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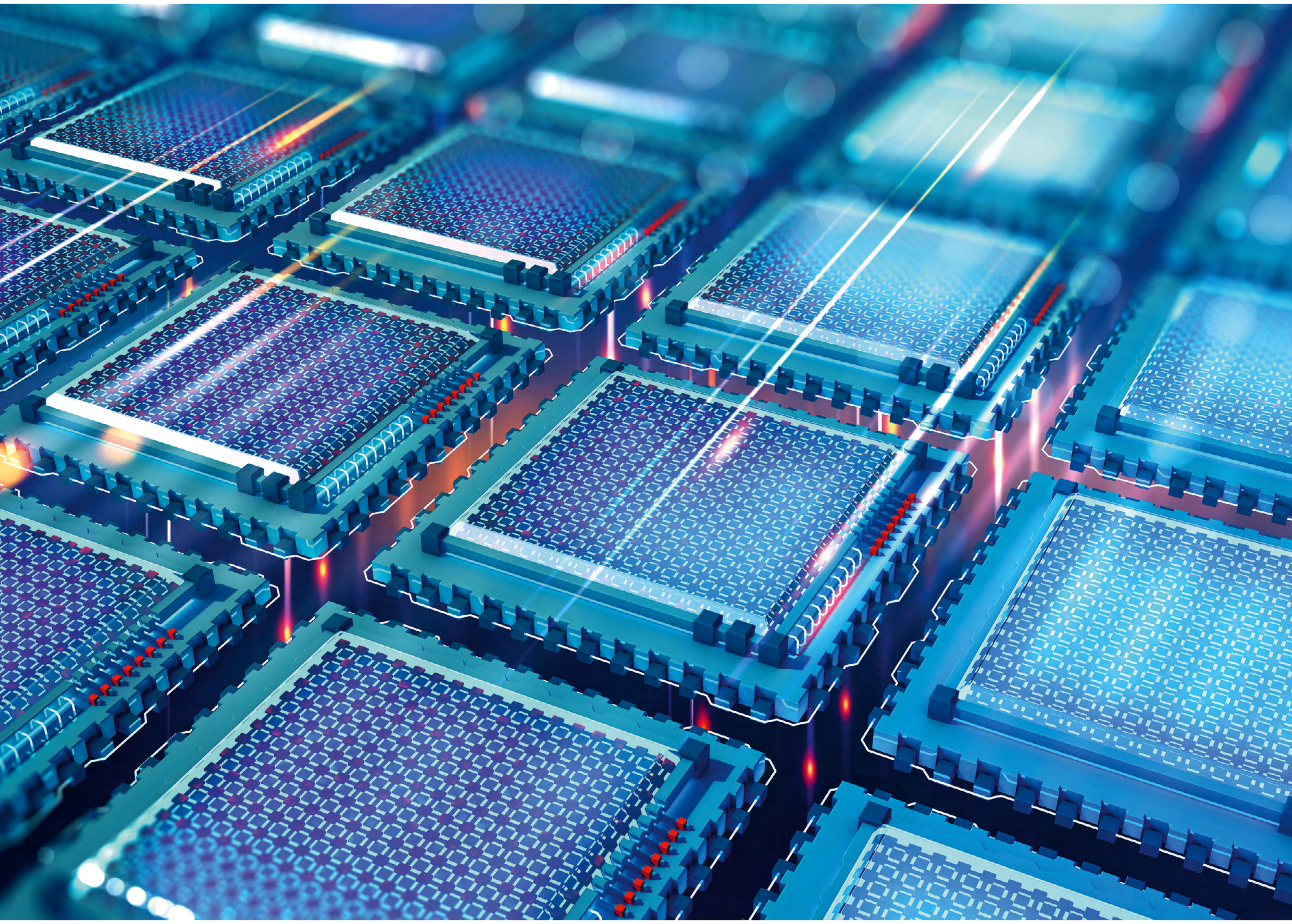

EUROPEAN
COMPETENCE FRAMEWORK FOR QUANTUM TECHNOLOGIES (CFQT)

Reference framework for planning, mapping and comparing QT-related educational activities, personal qualification and job requirements.

Version 3.0 (April 2025)

compiled by Franziska Greinert and Rainer Müller, QUCATS

European Competence Framework for Quantum Technologies (CFQT)
Update completed in April 2025
Version 3.0

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QUCATS – Quantum Flagship Coordination AcTion and Support

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All versions, more information on updates and related publications can also be found there.

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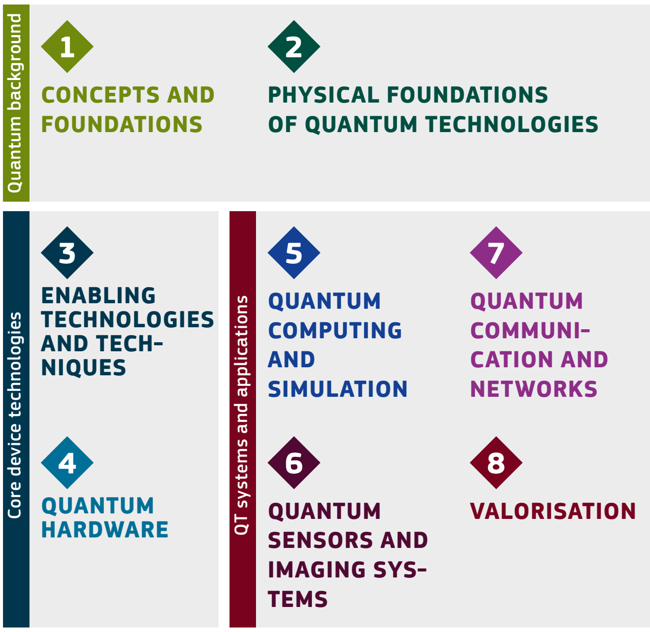
European Competence Framework for Quantum Technologies Overview

The framework consists of three parts:

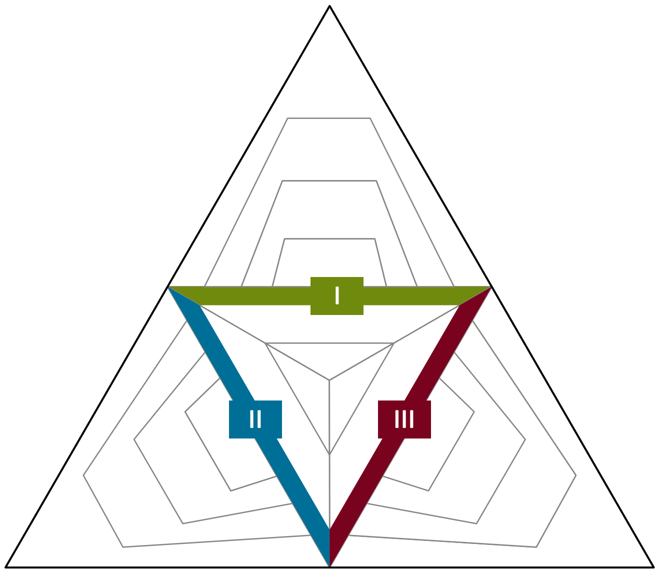
Part 1

Content Map: 8 domains with 42 subdomains (p. 5), detail pages for each domain with topics and subtopics (p. 6–13).



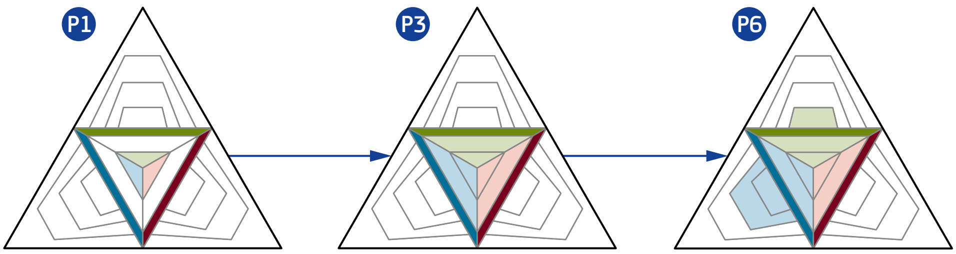
Part 2

Proficiency Triangle visualising **6 proficiency levels** for the **3 proficiency areas** (p. 45), with in-depth level descriptions and more (p. 15–17).



Part 3

9 Qualification Profiles overview (p. 18) and detailed descriptions incl. example personas and (training) suggestions (p. 19–27).



Extra

Two **examples** how to combine a profile with a content selection (p. 28–29).

Version 3.0 (April 2025) compiled by Franziska Greinert and Rainer Müller
QUCATS – Quantum Flagship Coordination AcTion and Support

About the CFQT

Value and objectives of the CFQT

The European Competence Framework for Quantum Technologies (CFQT) is a taxonomy of the possible knowledge and skills needed in Quantum Technologies (QT). It describes the **QT-specific** competences and qualifications necessary for involvement in the QT industry. In addition, **'classical' competences** will be essential, which are not QT-specific and therefore not covered by the CFQT, e.g. in an engineering discipline or in an application field such as finance or chemistry, as well as **transversal skills**, e.g. communication, collaboration, or digital skills. The CFQT has been compiled in the Quantum Flagship CSAs (QTEdu, QUCATS). It serves as the common reference in QT education and workforce development.

Use cases

The CFQT can be applied for a variety of purposes:

- **Educator/instructor:** Facilitate the *planning, mapping, and comparison of QT educational offers* (training, study or school curricula). A qualification profile can serve as the primary learning objective. Based on the proficiency levels, concrete learning goals can be defined and classified. The content map can be used to structure and align course content. By mapping a (planned) course using the CFQT, it can be compared to other mapped courses to identify gaps and redundancies.
- **Student/learner:** *Evaluate their current qualifications* and set *personalised learning objectives*. The qualification profiles provide insight into relevant qualifications and suggested training formats. When training programmes or courses are aligned to the CFQT, learners can *select the most appropriate* option based on their specific needs.
- **Recruiter:** *Evaluate team capabilities* and *define job requirements* to optimise the hiring process for QT-related roles. The CFQT enables structured competence mapping to identify skill gaps within teams and facilitate targeted recruitment strategies. It supports objective candidate evaluation by comparing applicants' QT-specific qualifications against predefined criteria.
- **Professionals:** *Plan and navigate career development* within the QT sector. With the CFQT, professionals can identify skill gaps, align their expertise with industry demands, and pursue targeted upskilling opportunities. The CFQT also helps professionals transition into new QT-related roles by outlining relevant proficiency levels and training pathways.
- **Jobseeker:** *Demonstrate QT-related expertise and align skills* with industry expectations. The CFQT provides a structured approach to showcasing qualifications, helping to match competences with employer requirements more effectively. It also helps applicants position themselves strategically in the competitive job market by identifying areas for further development.

Structure of the CFQT (see p. 1)

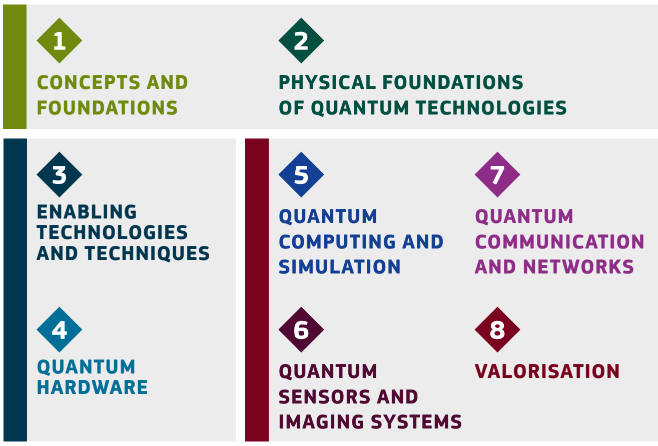
The CFQT consists of three parts:

1. The **content map** provides a hierarchical structure of relevant concepts and topics.
2. The **proficiency levels** specify six stages of knowledge and skills that can be reached, focused for three **proficiency areas** and visualised in the **proficiency triangle**.
3. The **qualification profiles** show prototypical QT-related qualifications relevant in the emerging quantum workforce, based on the required proficiency levels.

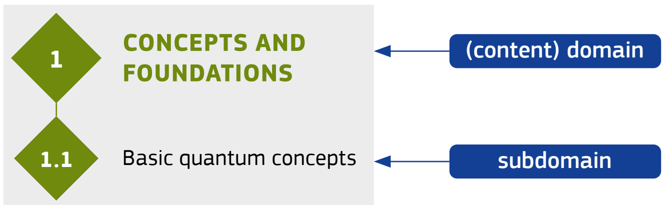
Two **examples** show how to **combine** a selection from the content map and a proficiency specification in the proficiency triangle to visualise, e.g., objectives of a training or requirements for a job. An additional **certification scheme** details the proficiency levels through sample tasks and assessment recommendations.

