Quantum Skills Gap
A thought about the near future

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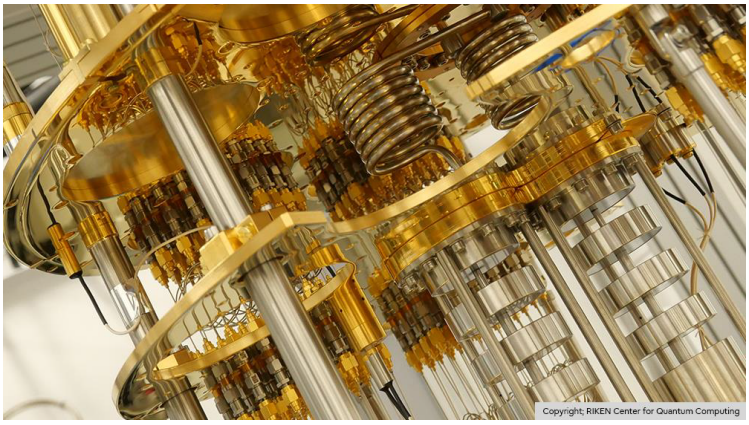
Quantum technologies have generated greater interest and expectations compared to other emerging technologies from the past. This is causing a substantial gap in the skills and knowledge of professionals approaching these technologies, which may lead, in the medium to long term, to a significant deficit of qualified personnel, not only from the perspective of hardware and/or software development, but also in the administration, operation, and maintenance of infrastructures based on, or inspired by, quantum technology.

The new paradigm of quantum technology

It has been just over 40 years since Professor Richard Feynman proposed the design of a quantum computer[i], until it has become a reality that is getting closer every day to being applied to solving real, complex, or unsolvable problems with conventional technologies of the digital era. Although there is no doubt that we are immersed in a bubble of expectations, the fact is that the potential of this technology is of very significant relevance in multiple domains of science, industry, and society. What is undeniable is that, just as it has happened in the field of bioinformatics and, more significantly, in the field of Artificial Intelligence (specifically in the realm of machine and deep learning), there is a very clear risk that technology will advance at a much faster pace than the educational efforts to prepare the professionals of the future, which may lead to a gap in skills and knowledge among specialists who have to create, use, operate, administer, or maintain systems based on quantum technology.

Fujitsu and quantum technology

Fujitsu has been working for years in its research areas and with its clients in the field of developing quantum technologies or those inspired by quantum mechanics.



In its offering of hardware, software, and services surrounding quantum technologies, solutions are already included to solve real problems of combinatorial optimization such as the Digital Annealer, general-purpose quantum computers based on superconductivity like the development with RIKEN of 64 qubits; one of the fastest quantum emulators on the market, such as mpiQulacs on its PRIMEHPC FX700 supercomputing platform, and consulting services as the Quantum Value Assessment, to help custoners on the path to introducing quantum technologies.

With over a hundred quantum technology specialists spread across the world and managed from the quantum technology laboratory located in Japan, technologies continue to be developed in collaboration with relevant centers worldwide.

The skills gap in quantum technologies

It is highly likely that quantum computing will produce amplified effects of what has already been seen in the domain of artificial intelligence: a tremendous gap between those who understand it and those who use it, coupled with a scarcity of necessary skills. Currently, there is no doubt that the world of quantum technology is a world of specialists, even more than in any other digital discipline. There is a high risk that, in the short or medium term, there will be a shortage of qualified professionals to work in this new discipline.

This is not a personal or isolated hypothesis. **The World Economic Forum**[ii] announced in January 2023 that the impact of quantum technology will be far-reaching, in fields ranging from cybersecurity to drug development, that only 17 countries had invested in a national quantum technology research and development program, while more than 150 had not, and that leaders in quantum technology must commit to inclusion in quantum education, in order to close the gap. In late 2021, the global strategic consulting firm **McKinsey** published an article [iii] warning of the skills gap problem in quantum technology and suggesting a series of measures to avoid what has happened in the case of AI. This same company emphasized in another article[iv] from June 2022:

> "[...] However, with this fast-paced growth, demand for experts with advanced degrees in the field is outpacing available talent. Our research suggests greater emphasis is necessary to upskill undergraduates with relevant quantum technology experience."

