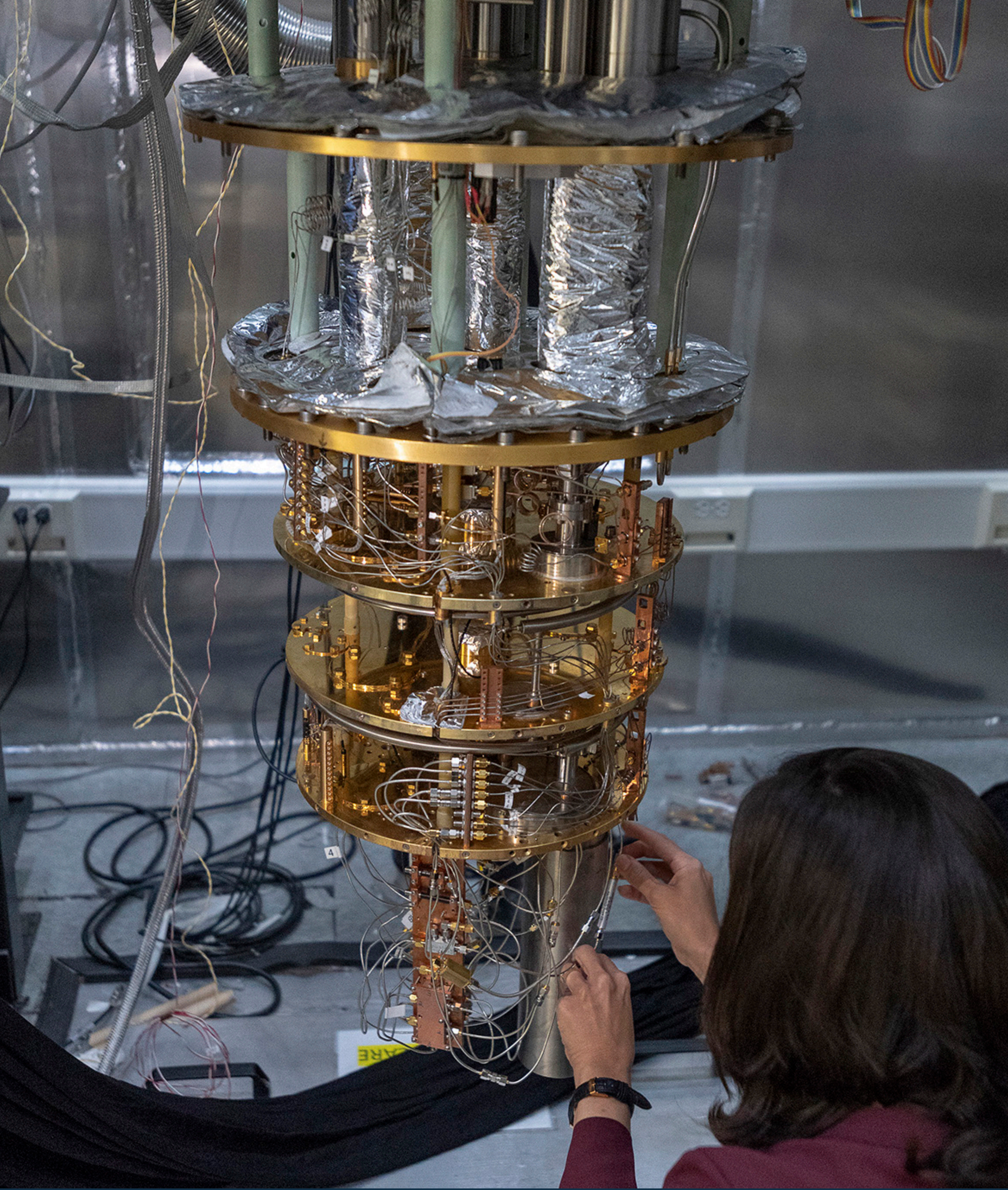
33 The Chatham House Rule is a long-standing and widely used guideline designed to promote open and frank discussions at meetings, encouraging participants to voice and share opinions and information without the concern of public attribution.

34 More specifically, the participants included the following profiles: senior researchers from both academia and industry (such as program directors, scientists, engineers, and social scientists); members of executive leadership teams (including founders, directors, vice presidents and chief executive/business/operating officers) along with strategic advisors at quantum technology companies, research institutes and technology investment organisations; senior educators and leaders of grassroots community engagement and education initiatives; senior representatives of European public sector institutions, stakeholder programs and industry consortia linked to quantum technology; and more broadly, representatives of large companies and startups within the quantum ecosystem.

facilitated by team members from RAND Europe and the Novo Nordisk Foundation.

Following the breakout group discussions, a plenary session was held where a rapporteur from each group summarised the key takeaways from their discussions. This session also provided an opportunity for broader dialogue between the groups, revealing areas of agreement and disagreement.

This roundtable report has some limitations that should be considered when interpreting its findings. First, the roundtable was exploratory in nature and aimed to generate ideas rather than establish consensus or best practice on the two key topics (skills and talent, and supply chains). Consequently, any policy considerations and conclusions extracted from the analysis should be treated with caution. Second, the themes presented in this report are neither exhaustive nor intended to offer a comprehensive account of all the discussions at the roundtable. Furthermore, they reflect the views and perceptions of the participants rather than providing a wide-ranging analysis of all aspects associated with quantum technology skills and talent. Moreover, some of the insights are Europe-centric, reflecting the regional focus of the participants – although they do apply more widely to quantum technology skills and talent-related discussions taking place in other jurisdictions as well. The themes therefore can be regarded as a set of cross-cutting topics inspired by the roundtable discussions, encompassing developments already underway in the broader quantum technology ecosystem. Additionally, the themes address factors identified during the discussions as crucial to the future development of the ecosystem. Finally, it should be acknowledged that the perspectives and ideas presented in this report under the high-level themes (Chapter 2) and policy considerations (Chapter 3) may not have the unanimous endorsement of everyone involved in the roundtable. Despite these limitations, we hope that the findings and forward-looking actions presented in this report will encourage further debate and enhance collective understanding of how various issues and opportunities related to skills and talent in the quantum technology ecosystem may be addressed in future.



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