The content map

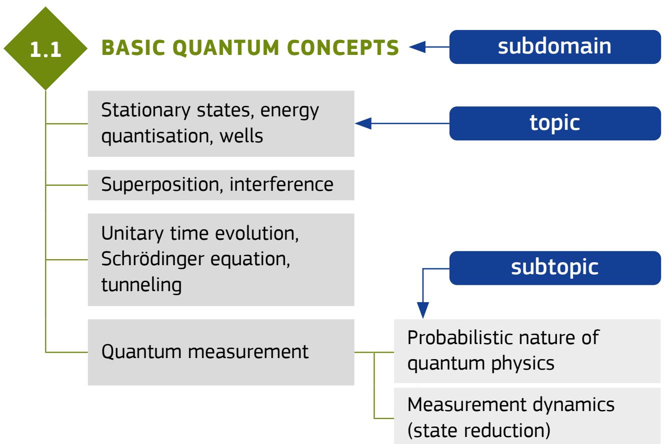
The content map (p. 5) consists of eight **domains** grouped into three **blocks**: **Quantum background** (top), **Core device technologies** (left) & **QT systems and applications** (right).



The *quantum background* block covers the quantum (physical) foundations relevant to QT. The *core device technologies* block covers enabling technologies (e.g. optics and electronics) and (laboratory) techniques as well as different quantum hardware approaches and technological realisation and implementation aspects. The *QT systems and applications* block covers the three main *QT pillars* (quantum computing, sensing, communication) as well as concepts of how to generate value from QT for industry, one's own company or society as a whole, as well as impact, responsibility, education, and public communication. The content map provides a graphical overview of the broad structure of QT concepts and topics. Each domain is detailed in **subdomains**.



For each domain there is a separate page with more details, i.e. **topics** and **subtopics** for each subdomain (p. 6–13), e.g.:



About the CFQT II

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The proficiency levels, areas and triangle

Depending on the target group, each educational offer will address different levels of depth and challenge. To reflect this, there is an additional dimension to the content map: **proficiency levels** from A1 (Awareness) to C2 (Innovation). The use of proficiency levels makes it easier to tailor education and training offers to the needs of the target groups and to determine job profiles.

A1	**Awareness**	**A2**	**Literacy**
B1	**Utilisation**	**B2**	**Investigation**
C1	**Specialisation**	**C2**	**Innovation**

The proficiency levels are described on the basis of the **knowledge** and **skills** required to reach the level. They are based on the **European Qualification Framework** (EQF, see references at the bottom) and correspond to a *bachelor's* (B2), *master's* (C1), or *PhD* (C2) degree. However, achieving these levels is not limited to academic routes; work experience, e.g. in R&D projects, can also bring someone to these high proficiency levels.

The proficiency levels are further specified for three **proficiency areas** covering different aspects of competence in QT:

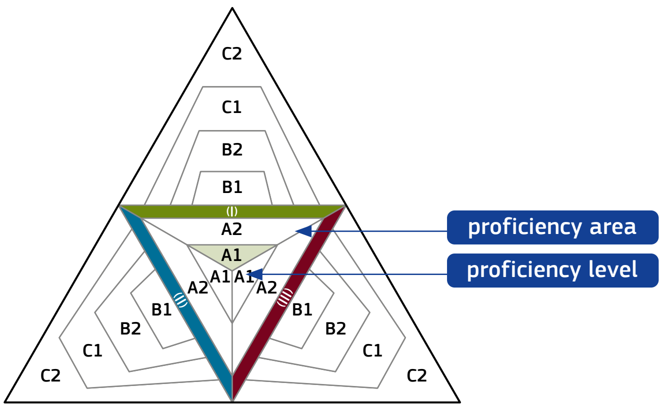
(I) Quantum concepts, incl. mathematical formalism & physics

(II) QT hardware (HW) & software (SW) engineering: everything related to working with or building and developing QT

(III) QT applications & strategies: everything related to the market, use cases, strategy development, etc., as well as impact, ethics and education

The proficiency areas are introduced on page 14, followed by dea scriptions of the proficiency levels (p. 15–17).

The **proficiency triangle** visualises the six proficiency levels in the three proficiency areas. Partially coloured proficiency triangles – as in the *qualification profiles* (see next page) – give a first impression of the qualifications covered by a person or required for a job or addressed in a course – independent of concrete content, i.e. the concrete QT.



References for proficiency levels:
Proficiency level system: Level A1 to C2 like in the *Common European Framework of Reference for Languages* (CEFR, 2020, 2001, www.coe.int/lang-cefr), which has been used in the *European Framework for the Digital Competence of Educators* (DigCompEdu, 2017, doi: 10.2760/159770), the model for the framework structure and level keywords. Proficiency level descriptions are based on the levels from *The European Qualifications Framework* (EQF, 2018. doi: 10.2767/750617).

The journey of a person towards quantum proficiency begins in the centre, at level A1, and widens out to A2 (the basic overview). This is the core, the central triangle in the graphic above, covering the **beginner A levels**. People start building **QT awareness** (A1) and reach **QT literacy** (A2) at the edge of the inner triangle. These proficiencies can be achieved within a few hours or days, *e.g. by instruction (workshops, seminars) or self-directed learning.*

Achieving QT literacy indicates readiness for the quantum era and potential specialisation, e.g. on the basis of self-study or learning on the job. In the long term, it is desirable that QT awareness, perhaps even QT literacy, is acquired at school, at least where there is a focus on physics and/or technology.

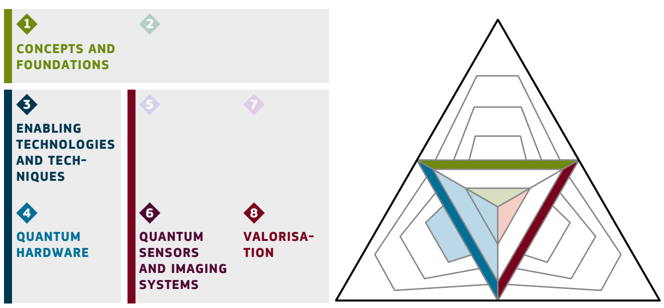
Progressing to the **B levels, intermediates** begin to refine their qualification in more specialised areas and therefore do not cover the full breadth of the A2 overview. Achieving a B level may require *weeks or months of focused effort, e.g. attending a lecture or summer school (B1) and conducting student research comparable to a bachelor's thesis (B2).* Alternatively, it can be achieved through *learning on the job, receiving mentoring and gaining personal research-like experiences.*

With each successive level, the proficiency increases towards the chosen specialisation, and especially the knowledge broadens and links more and more with other subdomains. Reaching the **advanced C levels** may require *years of work experience and further research, e.g. through a master's (C1) or PhD (C2) thesis, with the emphasis on experience working in the field in R&D or similar.*

When someone reaches level C2, e.g. after a PhD in a particular subdomain, they have (at that time) the state-of-the-art knowledge in that domain, represented by the tip of the triangle. In other subdomains they have less advanced or even basic knowledge, e.g. comparable to B1 level proficiency. Consequently, knowledge that can be acquired in a matter of days or weeks contributes to the C2 level, while the specialisation itself takes years. It is important to note that C2 proficiency at the cutting edge of technology may become outdated due to further developments in the corresponding field. Therefore, someone who does not keep up with developments may lose this proficiency over time.

Combining content and proficiency

To specify concrete competences, learning objectives, or job requirements, the two components need to be combined: a selection from the content map and the covered proficiency levels, e.g., as a partially coloured proficiency triangle (see examples p. 28–29):



Quantum control electronics practitioner for NV sensors

About the CFQT III

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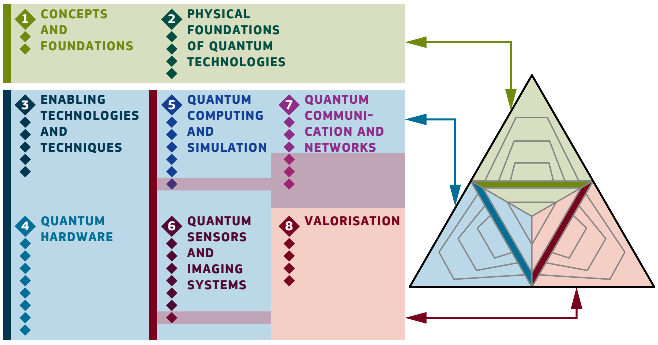
Relation of content map and proficiency areas

The **colouring** of the three proficiency areas corresponds roughly to the colouring of the content map with the eight domains (see also detailed level descriptions, p. 15–17):

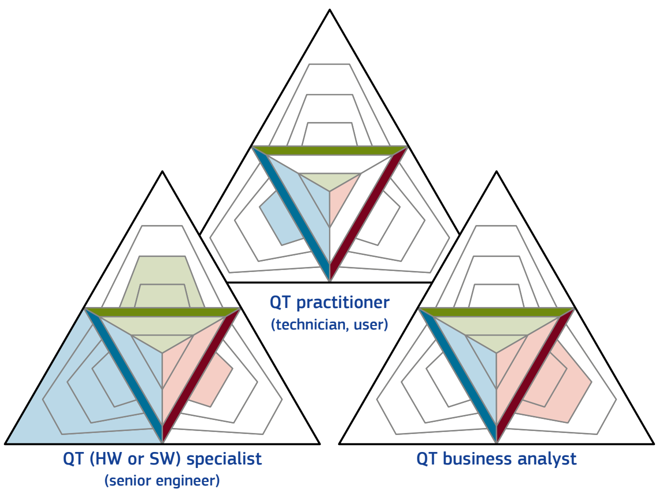


The proficiency level descriptions are intentionally general and not specific to any particular QT hardware, system or application. For clarity and illustration, examples of content specifications are provided on the three proficiency level detail pages (p. 15–17). To describe the qualification of an individual or the objectives of a course, the proficiency level specification must be combined with a suitable selection and adaptation of content (sub)domains.

The qualification profiles

A detailed analysis of interviews with experts from industry resulted in nine different **qualification profiles**. They provide an overview of common individual QT-specific qualifications relevant to industry. They are visualised by partially coloured proficiency triangles to allow easy comparison. The overview page (p. 18) shows relations between the profiles and illustrates the potential progression of professional development across different profiles.

Each profile is complemented by a **detail page** that provides additional insights, including descriptions of the highest levels addressed, a general description, example personas and related recommendations. These recommendations include prerequisites for individuals interested in acquiring the profile, suggested training modules or learning paths, and more.



Additional certification scheme

With the update to version 3.0, an additional **certification scheme for QT proficiency** is available to illustrate how the proficiency levels can be achieved. The certification scheme extends the proficiency level descriptions with example tasks and how it is typically verified that an individual has reached a particular proficiency level. The relationship between proficiency areas/levels and content (sub)domains is also made explicit in the certification scheme. It is available through Zenodo along with the CFQT versions, see below.

Development of the CFQT

The Competence Framework was compiled using a bottom-up approach. Between summer 2020 and spring 2021, a three-round study involving more than 150 participants mainly from the European QT community provided initial input (see paper *Future quantum workforce: Competences, requirements and forecasts*, Phys. Rev. Phys. Educ. Res., 2023, doi: 10.1103/PhysRevPhysEducRes.19.010137).

The results were refined through expert interviews for each domain, leading to version 1.0 (May 2021). Details are documented in the Methodology and Version History (2021, doi: 10.2759/130432).

For the update to version 2.0, feedback and usage experiences from the QT (education) community were incorporated (see paper *Towards a quantum ready workforce: the updated European Competence Framework for Quantum Technologies*, Front. Quantum Sci. Technol., 2023, doi: 10.3389/frqst.2023.1225733). This paper also documents the approach to the first descriptions of proficiency level based on the EQF and with the associated degrees.

An analysis of industry needs was conducted in summer 2023, which included more than 30 interviews (about 30 to 40 minutes each) with industry professionals (see paper *Advancing quantum technology workforce: industry insights into qualification and training needs*, EPJ Quantum Technol. 11, 82 (2024), doi: 10.1140/epjqt/s40507-024-00294-2). The update to version 2.5, and thus the addition of the proficiency triangle and qualification profiles, is based on these interviews and additional analysis (see paper *Extending the European Competence Framework for Quantum Technologies: new proficiency triangle and qualification profiles*, EPJ Quantum Technol. 12, 1 (2025). doi: 10.1140/epjqt/s40507-024-00302-5).

The update to version 3.0 is based on feedback and experience and focusses on minor refinements and error corrections. In addition, the CFQT was checked for consistency with data from the job market analysis conducted by the European Quantum Readiness Center (https://quantumready.eu), which are documented in preprint *The Quantum Technology Job Market* (arXiv:2503.19004).

For updates, previous versions and additional information, such as the Certification Scheme for QT Proficiency see the related Zenodo repository: F. Greinert and R. Müller, *European Competence Framework for Quantum Technologies*, doi: 10.5281/zenodo.6834598.