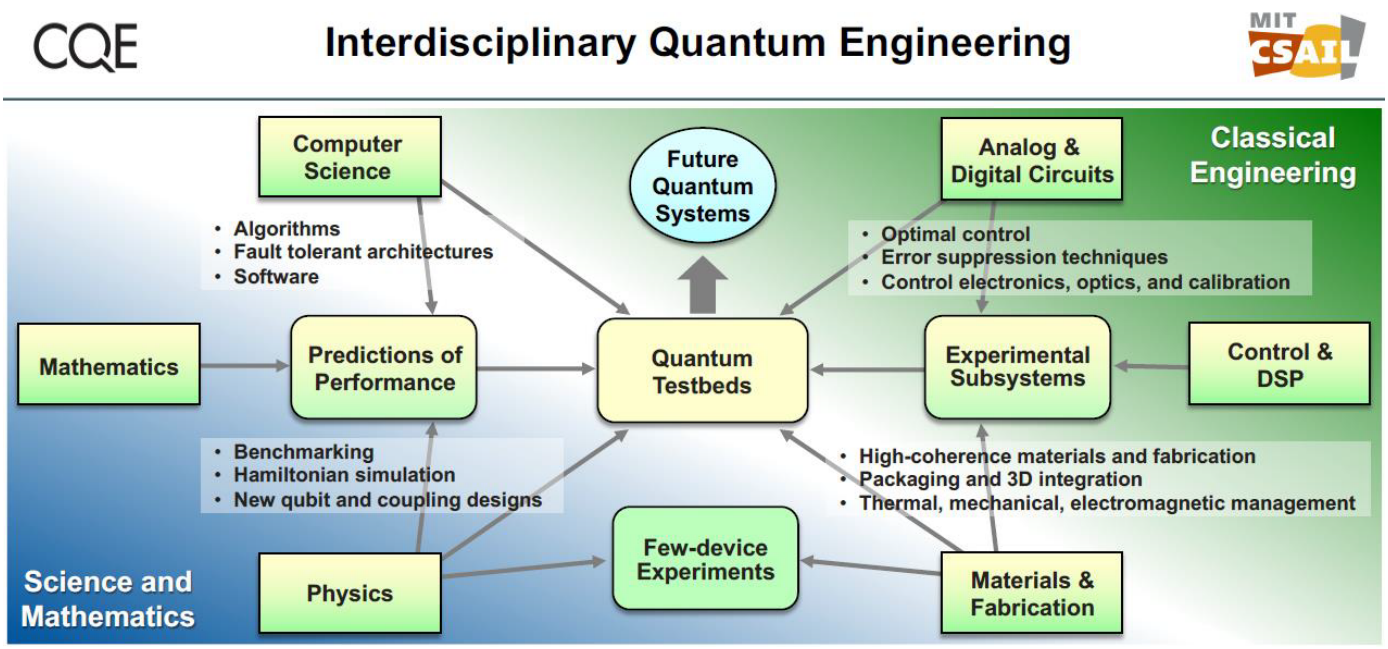
Many other experts at consulting firms or independent consultants such as Nancy Liu, **SDxCentral** editor in cybersecurity, quantum computing, networking, and cloud-native technologies, have reflected this same problem. As she indicated in an article[v] published in February 2023:

> "[...] Currently, only one qualified quantum candidate is available for every three quantum job openings. And the situation is expected to only worsen, with less than 50% of quantum computing jobs predicted to be filled by 2025 unless significant interventions occur, according to research from McKinsey."

Preparing professionals for quantum technologies not only involves developing unique cognitive skills to effectively develop quantum algorithms applicable to real problems but also involves dealing with a technology whose fundamentals and mode of operation are more akin to that of a research laboratory than a data center. On the other hand, the applicability of these technologies often requires understanding the underlying physical mechanisms, which, by their nature, are highly counterintuitive.

Regarding the development of cognitive skills for the production of quantum technology, professionals in disciplines such as physics, chemistry, and various branches of engineering will be able to contribute effectively to the development of these technologies; however, it will be necessary to develop specific knowledge and skills in quantum systems engineering to be able to effectively produce real machines that function end-to-end. This will require breaking down disciplinary barriers and bringing together physicists and engineers.

The technologies involved are varied and include photonics and lasers, analog and digital electronics, thermodynamics, fluid mechanics, various component manufacturing techniques, and the design of complete systems. Quantum engineering involves many complementary disciplines as can be seen in the following image.



Source: Introduction to Quantum Computing by William D. Oliver, MIT, November 2022

Quantum computing will progressively evolve and see its field of application expand as the number and quality of qubits in quantum computers grow. It will be a process of continuous innovation. As with classical computing, the importance of software is likely to become dominant in skill requirements. This explains why many publications insist on the need to develop quantum applications. Large companies like IBM, Fujitsu, Google, and Microsoft, not to mention D -Wave, Rigetti, and IonQ, are "evangelizing" about this. However, parallel to the development of the software market, an intermediate phase will require many skills in engineering and other disciplines related to quantum technologies.