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QUCATS – Quantum Flagship Coordination AcTion and Support

European Competence Framework for Quantum Technologies Content Map

8 domains with 42 subdomains; with topics and subtopics on following pages

Quantum background

1 CONCEPTS AND FOUNDATIONS

- 1.1 Basic quantum concepts
- 1.2 Mathematical formalism and information theory

2 PHYSICAL FOUNDATIONS OF QUANTUM TECHNOLOGIES

- 2.1 Atomic physics
- 2.2 Quantum optics and electrodynamics
- 2.3 Solid-state physics
- 2.4 Quantum many-body systems and open quantum systems

Core device technologies

3 ENABLING TECHNOLOGIES AND TECHNIQUES

- 3.1 Laboratory techniques, noise and shielding
- 3.2 Solid-state technologies, nanotechnologies
- 3.3 Optical technologies
- 3.4 Control technologies
- 3.5 Computers and software

4 QUANTUM HARDWARE

- 4.1 Superconducting electronic circuits
- 4.2 Spin-based systems
- 4.3 Neutral atoms and ions
- 4.4 Photonic systems
- 4.5 Emerging qubit concepts
- 4.6 Quantum state control
- 4.7 Hybrid quantum-classical systems
- 4.8 Technology realisation

QT systems and applications

5 QUANTUM COMPUTING AND SIMULATION

- 5.1 Basics
- 5.2 Quantum simulators
- 5.3 Quantum programming tools and software stack, error correction
- 5.4 Quantum computing subroutines
- 5.5 Quantum algorithms
- 5.6 Applications of quantum computing and simulation

7 QUANTUM COMMUNICATION AND NETWORKS

- 7.1 Basics
- 7.2 Quantum random number generators
- 7.3 Quantum key distribution
- 7.4 Applications of quantum cryptography
- 7.5 Infrastructure for quantum information networks (quantum internet)
- 7.6 Systems networks (composite systems), quantum internet applications

6 QUANTUM SENSORS AND IMAGING SYSTEMS

- 6.1 Basics
- 6.2 Electromagnetic field sensors
- 6.3 Temperature, particle and pressure sensors
- 6.4 Inertial and gravity sensors
- 6.5 Quantum imaging
- 6.6 Atomic clocks
- 6.7 Applications of quantum sensors

8 VALORISATION

- 8.1 Industry landscape and market analysis
- 8.2 Business strategy, entrepreneurship and management
- 8.3 Impact and responsibility
- 8.4 Education and communitcation

1 CONCEPTS AND FOUNDATIONS

1.1 BASIC QUANTUM CONCEPTS

- Stationary states, energy quantisation, wells
- Superposition, interference
- Unitary time evolution, Schrödinger equation, tunneling
- Quantum measurement
  - Probabilistic nature of quantum physics
  - Measurement dynamics (state reduction)
  - No-cloning theorem, incomplete state information from measurement
- Two-state systems (e.g. spin-1/2, polarisation), qubits
  - State representation, visualisation (e.g. Bloch/Poincaré sphere)
  - Dynamics of two-state systems
  - Physical manipulation with pulses
  - State evolution, Bloch equation, Larmor precession, Rabi oscillations
- Pure and mixed quantum states
- Decoherence and coupling to the environment
- Heisenberg principle, complementarity
- Entanglement, Bell inequalities, non-locality

1.2 MATHEMATICAL FORMALISM AND INFORMATION THEORY

- Mathematical foundations
  - Linear algebra, functional analysis
  - (Linear) differential equations
  - Statistics, probability theory, combinatorics
  - Advanced mathematics, e.g. topology, group theory, symmetry
  - Perturbation theory
- State space, Dirac notation
- Operators, eigenvectors, eigenvalues
- Classical information theory, Shannon entropy
- Quantum channels, distance measures, von Neumann entropy

2 PHYSICAL FOUNDATIONS OF QUANTUM TECHNOLOGIES

2.1 ATOMIC PHYSICS

- Electronic levels, quantum numbers, level transitions, Rydberg states
- Hyperfine structure, Zeeman effect, Stark effect
- Angular momentum (spin, orbital, total), interactions

2.2 QUANTUM OPTICS AND ELECTRODYNAMICS

- Classical, quantum and non-linear optics, polarisation degrees of freedom
- Photon statistics, bunching, antibunching
- Fock states, coherent states, squeezed states
- Quantum optical experiments, interferometry, microscopy and spectroscopy
- Quantum electrodynamics (QED)
- Light-matter interactions

2.3 SOLID-STATE PHYSICS

- Properties (band structure, electrical transport, optical properties, magnetism)
- Semiconductor theory
- Superconductivity, Josephson effect, Josephson junctions
- Mesoscopic phenomena, quantum confinement effects
- Topological effects
- Magnetometry, spin manipulation experiments

2.4 QUANTUM MANY-BODY SYSTEMS AND OPEN QUANTUM SYSTEMS

- Pauli principle, bosons, fermions, Fermi gases and Fermi liquids
- Quantum degenerate gases, Bose-Einstein condensation
- Quantum statistics, entropy
- Molecular physics
- Open quantum systems
- Decoherence mechanisms (relaxation, dephasing, photon loss)

3 ENABLING TECHNOLOGIES AND TECHNIQUES

3.1 LABORATORY TECHNIQUES, NOISE AND SHIELDING

- Noise analysis
- Cryogenic, vacuum and cleanroom technologies
- Shielding techniques, housing, magnets

3.2 SOLID-STATE TECHNOLOGIES, NANOTECHNOLOGIES

- Micro- and nanostructuring
- Quantum materials design
- Micro- and nanoelectronics, e.g. 2D electron gas and materials, single-electron transistor (SET), spintronics
- Semiconductor technologies
- Superconducting devices, SQUIDs

3.3 OPTICAL TECHNOLOGIES

- Classical optics
- Lasers
- Single photon sources
- Single photon detectors and cameras
- Photonics, fibres

3.4 CONTROL TECHNOLOGIES

- Signal and data processing
- Electronics, microwave and RF (radio frequency) technologies, frequency conversion, modulation and generation
- Laser cooling, laser stabilisation
- Generation of special quantum states, e.g. Bell states, squeezed states
- Resonators
- Opto-electronical and opto-mechanical systems

3.5 COMPUTERS AND SOFTWARE

- IT infrastructure and software stack
- Classical programming, algorithm design and software development techniques, mathematical modelling, data processing
- Control software: calibration, guide electronics/ optics, error-robust physical operations, tuning and stabilisation of hardware
- Quantum control algorithms
- Machine learning inspired and integrated approaches

4 QUANTUM HARDWARE

4.1 SUPERCONDUCTING ELECTRONIC CIRCUITS

- Qubit types, e.g. charge, flux, phase, transmon

4.2 SPIN-BASED SYSTEMS

- Electron-spin qubits, nitrogen-vacancy (NV) centres in diamond
- Semiconductor quantum dots
- Nuclear-spin qubits

4.3 NEUTRAL ATOMS AND IONS

- Trapped ions
- Rydberg atoms
- Cold atoms, molecules, quantum gases
- Neutral atoms in optical lattices

4.4 PHOTONIC SYSTEMS

- Linear optical elements and networks, optical instruments for photons as qubits
- Boson sampling techniques
- Entangled photon sources

4.5 EMERGING QUBIT CONCEPTS

- Topological qubits
- Molecular-spin qubits

4.6 QUANTUM STATE CONTROL

- State initialisation and readout
- State manipulation, realisation of quantum gates
- Qubit coupling & interconnectivity
- Interconversion of different qubit types

4.7 HYBRID QUANTUM SYSTEMS

- High performance computer (HPC) systems
- Machine learning integration
- Integration of classical and quantum networks
- Quantum interfaces

4.8 TECHNOLOGY REALISATION

- Noise, general and platform-specific capabilities and limitations, benchmarking
- Miniaturisation, scaling
- Prototyping, system composition and integration, assembly and fabrication
- Integration on a chip, e.g. photonic integrated circuits, atom chips

5 QUANTUM COMPUTING AND SIMULATION

5.1 BASICS

- Reversibility, DiVincenzo criteria
- Qubits, quantum gates, universal gate set
- Universal fault-tolerant quantum computers, NISQ quantum computers
- Circuit design, notation, matrix representation
- Basic quantum programming techniques
- Complexity theory, quantum complexity classes, computational limitations, quantum advantage

5.2 QUANTUM SIMULATORS

- Digital quantum simulators
- Analogue quantum simulators and (adiabatic) quantum annealers

5.3 QUANTUM PROGRAMMING TOOLS AND SOFTWARE STACK, ERROR CORRECTION

- Graphical platforms
- Quantum assembler languages and software development kits, quantum circuit simulators
- Quantum compilers, high-level programming with pre-definded subroutines
- Hybrid quantum-classical algorithms and quantum embedding
- Cloud platforms
- Quantum error correction, quantum error mitigation

5.4 QUANTUM COMPUTING SUBROUTINES

- Quantum amplitude amplification
- Quantum Fourier Transform (QFT), hidden subgroup finding
- Quantum phase estimation
- Quantum linear algebra subroutines, quantum singular value decomposition
- Other techniques and subroutines, e.g. quantum walks, amplitude estimation

5.5 QUANTUM ALGORITHMS

- Number theory and factorisation (e.g. Shor algorithm)
- Oracular algorithms and database search (e.g. Grover algorithm)
- Linear algebra (e.g. Harrow-Hassidim-Lloyd algorithm)
- Quantum optimisation
- Quantum machine learning, quantum neural networks
- Quantum simulation algorithms
- Noisy intermediate-scale quantum (NISQ) algorithms: Variational Quantum Eigensolver (VQE), Quantum Approximate Optimisation Algorithm (QAOA)

5.6 APPLICATIONS OF QUANTUM COMPUTING AND SIMULATION

- Materials science
  - Manufacturing, e.g. new types of batteries
  - Pharmaceutical drug discovery
  - Catalyst discovery (improvement of chemical processes like Haber-Bosch)
- Engineering and design
  - Simulation of complex processes, e.g. aerodynamics, structural dynamics, crash & safety
  - Computational fluid dynamics, e.g. airflow around aircraft
  - Surrogate machine learning based models for numerical simulations
  - Design optimisation
- Optimisation in finance, production, network and logistics
  - Routing
  - Supply chain management, loading and sizing, production planning
  - Insurance risk assessment
  - Financial portfolio optimisation
  - Satisfiability problems (SAT): possible solutions for a set of constraints
  - Sequencing problems for optimal sequence for executing jobs
- Data security and cryptography

6 QUANTUM SENSORS AND IMAGING SYSTEMS

6.1 BASICS

- Fundamental quantum limits (standard quantum limit, Heisenberg limit)
- Definition of SI units
- Measurement criteria (sensitivity, resolution, etc.), classical alternatives, performance analysis

6.2 ELECTROMAGNETIC FIELD SENSORS

- NV centres, Rydberg atoms, superconducting sensors
- Atomic magnetometers and optically pumped magnetometers (OPMs)

6.3 TEMPERATURE, PARTICLE AND PRESSURE SENSORS

- Spin-qubit based sensors
- Precision spectroscopy gas sensors
- Optomechanical sensors

6.4 INERTIAL AND GRAVITY SENSORS

- Micro-electromechanical sensors (MEMS)
- Atom interferometers
- Rotating nanoparticle sensors

6.5 QUANTUM IMAGING

- Interaction-free measurement
- Quantum ghost imaging, lithography, imaging with undetected photons, tomographic imagin
- Quantum radar, quantum lidar

6.6 ATOMIC CLOCKS

- Microwave clocks, atomic fountain clocks, coherent population trapping (CPT) clocks
- Optical clocks, trapped ion clocks, neutral atoms in optical lattices clocks, quantum logic clocks
- Nuclear clocks
- Transportable atomic clocks

6.7 APPLICATIONS OF QUANTUM SENSORS

- Metrology at a single quantum level
  - Precision spectroscopy, quantum logic spectroscopy
- Medicine and molecular biology
  - Magnetic detection of neuronal and cardiac signals
  - Imaging (e.g. living cells)
  - Microwave diagnostics
- Civil and environmental monitoring
  - Geology, underground surveys, natural resource exploration, archaeology
  - Civil engineering, infrastructure monitoring
  - Earth monitoring, natural hazard prevention
- Transport and navigation, precise timing and position detection
- Control in industrial processes
  - Inspection in microelectronics
  - Ultra-precise timing and synchronisation, reference time

7 QUANTUM COMMUNICATION AND NETWORKS

7.1 BASICS

- Conventional and post-quantum cryptography, combined cryptographic approaches
- Quantum teleportation, Bell state measurement
- Security proof, side-channel attacks

7.2 QUANTUM RANDOM NUMBER GENERATORS (QRNG)

- Secure keys, e.g. for Quantum Key Distribution (QKD)
- Random numbers for algorithms, e.g. online gambling

7.3 QUANTUM KEY DISTRIBUTION (QKD)

- QKD basic protocols, e.g. BB84 (Bennett/Brassard), B92 (Bennett), E91 (Ekert)
- QKD advanced protocols, discrete and continuous variable protocols
- Measurement-device-independent (MDI) QKD and device-independent (DI) QKD
- Quantum key management systems, QKD modules (full devices)

7.4 APPLICATIONS OF QUANTUM CRYPTOGRAPHY

- Sector-specific use cases, e.g. financial transactions, health records, protection of critical infrastructure, e-government, defence, e-commerce, voting
- Secure access to cloud-based quantum computing, delegated quantum computing
- Protection of quantum data (encryption, authentication), advanced primitives (unclonable data, quantum money etc.)
- Quantum remote sensing with secure data transmission

7.5 INFRASTRUCTURE FOR QUANTUM INFORMATION NETWORKS (QUANTUM INTERNET)

- Quantum network nodes, memories and switches
- Quantum repeaters, entanglement swapping, entanglement purification
- Quantum channels, free-space communication, fibre-based systems, satellite-based systems

7.6 SYSTEM NETWORKS (COMPOSITE SYSTEMS), QUANTUM INTERNET APPLICATIONS

- Full quantum communication network, QKD trusted node networks (secure data transfer)
- Quantum enabled synchronisation networks, sensor and clock networks
- Connected and distributed quantum computing

8 VALORISATION

8.1 INDUSTRY LANDSCAPE AND MARKET ANALYSIS (SECTOR LEVEL)

- Market size and growth potential
- Policy and regulatory environment
- Strategic foresight
- Customer trends, needs and preferences
- Data integration

8.2 BUSINESS STRATEGY, ENTREPRENEURSHIP AND MANAGEMENT (BUSINESS LEVEL)

- Governance, leadership, risk management and strategic decisionmaking
- Competitive analysis
- Product and service innovation, Technology Readiness Level (TRL), intellectual property, business model innovation
- Industrial processes, standardisation, certification, evaluation, compliance, benchmarking (application-driven)
- Organisational design, change management and value chain optimisation
- Project and resource management
- Marketing

8.3 IMPACT AND RESPONSIBILITY

- Funding and initiatives landscape
- Economic impact (energy consumption, sustainability)
- Societal and environmental impact
- Scientific impact
- Responsibility, ethics

8.4 EUCATION AND COMMUNICATION

- Public communication and outreach, awareness raising, hype mitigation
- Education and (internal) training

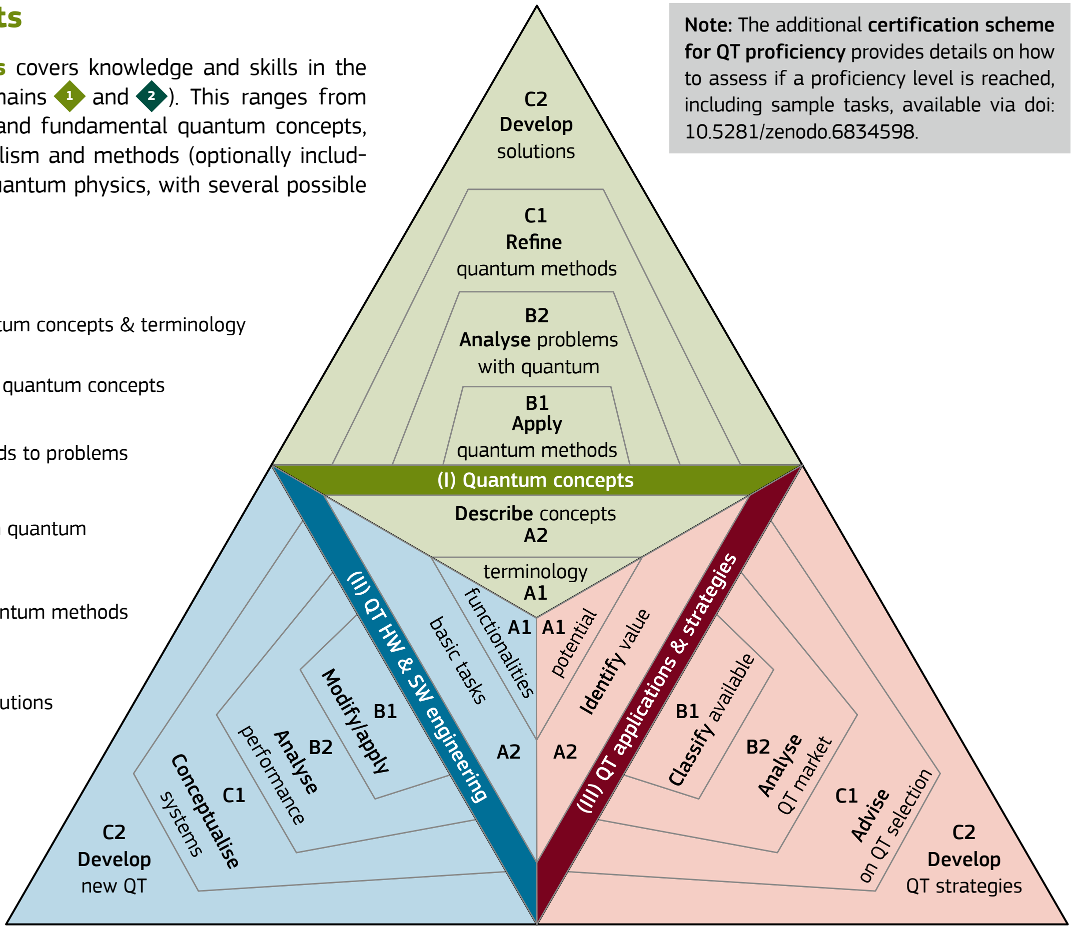
European Competence Framework for Quantum Technologies Proficiency Triangle

and proficiency levels overview; extended descriptions and examples on following pages

(I) Quantum concepts

Area **(I) Quantum concepts** covers knowledge and skills in the **quantum background** (domains 1 and 2). This ranges from basic quantum terminology and fundamental quantum concepts, through mathematical formalism and methods (optionally including information theory), to quantum physics, with several possible specialisations.

Note: The additional **certification scheme for QT proficiency** provides details on how to assess if a proficiency level is reached, including sample tasks, available via doi: 10.5281/zenodo.6834598.



- **A1 A1 Awareness**
  Reproduce basic quantum concepts & terminology
- **A2 A2 Literacy**
  Describe fundamental quantum concepts
- **B1 B1 Utilisation**
  Apply quantum methods to problems
- **B2 B2 Investigation**
  Analyse problems with quantum
- **C1 C1 Specialisation**
  Refine and extend quantum methods
- **C2 C2 Innovation**
  Develop innovative solutions

(II) QT HW & SW engineering

Area **(II) QT hardware & software engineering** covers aspects of technology functionality, detailing how to operate and interact with it. This includes practical tasks, e.g. for engineers in a QT development company or computer scientists using quantum computing, extending to technology integration and development. Related topics span across domains 3, 4, 5, 6, 7.

- **A1 A1 Awareness**
  Reproduce basic functionalities of a QT facet
- **A2 A2 Literacy**
  Perform basic tasks on a QT facet
- **B1 B1 Utilisation**
  Modify/apply a QT facet
- **B2 B2 Investigation**
  Analyse performance, improve QT
- **C1 C1 Specialisation**
  Conceptualise integrated QT systems
- **C2 C2 Innovation**
  Develop new QT facet

QT facet: core, component, system, application; HW/SW

(III) QT applications & strategies

Area **(III) QT applications & strategies** addresses the business dimension of QT applications 5.6, 6.7, 7.4, 7.6. It focuses on the question of “how to generate value with QT” (domain 8). This also includes considerations of impact and responsibility, extending to the exploration of novel applications and the design of new products utilising QT.

- **A1 A1 Awareness**
  Recognise potential of QT
- **A2 A2 Literacy**
  Identify value of QT
- **B1 B1 Utilisation**
  Classify available QT applications/approaches
- **B2 B2 Investigation**
  Analyse QT market and opportunities
- **C1 C1 Specialisation**
  Advise on QT appl. selection or strategies
- **C2 C2 Innovation**
  Develop and **assess** QT (product) strategies

Proficiency levels for (I) Quantum concepts
with knowledge, skill and more

The A levels concentrate on the **basic quantum concepts**, subdomain 1.1, with basics of the **mathematical formalism** 1.2. **Quantum physics** details from domain 2 become relevant at B levels, growing to high specialisation at C levels in one of the subdomains of domain 2, i.e. what is expected of the "tradiditonal quantum physicists".

Alternatively, specialisation may focus on **information theory** and advanced **mathematical** methods (subdomain 1.2), particularly relevant for quantum algorithm development.

Already A level education can include example experiments from **quantum physics** 2 and from **QT** (domains 5, 6, 7), for example **QRNG** 7.2 for the probabilistic behaviour.

Proficiency levels
with **K:** knowledge and **S:** skills

related content (sub)domains & examples

A1 Awareness: Reproduce basic quantum concepts & terminology
K: Basic idea (phenomena-oriented) of elementary quantum concepts with the corresponding terminology.
S: Ability to identify basic quantum concepts and assign the appropriate term, e.g. to follow (media) conversations about quantum.

A1

A1: Subdomain 1.1**: basic quantum concepts,** including e.g. superposition, interference, measurement process, decoherence, complementarity, entanglement.
Differ between several quantum concepts; match description and technical term; reproduce basic description.

hours

A2 Literacy: Describe fundamental quantum concepts with appropriate terminology, e.g. in conversations
K: Knowledge of fundamental quantum concepts with underlying mathematical formalism and/or representations.
S: Ability to explain basic quantum concepts and describe them using basic mathematics and/or representations as well as appropriate terminology, e.g. to communicate with quantum experts and novices.

A2

A2: Quantum **concepts** and related **mathematical foundations** (domain 1), including e.g. the Dirac notation, quantum states, and the concept of a qubit, with the related quantum effects, e.g. superposition states for a qubit and how they can be visualised.
Describe a concept or experiment, or calculate a quantum state, e.g. using the Dirac formalism.

days

B1 Utilisation: Apply quantum methods to a variety of theoretical problems
K: Knowledge of a variety of quantum (physics) concepts, including the mathematical formalism, specialised knowledge in a selected subdomain.
S: Ability to describe abstract problems with quantum physics and/or mathematics, solve them with quantum physical and/or mathematical methods.

B1

B1: Domain 1 together with some specialisation, in a quantum physics subdomain, e.g. **atomic physics** 2.1, **quantum optics and QED** 2.2, **solid-state physics** 2.3, ... or also e.g. QT-relevant **information theory** 1.2.
Describe a previously unknown (for example interferometric) setup using mathematics and calculate the expected quantum state for each step in the setup.

weeks

B2 Investigation: Analyse real-world problems with quantum methods
K: Advanced knowledge in a quantum (physics) subdomain, including a variety of methods and their validity.
S: Ability to describe and analyse real-world problems with mathematics, select quantum (physics/mathematics) methods to use to solve them; ensure quantum (physical) requirements are met.

B2

B2: See B1, may also include advanced **mathematical methods** 1.2, with a focus on real-world problems.
Short research project with documentation, e.g. student research project or bachelor thesis.

months

C1 Specialisation: Refine and extend quantum methods to solve new problems
K: Highly specialised knowledge in one subdomain and critical awareness of connections between different subdomains.
S: Ability to refine or extend solutions for new problems (e.g., real-world use cases), using quantum physical and/or mathematical methods and incorporating methods from different subdomains to generate new methods.

C1

C1: May be the "traditional" quantum physicist (theoretical), continuing the specialisation started at B levels, learning on their own as much as necessary about different subdomains (may go beyond **quantum physics subdomains** 2.X, e.g. quantum chemistry) and corresponding methods or focus.
Research project with documentation, e.g. master thesis on ***quantum information science****.*

years

C2 Innovation: Develop innovative solutions for critical problems
K: State-of-the-art knowledge in the subdomain and about connections with different approaches and (sub)domains.
S: Ability to find or develop innovative solutions for critical problems or real-world use cases; to evaluate and assess solutions (based on theoretical physics and mathematics), thus verify advantage; to extend and redefine knowledge or professional practice.

C2

C2: See C1, with research at the frontier of the subdomain considering connections with other subdomains, may include building B level expertise also in these subdomains.
Long research project on innovative, new developments with scientific publications, e.g. for PhD.

experience

Proficiency levels for (II) QT HW & SW engineering

with knowledge, skill and more

A **QT facet** can be – together with the underlying basics 5.1, 6.1, 7.1 – e.g.:

- [core] a QT core, e.g. a physical qubit realisation, see subdomains 4.1 to 4.5, or a quantum programming language 5.3;
- [component] a component around the QT core, e.g. a single photon detector, control software, an error correction algorithm, a user interface, see 3, 4.6 to 4.8, 5.3, 5.4;
- [system] a QT system, e.g. a quantum gravity sensor, quantum processor or quantum algorithm, see 5.2, 5.5, 6.2 to 6.6, 7.2, 7.3, 7.5;
- [application] a full application, i.e. an integrated system, e.g. a navigation system using a quantum gravity sensor or a full software program for simulating chemical processes using quantum-enhanced methods and running partly on a quantum device, see 5.6, 6.7, 7.4, 7.6.