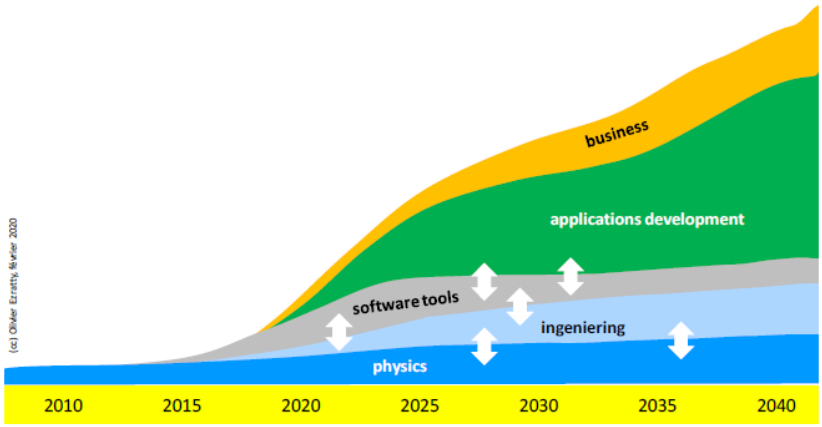
As has happened at other times in the history of computing, economies of scale will be more significant in the software domain than in the hardware domain, so it will be in this domain where the demand for qualified professionals is likely to be higher than the available supply. Although it is also foreseeable that in the medium term, the market for quantum computers will not be a high-volume market.

Although It is more likely that the knowledge gap will be most significant in the domain of software development, leading to a deficit in the market for qualified professionals.

We are referring to specific areas such as:

- Error Correction
- Quantum algorithms
- Quantum communications
- Applications and tools for commercial use of quantum technologies

The creation of enterprise applications also requires competencies in multiple domains such as life sciences (organic chemistry, protein folding, photosynthesis, ...), materials science (battery chemistry, superconducting materials, ...), or other fields like portfolio management and risk assessment in finance or optimization problems in logistics, transportation, and marketing.



The image reflects the potential evolution of skill needed in quantum technology over time, according to a publication by Olivier Ezratty in 2020, it also reflects the fact that researchers and engineers must become increasingly versatile in many disciplines. Working Teams need to be structured around strong interdisciplinarity and transversality. They require "versatile technological teams" that link all these professions and skills. In particular, physicists will have to become increasingly interested in engineering, and engineers in physics. The situation is similar to what happened years ago in the domain of genomics biology and medicine with bioinformaticians.

Regarding the management of quantum infrastructures, the operation, exploitation, and maintenance require skills more akin to laboratory technicians than experts in data centers. However, many of these infrastructures will integrate into current data centers and tend to offer services under the same guidelines of quality and reliability as other services in the digital era. This will require new skills and qualifications for the personnel responsible for the administration and operation of such advanced data centers.

Finally, when it comes to the business aspect with real products that can be marketed and sold, it requires the entire combination of skills typically found in technology marketing and sales: product marketing, operational marketing, business development and partnerships, ecosystem creation, and above all, pure and simple B2B sales to start. This is complemented by generic competencies associated with the creation of deep tech startups (organization, business planning, hiring, financing, etc.) and legal specialists in intellectual property, who must assimilate the specificities of quantum vocabulary.

Initiatives on training in quantum technology

Many initiatives focused on training in physics and quantum technologies have been developed worldwide, both institutional and private. Here are some of the most significant ones:

In the United States, the **White House Office of Science and Technology** Policy and the **National Science Foundation** are leading a partnership between the federal government, industry, professional societies, and the educational community aimed at fostering a variety of training opportunities to enhance capabilities, diversity, and the number of students ready to participate in the quantum workforce.

This effort begins with outreach and education in middle and high schools, introducing quantum technologies and science to inspire the next generation. It continues by expanding access to quantum-related learning materials and curricula beyond university labs and classrooms, reaching community colleges and online courses.

This association provides a foundation for classroom and curriculum materials, developed collaboratively with key stakeholders in the quantum information science community. It promotes hands-on experiences with quantum tools in the classroom and through online spaces and connects students with public and private quantum professional opportunities through internships, externships, and other avenues.

As a result, **the National Q-12 Education Association** commits to working with educators in the United States over the next decade to ensure a robust quantum learning environment. This includes providing classroom tools for practical experiences, developing educational materials, and supporting pathways to quantum careers. By expanding access to quantum materials and technologies through this association, educators in classrooms and other settings can develop programs, courses, and activities to introduce students to the field and create opportunities for quantum careers. Industry participants in this association include IBM, Google, Microsoft, AWS, Rigetti, Intel, Lockheed Martin, Boeing, Zapata Computing, APS Physics, Optica, IEEE USA, and QubitbyQubit (a training organization). This North American association organized the QuanTime event in the spring of 2022, featuring hundreds of quantum activity classrooms for K-12 education.