Proficiency levels

with **K:** knowledge and **S:** skills

related content (sub)domains & examples

hours → days → weeks → months → years → experience

A1 Awareness: Reproduce basic functionalities of a QT facet
K: Basic idea of the functionalities of a QT facet.
S: Ability to follow basic instructions or conversations on the QT facet; reproduce basic processes.

A1

A1: Examples for QT facets: basic **quantum gates** 5.1 OR **magnetic field measurement with NV centres** 6.2 OR **BB84 protocol** 7.3 OR ...
List basic gates, sort gates and functionalities; list steps of a protocol; name measurable property for a quantum sensor.

A2 Literacy: Perform basic tasks on a QT facet
K: Knowledge of fundamental working principles of different parts in the context of a QT facet and how they can be used (technically), focusing on the difference to classical counterparts.
S: Ability to perform practical tasks (operate) with the QT facet (work in a lab or with software).

A2

A2: Details on functionalities including related **hardware** (4) and/or **enabling technologies** with basic laboratory techniques (3), e.g. what is needed for **quantum state control** 4.6 OR **quantum programming tools** 5.3 OR what is needed for **quantum imaging** 6.5 OR ...
Describe a working principle [free text format]. Operate the QT facet (HW or SW) appropriately as previously trained.

B1 Utilisation: Modify/apply a QT facet
K: Knowledge of a variety of parts for QT facets and their influence (e.g. which quantum effects may occur and have some influence) on other (classical or hybrid) parts/systems and QT facets; specialised knowledge on a selected QT facet (hardware and/or software).
S: Ability to adapt and test QT facets, interpret and compare results.

B1

B1: see A2, for multiple QT parts, along hybrid systems and interfaces (4.7), e.g. **Trapped ions as qubits** 4.3 OR a **quantum simulation algorithm** 5.2 OR ...
Perform modification as described below (see B2).
Modify a HW setup or apply an algorithm or replace a computing subroutine to solve an abstract problem, interpret the result (e.g., measurement result or algorithm output).

B2 Investigation: Analyse performance, improve QT
K: Advanced knowledge in the context of a QT facet, including standards, requirements/performance criteria and aspects of technology realisation (turn into product).
S: Ability to analyse the adaptation or integration of a QT facet in order to improve it.

B2

B2: QT facet see B1, plus **techn. realisation** (for **HW** 4.8); analyse performance after replacing, e.g.
(i) a classical optimisation subroutine by a **quantum optimisation** approach 5.6 to improve a software product;
(ii) a classical with a **quantum gravity sensor** 6.4 to improve a navigation system.
Write report on requirements analysis and performance results.

C1 Specialisation: Conceptualise integrated QT systems
K: Highly specialised knowledge of one QT facet and critical awareness of connections between different QT facets and classical systems; methods of integration, also for hybrid quantum systems.
S: Ability to refine or extend systems, combine and integrate a quantum core and different components into a (hybrid) system/application (hardware and/or software), supervise QT manufacturing.

C1

C1: Plan replacements as described above (B2) considering the whole **(hybrid) system** 4.7.
Document integration concept including justification of decisions, assess weighing up the pros and cons for quantum-related components or for classical vs. quantum components, e.g. in a project report or a master thesis.

C2 Innovation: Develop new QT facet
K: State-of-the-art knowledge of a QT facet and its connections with various other QT facets.
S: Ability to develop innovative QT facet (core, system or application), evaluate and assess solutions, push the boundaries of current technology (thus, conduct research).

C2

C2: (Industrial) research and development considering challenges in technological realisation (4.8), e.g. to design a new device, e.g. a quantum-enhanced **magnetometer** 6.2 or a new **quantum memory** 7.5; develop a new **quantum programming** tool (e.g. a **compiler**) 5.3.
Research report, scientific paper.

Proficiency levels for (III) QT applications & strategies
with knowledge, skill and more

Covers aspects from domain 8 and may be focused on:

- one QT application, with possible use cases, e.g. quantum simulation in chemistry, see 5.6, 6.7, 7.4, 7.6;
- one field of application, e.g. pharmaceutical drug development, where quantum simulation is one approach that might bring an advantage for specific use cases;

and the value and impact for, e.g.:

- an industry sector or the own company/business (see related content and examples below);
- the society and education: subdomain 8.4 focuses on **education and communication**, including e.g. using QT to convey quantum concepts, taking into account common misconceptions, explaining an approach to the general public, or workforce and career development, such as analysing available training opportunities and planning professional development. For more details, see the Certification Scheme for QT Proficiency, available via doi 10.5281/zenodo.6834598.

Proficiency levels

with **K:** knowledge and **S:** skills

related content (sub)domains & examples

A1 Awareness: Recognise potential of QT

K: Basic idea of the potential of QT systems and applications, overview of possibilities, challenges and limitations.

S: Ability to follow public media and discussions with critical awareness of hype.

A1

A1: Applications for a QT, see 5.6, 6.7, 7.4, 7.6, or a selected (sub)topic (concrete field of application, e.g. **quantum optimisation in logistics** 5.6), with relevance for **business** 8.2 and considering impact 8.3 and hype 8.4 (especially for computing).

Multiple choice questions on expectations or challenges; list potential advantages, identify hyped statements..

A2 Literacy: Identify value of QT

K: Knowledge of applications landscape (e.g. products on market) and use cases as well as expected technological development (impact, timelines) and ethical implications.

S: Ability to identify potential use cases (i.e. opportunities for value creation, where to seek expert assessment).

A2

A2: Application see A1, plus creating strong awareness on (not only) economic **impact** and **responsibility** issues 8.3, and how to **communicate** about QT 8.4. Identify value for own business or an industrial sector.

Describe expected impact of a QT application for a specific company or industrial sector (generic description without analysis).

B1 Utilisation: Classify available QT applications/approaches

K: Knowledge of a variety of (potential) applications/approaches with (dis)advantages and related providers and experts, specialised knowledge on a selected QT application or on a field of application.

S: Ability to compare and select an application/approach for a specific problem/scenario.

B1

B1: See A2, plus **industry landscape, market analysis** 8.1, e.g. to select a specific QT product for (a company's) concrete circumstances (e.g. for sales or as a QT user).

For a specific situation (use case and QT customer or other concrete scenario), compare a limited number of options and select the most suitable fit.

B2 Investigation: Analyse QT market and opportunities

K: Advanced knowledge of a QT application and the related industry landscape and business models, including critical awareness on risks and potential consequences.

S: Ability to identify promising QT use cases with advances and risks, relate strategic QT reports to own business.

B2

B2: See B1, additional competitive analysis etc. (**business strategy** ... 8.2), including review of strategic reports focusing on potential advances and risks of QT.

Document an analysis for a concrete potential use case covering potential advances, risks, competitive analysis, ...

C1 Specialisation: Advise on QT application selection or strategies

K: Highly specialised knowledge in a field of application for a QT application incl. market situation etc., critical awareness of technologies and applications for a variety of application fields, including critical and ethical perspectives, impact assessment.

S: Ability to advise/assist companies in developing QT strategies and realising QT projects (investment or education), analyse and select available (technology/software) building blocks for integration.

C1

C1: See B2, with strong background in the field of application, e.g. finance or pharma looking at quantum computing, or e.g. internal education for a company, with available classical solutions and considering **impact** and **ethical** consequences 8.3, to make suggestions where to invest, what to buy, which strategy to follow, ...

Document an analysis for a specific situation (incl. e.g. benchmarking) and make a suggestion (such as a strategic report).

C2 Innovation: Develop and assess QT (product) strategies

K: State-of-the-art knowledge in a field of application for a QT application incl. market situation etc. and how it relates to different approaches.

S: Ability to develop or evaluate/assess strategies/roadmaps for the development of quantum (enhanced) applications (HW/SW products) or curricula.

C2

C2: See C1, focus on 8.2, e.g. **product and service innovation**, to create ideas and make assessment what product to develop, or what to address (e.g. market, end-user sector).

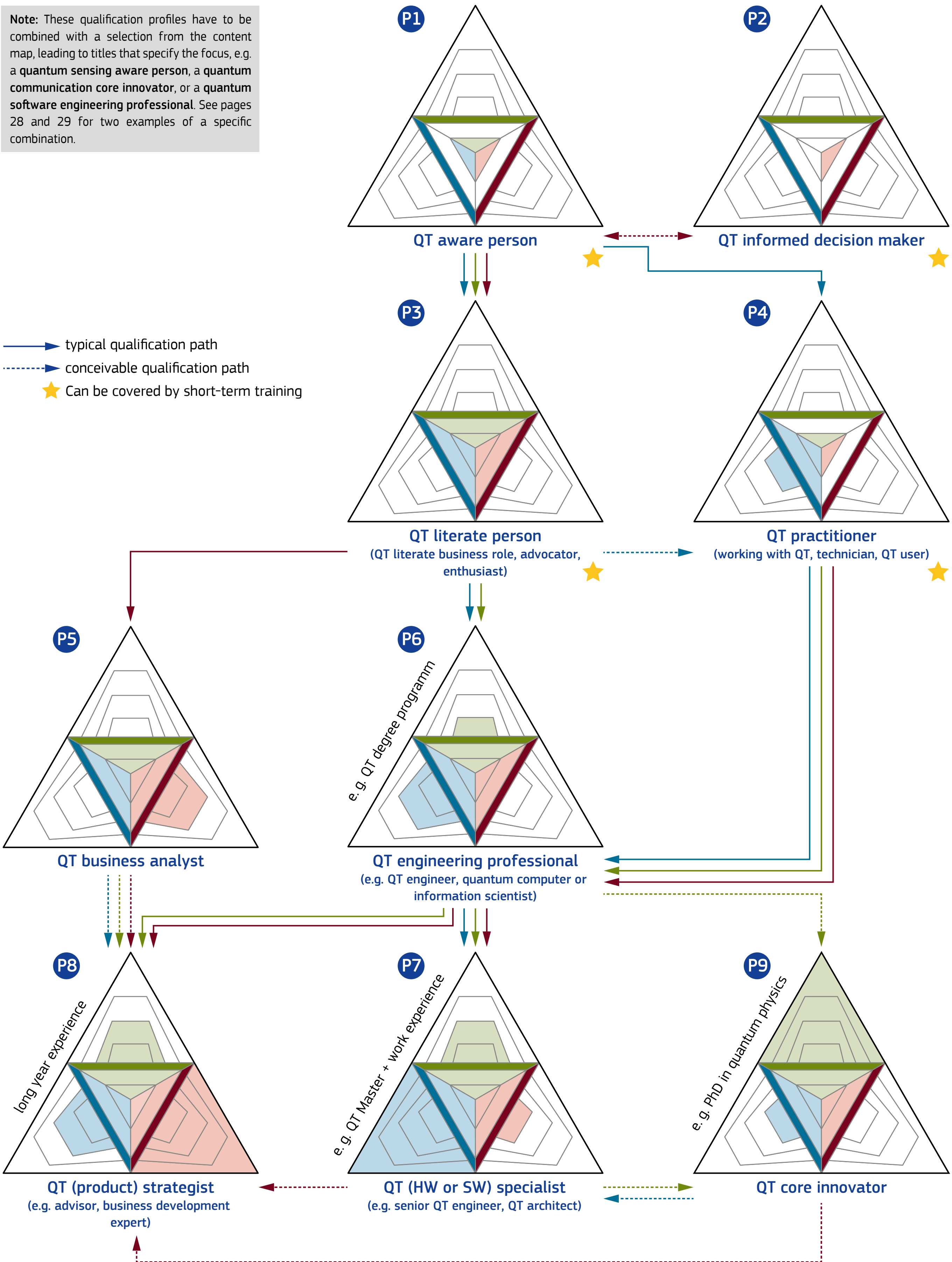
Evaluate quality and reach of product; write or assess proposal.

hours → days → weeks → months → years → experience

European Competence Framework for Quantum Technologies Qualification Profiles

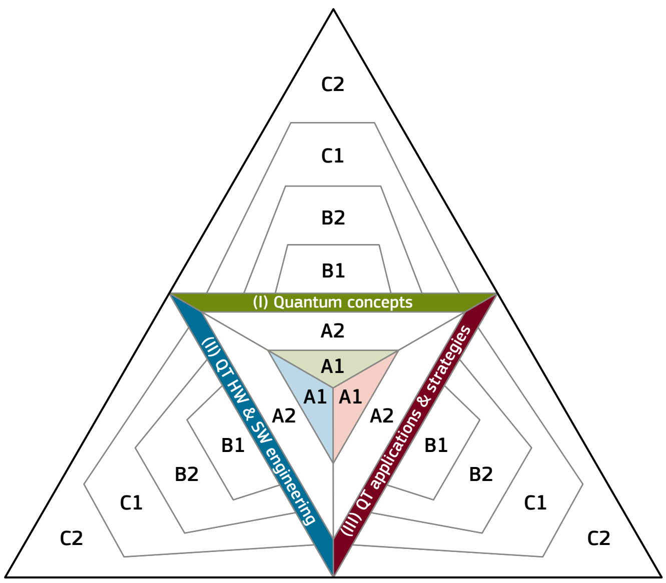
Overview and relations, details on following pages

Note: These qualification profiles have to be combined with a selection from the content map, leading to titles that specify the focus, e.g. a **quantum sensing aware person**, a **quantum communication core innovator**, or a **quantum software engineering professional**. See pages 28 and 29 for two examples of a specific combination.



QT proficiency for the **QT aware person**

P1



A1 Awareness: Reproduce basic quantum concepts & terminology
K: Basic idea (phenomena-oriented) of elementary quantum concepts with the corresponding terminology.
S: Ability to identify basic quantum concepts and assign the appropriate term, e.g. to follow (media) conversations about quantum.

A1 Awareness: Reproduce basic functionalities of a QT facet (core, component, system, application; HW/SW)
K: Basic idea of the functionalities of a QT facet.
S: Ability to follow basic instructions or conversations on the QT facet; reproduce basic processes.

A1 Awareness: Recognize potential of QT
K: Basic idea of the potential of QT systems and applications, overview of possibilities, challenges and limitations.
S: Ability to follow public media with critical awareness of hype.

Note: This qualification targets business and administrative staff who work with QT experts, as well as 'classical' engineers who want to understand the basics of QT to improve interdisciplinary communication, and perhaps even people with a basic interest in QT, such as those who use QT at the touch of a button.

General description

The **QT aware person** has the minimum additional QT specific qualification required to access QT ideas:
- has an overview of the possibilities, challenges and limitations of QT, and
- knows the basic quantum concepts and terminology in the context of QT functionalities, thus is
- able to follow conversations in the company and also what is being discussed in media with an awareness of QT opportunities and possible hype.

Example personas

Business/administrative people:
A **business person** – perhaps responsible for logistics or human resources in a QT-related company – needs a basic idea of what the others are doing and talking about. With this basic idea they can learn more on the job, e.g. ask questions to the engineers if a problem arises where they need more details about QT. The same applies to someone in **marketing** for a large company with many products, some of which have a quantum core and could be advertised as such.

Classical engineer (electronics, mechanics, software, etc.), end user (click-a-button level):
An **electronics engineer** who does 'classical' work, working on a quantum product, but with tasks no different from other high-tech products, and who sometimes comes into contact with the quantum people and needs to understand roughly what they are talking about. The **basic end user**, using a device with a quantum sensing core or a software program that uses quantum computing in the background, may not even notice that anything quantum is going on.
Such a person may not need QT specific training, but may be interested in it – perhaps even in parts of the training for a **QT practitioner** P5.

Needs and suggestions

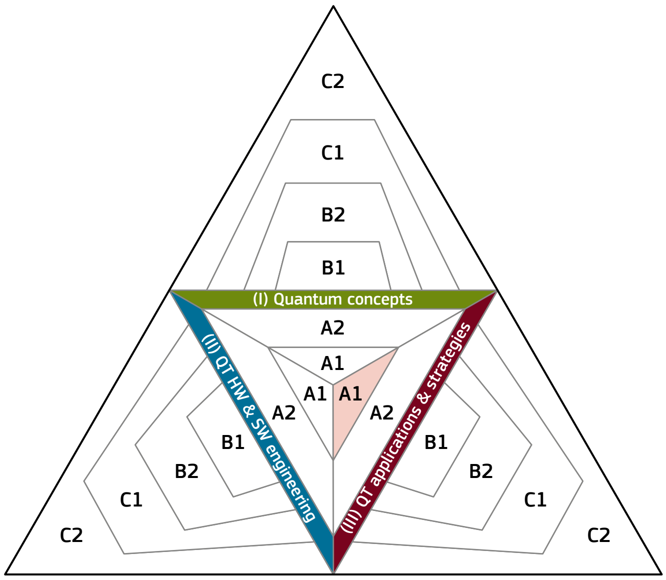
Suggested previous qualification:
- None – can be the basis for further training, or to get people interested and identify who should be upskilled

Suggested training modules:
A1 **(I)** Basic quantum concepts: phenomena-oriented introduction with basic terminology (subdomain 1.1), in the context of QT and their basic functionalities, thus **II:** A1, possibly focused on a QT pillar, see below.
A1 **(III)** Overview of possibilities, challenges and limitations for *one or all QT pillars* (5.6, 6.7, 7.4, 7.6), ideally already outlining the change of era and the expected (societal) impacts and ethical implications (8.3, 8.4, rather A2 level); as well as coverage and possible hype in the media (especially for quantum computing applications, 5.6).
In-person training would be nice for questions, but many people prefer self-learning for flexibility, such as short video clips, podcasts, etc. Easy and fun – make people feel that quantum is great, make them want to learn about QT; also to identify whom to train further. Some may not need the basic functionalities (**II:** A1) to do their jobs, but most people working around QT are technically interested by themselves, and learning the basic quantum concepts and terminology in the context of QT functionality may increase the interest and sustainability of the knowledge gained.
Advantageous if covered in school education (in the long term).

Suggested general conditions:
- Language: If it is in the native language, it opens it up to more people (e.g. older people), makes it easier to grasp.
- Certificate: Just to show the seriousness of the course/provider, proof of attendance should be sufficient.
- Easy accessibility important, e.g. include it on the (intranet) homepage of a company.

QT proficiency for the **QT informed decision maker**

P2



A1 Awareness: Recognise potential of QT
K: Basic idea of the potential of QT systems and applications, overview of possibilities, challenges and limitations.
S: Ability to follow public media and discussions with critical awareness of hype.

Note: Decision makers with higher QT expertise may be, e.g., **QT business analyst** P5 or **QT strategist** P8, and some may be interested in becoming a **QT aware** P1 decision maker.

General description

The **QT informed decision maker** is someone in a position with a lot of responsibility and cannot be an expert for all decisions to be made, therefore has some experts for QT; regarding QT is only aware of:

- the opportunities with expectations of impact, timelines, etc., i.e. recognises the disruptive character of QT,
- potential use cases within their own field of work, i.e. how to gain value from QT.

Their understanding of the relevance of QT is important to provide the resources for others to work on QT.

Example personas

CEO, manager:
A **CEO of a large pharma company** who is interested in the use of QT (computing and simulation) in drug discovery, especially which approaches promise better or cheaper solutions to the challenges the company is working on. Needs enough background knowledge to understand the essence of a QT-related proposal, e.g. from a **QT business analyst** P5 or **QT strategist** P8, and to make an informed decision about where to invest or which people to hire or train.
A **manager in a manufacturing company** might be interested in using quantum computing to optimise processes, and needs some information material to get an idea of the potential value to be expected, to make a first decision whether to consult experts to develop a quantum strategy for the company, or to wait for more powerful quantum computers.

Politicians, government:
A **politician** needs to understand enough about QT to decide on a strategy, for example to invest in QT. To do this, they need enough basics to follow, e.g., expert advice, to understand the potential added value of QT and why it makes sense to promote QT projects.

Needs and suggestions

Suggested previous qualification:

- Some background in an application area, i.e. the own field of work in which QT might add value.

Suggested training modules:

A1 **(III)** Potential/value of QT for the own activities: short, condensed summary (e.g. short video clips or one-page overview, no in-person training) of opportunities and expectations (bigger goals, promises, timelines) to see the potential value for the own business or for the country/society, also with comparison of the options and information on how much to invest.
Impacts (not only for the industry, but also for society and the environment, 8.3) and ethical aspects (incl. risks of QT, 8.4) also should be addressed, may already touch A2 level, strongly focused on the own activities (own business or country or other field of work).

Usually, the decision maker will ask experts or consultants, e.g. to get a presentation, or use public sources or reports.
Even then some more basics are desirable, some might additionally (or in advance) become a **QT aware person** P1, thus combining to a **QT aware decision maker.**

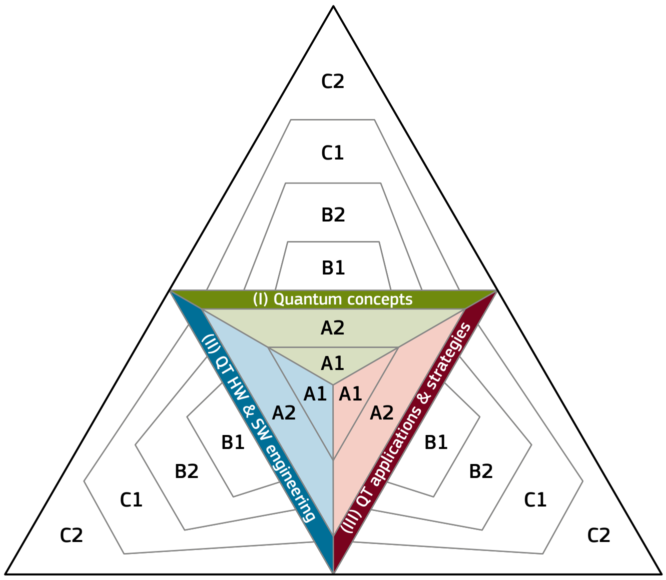
Suggested general conditions:

- Language: English or native language, depending on the specific target group, especially for older people or where trust is important, the native language may be an advantage.
- Certificate: no, and no interactive elements such as quizzes or tests.

QT proficiency for the **QT literate person**

(QT-literate business role, advocator, enthusiast)

P3



A2 Literacy: Describe fundamental quantum concepts with appropriate terminology, e.g. in conversations
K: Knowledge of fundamental quantum concepts with underlying mathematical formalism and/or representations.
S: Ability to explain basic quantum concepts and describe them using basic mathematics and/or representations as well as appropriate terminology, e.g. to communicate with quantum experts and novices.

A2 Literacy: Perform basic tasks on a QT facet (core, component, system, application; HW/SW)
K: Knowledge of fundamental working principles of different parts in the context of a QT facet and how they can be used (technically), focusing on the difference to classical counterparts.
S: Ability to perform practical tasks (operate) with the QT facet (work in a lab or with software).

A2 Literacy: Identify value of QT
K: Knowledge of applications landscape (e.g. products on market) and use cases as well as expected technological development (impact, timelines) and ethical implications.
S: Ability to identify potential use cases (i.e. opportunities for value creation, where to seek expert assessment).

Note: This profile can also describe a **science (or QT) communicator** who is prepared to raise awareness among students on QT.

General description

The **QT literate person** is a professional add-on for various roles such as: first contact sales or marketing, in management or in business related roles with tasks related to potential use cases, or more general bridge roles, *or the basis for learning more on the job*. Such a person:

- "speaks quantum" (knows concepts and terminology as well as QT functionalities) and can communicate at a basic level with both
- quantum experts and novices, i.e. with technical and business colleagues as well as with customers or the general public, has a basic understanding of the opportunities and challenges for (one or several) QT.

Example personas

Technical sales, marketing, PR/public communications executives:
A **salesperson** working for a company selling a quantum-enhanced product, e.g. a navigation system using a quantum sensor, OR for a company providing enabling technologies (components) for QT; who needs to communicate with customers and understand enough to avoid promising something impossible, but does not need to understand the details, for in-depth discussion refer to e.g. a **QT specialist** P7. Usually has a technical background and is interested in trying something hands-on.

HR, people managers, training and development professionals:
A **people manager** who needs to communicate with people from different departments and with different quantum expertise, and therefore needs to understand enough to communicate effectively, e.g. to understand the needs of quantum and non-quantum people, and also to understand enough about the company's own product to be able to answer basic questions or refer to the appropriate person.
Similarly, someone responsible for **internal training and personal development** of employees, suggesting upskilling programs or mentors.

QT use case explorer, innovation officer
An **employee in a business unit** dealing with problems like optimising manufacturing processes, who has an idea of the type of problems that might benefit from quantum, who has a background in the application area (e.g. logistics problems) and who has an idea of the novel possibilities opened up by the use of quantum effects, can generate ideas for potential use cases and then ask an expert to validate them.

Needs and suggestions

Suggested previous qualification:

- Experience in the own field ('classic' qualification, e.g. in a potential QT application area and/or business unit, e.g. in marketing/sales, HR or in education and training; 'classic' communication skills)
- Completed training for the **QT aware person** P1: already all three A1 A1 A1 levels for the relevant QT pillar(s) or application area(s).

Suggested training modules:

A2 **(I)** "Speaking quantum": training on quantum concepts with peer interaction (i.e., talking to people on the same level), providing an opportunity to ask questions and to feel that one is not alone with difficulties in understanding quantum concepts.

A2 **(II)** Basic functionalities around QT, highlighting the differences between quantum and classical technologies, with didactically selected examples and hands-on tasks with strong guidance (e.g. real QT devices or analogy experiments, or basic quantum programming tasks).