In the European Union, the **"Journey towards the Digital Decade"** policy was adopted in 2019, aiming for a sustainable and human-centered vision, which included quantum computing as one of the future technological pillars. One outcome of this policy is the Quantum Flagship initiative, a large-scale endeavor funded with one billion euros over a period of 10 years. This initiative comprises a cohesive set of research and innovation projects selected through a rigorous peer-review process. The goal is to consolidate and expand European scientific leadership and excellence in this research area, establish a competitive European industry in quantum technologies, and make Europe a dynamic and attractive region for innovative research, business, and investments in this field.

In our country, most public and private universities already offer specialization programs in quantum technologies, either as part of postgraduate master's programs or as mentoring for Bachelor's Theses. However, integrating quantum technology into undergraduate programs or developing new specialized degree programs in this field may require a process of adapting faculty, preparing content, and obtaining institutional approval. Currently, to our knowledge, only the Autonomous University of Barcelona (UAB) offers a bachelor's degree program in Computational Mathematics and Data Analytics covering specific aspects related to quantum technology. Nevertheless, almost all universities, both public and private, offer double degrees in Mathematics and Physics that also address quantum technologies to varying degrees, as well as postgraduate master's programs specializing in quantum computing.

Here are some additional training initiatives in quantum technologies, both public and private:

QubitbyQubit (USA): An online quantum programming learning initiative by The Coding School, founded by a university student at Brown University in 2014. Sponsored by IBM and Google.

Qplaylearn (Finland,2020): Develops an online visual quantum programming training tool aimed at a broad audience, including high school students. Collaborates with various universities in Finland as well as IBM.

QuTech Academy: Offers free online courses on quantum technologies for engineers.

CERN: Conducts a series of introductory conferences on quantum computing at CERN (7 sessions of two hours each), also aimed at engineers.

Qureca (2019, UK): Offers "Quantum for Everyone" online courses for entrepreneurs. These courses are taught by Araceli Venegas-Gómez, founder of Qureca, Bruno Fedrici, a French consultant and professor specializing in quantum technologies, and QuantFi, a French startup specializing in financial applications.

EFEQT (Empowering the Future Experts in Quantum Science and Technology for Europe): Provides a free interdisciplinary learning experience between academic research and exploration for 25 students and young researchers. It involves a scientific hackathon; the first was organized in October 2021 and concluded with a graduation in September 2022. The top participants will receive expedited access to pursue a PhD or postdoctoral position at associated universities in Germany and Strasbourg, France.

The program is supported by the Quantum Flagship's Quantum Technology Education Support and Coordination Action (QTEdu CSA).

Quantum Spain is an initiative driven by the Ministry of Economy through the Secretary of State for Digitalization and Artificial Intelligence and financed with Recovery Funds, with the aim of promoting and financing a competitive and comprehensive quantum computing infrastructure in Spain. Within this initiative, the **TALENTQ** project has been included, which aims to enhance the search for and training of Spanish quantum talent through the organization of online and face-to-face courses, quantum programming marathons, promotion of initiatives and local groups in quantum computing, among many other activities. This TalentQ initiative is coordinated by the University of Santiago de Compostela (USC).

This effort to prepare professionals in these disciplines of the very near future seems not to have spread in our country to training programs in middle education, such as vocational training. As mentioned earlier, the future anticipates that technicians and higher technicians will be required for the administration, operation, and maintenance of quantum technology infrastructures, and this could occur in the medium or even short term, given the momentum that this type of technology is receiving from both public and private institutions worldwide.

It is the responsibility of public administrations to become aware of this need and to finance and stimulate activities that allow for the training of the technicians of the future, which will result in greater employability for young people and a boost to regional or national economies.

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[i] https://arxiv.org/abs/2106.10522
[ii] https://www.weforum.org/agenda/2023/01/the-world-quantum-divide-why-it-matters-davos2023/
[iii] https://www.mckinsey.com/capabilities/mckinsey-digital/our-insights/five-lessons-from-ai-on-closing-quantums-talent-gap-before-its-too-late
[iv] https://www.mckinsey.com/capabilities/mckinsey-digital/our-insights/quantum-computing-funding-remains-strong-but-talent-gap-raises-concern
[v] https://www.sdxcentral.com/articles/analysis/ibm-microsoft-and-google-race-to-close-quantum-skills-gap/2023/02/