A2 **(III)** Overview of use cases for (the own QT product and for other) available QT products to get a realistic picture of what can be done with such QT, as well as expected impact 8.3 ethical implications 8.4.
Also training on how to communicate about QT and how to explain quantum concepts (public communication, outreach, education, 8.4).

For a particular QT or product, the intermediate level training needs may be so company specific that they can only be covered by internal training. The A level basics are suitable for external training, e.g. a crash course, to prepare employees with this QT literacy for further learning on the job, e.g. to get **III:** B1 to be able to compare and select available QT applications for problems in own company or as sales, or **II:** B1 to work with QT (see **QT (literate) practitioner** P4). In person to meet other people, talk about problems, etc., and get to know people (experts) to ask.
Alternative: (small) part of the study program (minor or elective subject), especially for the potential use case explorer.

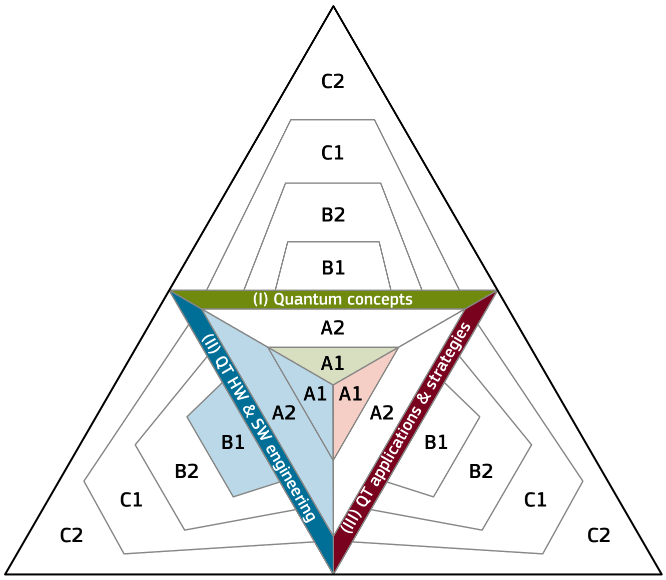
Suggested general conditions:

- Language: Depends, the training should be in the same language as the QT literate person has to communicate in.
- Certificate: To show seriousness of the course/provider or if a specific skill is trained, proof of attendance should usually be sufficient.

QT proficiency for the **QT practitioner**

(working with QT, technician, QT user)

P4



A1 Awareness: Reproduce basic quantum concepts & terminology
K: Basic idea (phenomena-oriented) of elementary quantum concepts with the corresponding terminology.
S: Ability to identify basic quantum concepts and assign the appropriate term, e.g. to follow (media) conversations about quantum.

B1 Utilisation: Modify/apply a QT facet (core, component, system, application; HW/SW)
K: Knowledge of a variety of parts for QT facets and their influence (e.g. what quantum effects may occur and have some influence) on other (classical or hybrid) parts/systems and QT facets; specialised knowledge on a selected QT facet (hardware and/or software).
S: Ability to adapt and test QT facets, interpret and compare results.

A1 Awareness: Recognise potential of QT
K: Basic idea of the potential of QT systems and applications, overview of possibilities, challenges and limitations.
S: Ability to follow public media and discussions with critical awareness of hype.

Note: This profile may be combined with the **QT literate person** P4 to a **QT literate practitioner**.

General description

The **QT practitioner** is someone who works around the development, assembly and operation of QT (technicians or 'classical' engineers with some QT specific additional qualifications), or uses QT with some customisation:

- is QT aware, thus is able to follow team discussions and has an idea of the potential of the QT working on,
- has an overview of the relevant parts (hardware and/or software) for QT, and
- focuses on the specific QT relevant to their own work, and knows how to work with it.

Example personas

'Classical' engineer with QT add-on, QT lab technician (e.g. for operation and maintenance), QT assembly and test technician, …
An **engineer working on QT development**, could be an electronic or mechanical engineer or a software engineer/computer scientist, working on the control hardware/software for a qubit, needs mainly traditional engineering skills, but works together with the quantum people, so needs an idea of the special challenges in QT development (but does not need to understand the details, has a supervisor who ensures compliance with quantum requirements) and also has an idea of the applications etc. to know what they are working for.

QT user with adaptation/customisation, e.g. quantum computing end user with basic adaptation (forecast):
A **data scientist in finance** has a software/algorithm, e.g. for a specific optimisation problem, and adapts the algorithm by replacing some packages and subroutines with those from quantum programming libraries, and interprets the results in the context of their own field of work. Needs some background in quantum to understand the 'new way of thinking' behind the new libraries.

Needs and suggestions

Suggested previous qualification:

- Engineer or technician in the relevant domain or background in STEM*/the application area, preferably with experience in the subdomain of the enabling technologies and techniqes 3 relevant to the (targeted) position, e.g. in laboratory techniques, optical or control technologies or in classical computing
- Completed training for the **QT aware person** P1: already all three A1 A1 A1 levels for the relevant QT pillar(s) or application area(s).

Suggested training modules:

A2 **(II)** Training on the parts of QT, focusing on one system/application, e.g. what components are needed to build a quantum processor or a quantum sensor, what components are needed in a quantum network, or what packages and subroutines are available for a problem type (e.g. optimisation) in a quantum programming library, focusing on the differences to their classical counterparts, with hands-on tasks (in lab or programming). May already be focused on what is relevant to their own work, or more general, see above.

B1 **(II)** Further, more specialised training, with guidance, e.g. learning on the job or a longer course, summer school or internship, to get the skills and experience needed for the concrete job/task (how to use/integrate/work with it in everyday work).

Alternative: Minor or elective subject in a Bachelor's program, some might also be interested in the other part of a **QT literate person** P3 to combine to a **QT literate practitioner**.

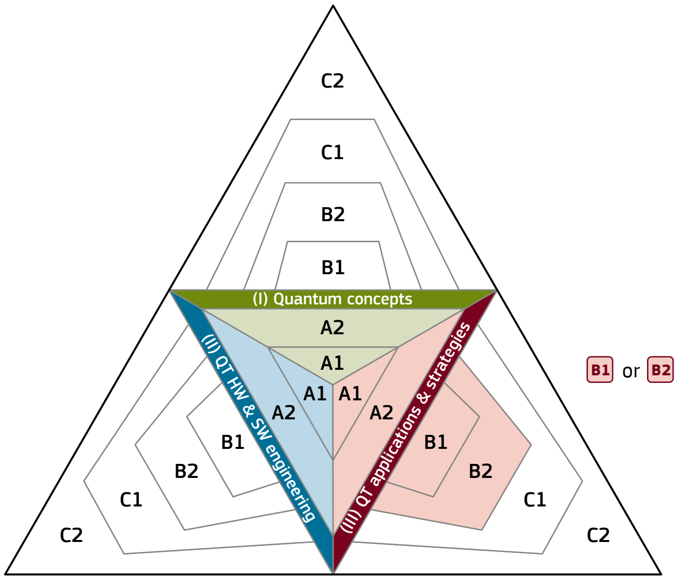
Suggested general conditions:

- Language: English
- Certificate: Becomes more relevant if a specific skill is trained, e.g. after a summer school or longer course with practical tasks.

* STEM: Science, Technology, Engineering and Mathematics

QT proficiency for the **QT business analyst**

P5



A2 Literacy: Describe fundamental quantum concepts with appropriate terminology, e.g. in conversations
K: Knowledge of fundamental quantum concepts with underlying mathematical formalism and/or representations.
S: Ability to explain basic quantum concepts and describe them using basic mathematics and/or representations as well as appropriate terminology, e.g. to communicate with quantum experts and novices.

A2 Literacy: Perform basic tasks on a QT facet
K: Knowledge of fundamental working principles of different parts in the context of a QT facet and how they can be used (technically), focusing on the difference to classical counterparts.
S: Ability to perform practical tasks (operate) with the QT face.

B1 Utilisation: Classify available QT applications/approaches
K: Knowledge of a variety of (potential) applications/approaches with (dis)advantages and related providers and experts, specialised knowledge on a selected QT application or on a field of application.
S: Ability to compare/select application/approach for a specific problem/scenario.

B2 Investigation: Analyse QT market and opportunities
K: Advanced knowledge of a QT application and the related industry landscape and business models, including critical awareness on risks and potential consequences.
S: Ability to identify promising QT use cases with advances and risks; relate strategic QT reports to own business.

General description

The **QT business analyst** is someone who looks for opportunities, e.g. in which direction to develop a new type of product, therefore:
- has detailed knowledge on the market, available products, options, etc., and
- can identify highly promising use cases, e.g. a problem as suitable for quantum computing, and
- has enough background knowledge to understand strategic reports, including expectations, trends, etc., as well as market demands.

Especially interesting for quantum computing use cases: within the NISQ era, people could start e.g. becoming a **QT literate person** P3, and continue (over years while following classical careers) to read reports, etc., and start to generate ideas for use cases to be addressed when more powerful quantum computing becomes possible.

Example personas

Market analyst, business developer, (junior) consultant, patent examiner:
An **analyst in a company developing navigation systems** interested in integrating (quantum) sensors for gravity measurement into a navigation product, so the analyst has advanced knowledge of the available sensors (classical and quantum) with pros and cons, knows about their roadmaps, etc., to identify whether a quantum sensor might be interesting to integrate into their own product – and also knows the market for navigation systems to assess the need for such a quantum-enhanced product, thus influencing the direction of product development (initiating the process, bringing the experts together for a decision).

Quantum computing end user (forecast), expert for identifying promising use cases, creator of patent ideas:
An **analyst in a pharmaceutical company** who researches potential use cases for quantum computing, reads reports, knows the available (classical and quantum) solutions and approaches with their advantages, disadvantages and risks, selects the concrete problem and the appropriate quantum approach to start research, communicates these insights to experts in the company, e.g. software developers who will include quantum libraries and algorithm subroutines in their software, but do not need to be able to do the programming or even know how the quantum-enhanced solution works.

Needs and suggestions

Suggested previous qualification:
- Advanced knowledge in the application area and of classical solutions, maybe also advanced mathematics to see the mathematical structure behind a real-world problem as a potential use case, but not necessarily being able to do the 'translation' (e.g. mathematical description) and to find a solution, for this refer to **QT (HW or SW) specialist** P7 or **QT strategist** P8.
- Completed training for the QT literate person (already all three A2 A2 A2 levels for the relevant QT pillar or application area)

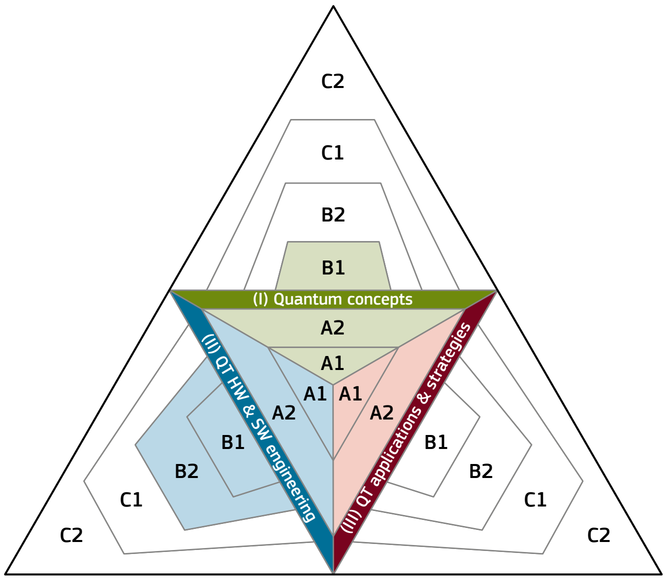
Suggested learning path:
B1 **(III)** Attend conferences, talk to people from different companies, gather experiences.
B2 **(III)** Read reports and papers, market updates, roadmaps from different companies/providers and on different approaches (classical and quantum).
Some may not require technical details and hands-on experience (**II:** A1 A2), but usually they have a technical background and are interested in it.

Suggested general conditions:
- Language: English
- Certificate: not applicable

QT proficiency for the **QT engineering professional**

(e.g. QT engineer, quantum computer or information scientist)

P6



B1 Utilisation: Apply quantum methods to a variety of theoretical problems
K: Knowledge of a variety of quantum (physics) concepts, including the mathematical formalism, specialised knowledge in a selected subdomain.
S: Ability to describe abstract problems with quantum physics and/or mathematics, solve them with quantum physical and/or mathematical methods.

B2 Investigation: Analyse performance, improve QT
K: Advanced knowledge in the context of a QT facet (core, component, system, application; HW/SW), including standards, requirements/performance criteria and aspects of technology realisation (turn into product).
S: Ability to analyse the adaptation or integration of a QT facet in order to improve it.

A2 Literacy: Identify value of QT
K: Knowledge of applications landscape (e.g. products on market) and use cases as well as expected technological development (impact, timelines) and ethical implications.
S: Ability to identify potential use cases (i.e. opportunities for value creation, where to seek expert assessment).

Note: This intermediate profile may describe an interim step to evolve with experience to an advanced profile like the **QT specialist** P7, or in the traditional discipline and stay at this QT-specific level.

General description

The **QT engineering professional** is someone who typically comes from a degree program in (HW or SW) engineering with QT expertise:

- knows about a variety of QT facets (usually components) with standards, requirements, etc., and also
- has a profound background in quantum concepts and mathematics, as well as an overview of potential applications
- and has relevant practical experience (laboratory work, experimental physics or software development),

and works on the development or improvement of QT facets, on the hardware or software side, e.g. on improving the control electronics for a qubit realisation, or on integrating quantum algorithm subroutines into a software application to improve it.

Example personas

Engineering or computer science graduate:
A **QT master's student** with a bachelor's degree in electronic engineering who starts a master's project (internship) in a start-up company on the control electronics for a qubit needs mainly traditional engineering skills, but also a profound knowledge of the particularities of quantum technologies, the special challenges in developing QT components, and the available components, standards and requirements to analyse and adapt the control electronics to improve the QT system the start-up is developing, with an idea of the applications and the big picture etc. as motivation for what they're working on.

Assessor, technical solutions or benchmarking analyst:
An **assessor for functional safety and security** who works in a certification institution and has to assess whether standards for technology performance and device security are met, so needs to understand how the technology works, what standards and requirements there are to meet, and also needs to work with the QT system/application to do extensive testing, including e.g. running algorithms or checking if there are security issues in a quantum communication device.

Needs and suggestions

Suggested previous qualification:

- Engineer in the relevant domain or other STEM* background, e.g. computer scientist
- For degree program: STEM Bachelor; for upskilling: trained as **QT literate practitioner** P3 P4

Suggested learning paths:

- (A) Degree program: focused master's programme for people with a bachelor's degree in a STEM discipline, with lectures on the necessary quantum physics (including mathematics) and on the bigger picture (overview of different QT systems and applications and expectations), but with a strong focus on practical (engineering) tasks such as QT-related lab work or quantum programming.
- (B) Upskilling, starting with the **QT literate practitioner** P3 P4: continue e.g. with online lectures for the additional background knowledge **I:** B1 and standards etc. **II:** B2, or work through textbooks and papers yourself, and continue 'learning by doing', maybe take online courses on programming with homework to be uploaded, or continue learning from experts in company lab.

Alternative: Start with a minor or electives on QT in bachelor's program and continue with further electives on QT in master's program.

Suggested general conditions:

- Language: English
- Certificate: Important, especially for specific skills such as quantum programming, may be covered by the degree certificate.

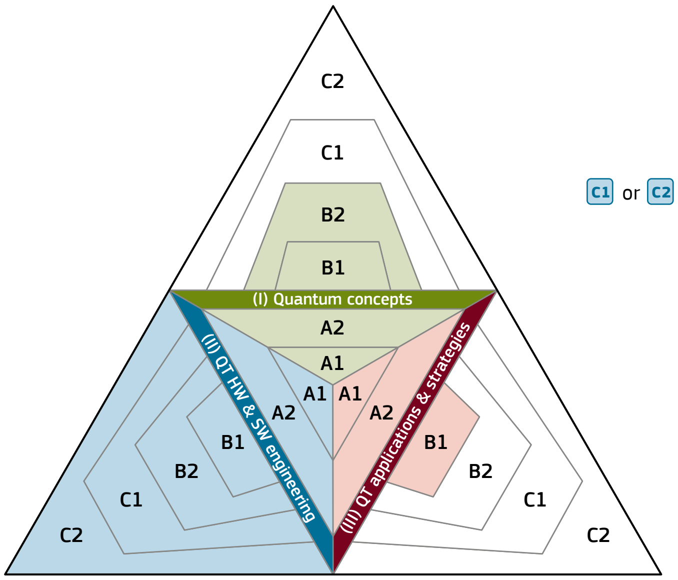
* STEM: Science, Technology, Engineering and Mathematics

Note: This profile was rarely discussed in the interviews, the traditional engineering/STEM* skills seem to remain more important. To really make use of the QT expertise, further specialisation is needed, so this could be seen as too much or too little QT to be really useful in industry at this early stage – but as technology readiness increases, the demand for engineers and similar with this intermediate QT specialisation should also increase.

QT proficiency for the **QT (HW or SW) specialist**

(e.g. senior QT engineer, QT architect)

P7



B2 Investigation: Analyse real-world problems with quantum methods
K: Advanced knowledge in a quantum (physics) subdomain, including a variety of methods and their validity.
S: Ability to describe and analyse real-world problems with mathematics, select quantum (physics/mathematics) methods to use to solve them; ensure quantum (physical) requirements are met.

C1 Specialisation: Conceptualise integrated QT systems
K: Highly specialised knowledge of one QT facet and critical awareness of connections between different QT facets and classical systems; methods of integration, also for hybrid quantum systems.
S: Ability to refine or extend systems, combine and integrate a quantum core and different components into a (hybrid) system/ application (hardware and/or software), supervise QT manufacturing.

C2 Innovation: Develop new QT facet
K: State of art knowledge of QT facet and its connections with various other facets.
S: Ability to develop innovative QT facet (core, system or application), evaluate and assess solutions, push the boundaries of current technolog.

B1 Utilisation: Classify available QT applications/approaches
K: Knowledge of a variety of (potential) applications/approaches with (dis)advantages and related providers and experts, specialised knowledge on a selected QT application or on a field of application.
S: Ability to compare/select an application/approach for specific problem/scenario.

General description

The **QT (HW or SW) specialist** is someone who knows the big picture of the technology, related applications, and has an advanced understanding of the underlying quantum concepts (physics/mathematics/information theory), a role that has different characteristics in 'traditional' roles depending on experience, e.g. with classical technologies in the same application area. For example, this could be:

- QT systems architect, with classical systems engineering or software development specialisation and this additional quantum expertise;
- QT customer or requirements engineer, who understands the technology details and customer needs, and can translate their problems;
- QT supervisor, e.g. project manager in development of a QT product, ensuring that special requirements for the quantum part are met;

working together and with other experts, such as a **QT strategist** P8 (or at least a **QT analyst** P5), **QT core innovator(s)** P9.

Example personas

Hardware integration engineer, software, security or network architect:
A **QT systems engineer** who integrates the quantum hardware core (e.g. based on NV centres) into the whole system (e.g. the magnetic field sensor), or the quantum system into a full industrial product or existing infrastructure (e.g. a medical device). A **quantum software architect at an IT service provider** who combines quantum and classical algorithm subroutines etc. into a full software program with a graphical interface, so that e.g. smaller banks can use it to perform quantum-enhanced portfolio optimisation without worrying about the quantum parts.

Customer or requirements engineer:
A **QT customer engineer** at a quantum computing start-up who receives problems or requirements from customers, at an early stage e.g. academic research labs, and translates them for the systems engineers and core developers to make sure the product can be used as needed.

Supervisor, research leader:
A **product innovation manager** who coordinates the product development, thus knows the technology and physics details, talks to the other characteristics of the **QT specialist** as well as the **QT core innovator(s)** P9 and **QT analyst/strategist** P5 P8 and understands their needs, supervises the **QT practitioner** P4 etc and the whole process to ensure that the product fits all requirements.

Needs and suggestions

Suggested previous qualification:

- Highly specialised in the 'classic/traditional' characteristic, e.g. systems or requirements engineering (see general description), and/or in classic alternatives for the QT, e.g. traditional software engineering for the QT SW specialist, as well as good communication skills.
- **QT engineering professional** P6

Suggested learning path:

- Additional research and work experience from QT projects with learning from colleagues/mentors and additional self-learning, maybe also dedicated lectures on advanced concepts, e.g. from mathematics/information theory 1.2 or a quantum physics subdomain 2.X,
- keeping up to date with technology developments, going to conferences, networking, maybe reading research papers and reports, some may participate in competitions and hackertrons.

Alternative: new, dedicated bachelor + master programs covering the QT and the 'classical' parts, e.g. QT systems engineering.

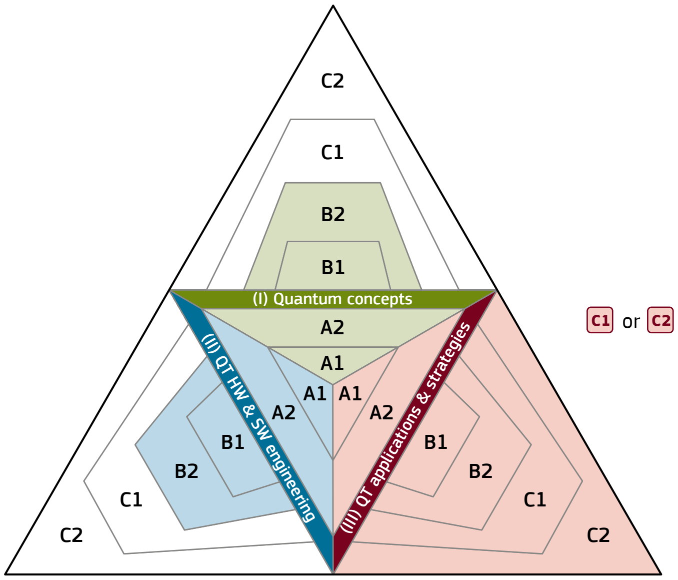
Suggested general conditions:

- Language: English
- Certificate: not applicable

QT proficiency for the **QT (product) strategist**

(e.g. advisor, business development expert)

P8



B2 Investigation: Analyse real-world problems with quantum methods
K: Advanced knowledge in a quantum (physics) subdomain, including a variety of methods and their validity.
S: Ability to describe and analyse real-world problems with math, select quantum methods to use to solve them; ensure quantum requirements are met.

B2 Investigation: Analyse performance, improve QT
K: Advanced knowledge in the context of a QT facet (core, component, system, application; HW/SW), including standards, requirements/performance criteria and aspects of technology realisation (turn into product).
S: Ability to analyse the adaptation or integration of a QT facet in order to improve it.

C1 Specialisation: Advise on QT application selection or strategies
K: Highly specialised knowledge in a field of application for a QT appl. incl. market situation etc., critical awareness of technologies and appl. for a variety of appl. fields, including critical and ethical perspectives, impact assessment.
S: Ability to advise/assist companies in developing QT strategies and realising QT projects (investment or education), analyse and select available (technology/ software) building blocks for integration.

C2 Innovation: Develop and assess QT (product) strategies
K: State-of-the-art knowledge in a field of application for a QT application incl. market situation etc. and how it relates to different approaches.
S: Ability to develop or evaluate/assess strategies/roadmaps for the development of quantum (enhanced) applications (HW/SW products) or curricula.

General description

The **QT strategist** is e.g. someone who advises companies on QT strategies or a product development roadmap leader in a company:

- has highly specialised or state-of-the-art knowledge in an application area for a QT application, can advise companies on their strategies (what to buy or where to invest), or even develop new product strategies and roadmaps,
- has the physics and engineering background to translate real-world use cases into quantum (physics) problems to be solved by QT,
- knows the standards and requirements to decide on an engineering strategy, or e.g. which quantum computing hardware (qubit realisation) is best suited for a particular problem type, with a deep understanding of the problems, but not necessarily the need to build the solution.

Example personas

Consultant, advisor, transformation leader, solutions architect, product designer, applications strategist:
An **IT consultant** (senior, many years of experience) responsible for all issues that may arise in relation to quantum computing and related cybersecurity issues, explaining options and expectations, translating real world problems into problems to be solved by QT, making assessments of a client's ideas and strategies or developing a strategy for the client, supporting and guiding the realisation of the strategy, e.g. by selecting the concrete technologies/ approaches to be implemented. Similarly for a QT **policy advisor** working with government. A **manager of an optimisation group** in a financial department who identifies a need (use case), designs a new software product to meet that need, selects quantum computing subroutines and hardware as well as classical components to integrate into the product, and leads a team to implement this product strategy.

Roadmap leader, CTO, head of QT R&D, subject matter expert:
A **CTO in a quantum sensing** company responsible for developing the company's strategy, e.g. in terms of the concrete systems or applications to be developed to meet market needs, and for drawing up a detailed roadmap for the company, including what is available and what partnerships to seek.

IP, patent lawyer:
A **patent lawyer** commissioned by a quantum communication company to formulate the patent for a new QKD device, emphasising the (technological) differences to other available approaches.

Needs and suggestions

Suggested previous qualification:

- Master/PhD in quantum physics or in the application area (e.g. chemistry or finance) and advanced (classical) communication and networking skills.
- Completed training (degree program) as a **QT engineering professional** P6.

Suggested learning path:

- Lectures or self-study in advanced quantum methods and some work experience, e.g. in quantum hardware development or quantum programming, may be similar to that of the **QT (HW or SW) specialist** P7.
- Intensive market research, keeping up to date, reading papers and reports, knowing what others are doing, networking.

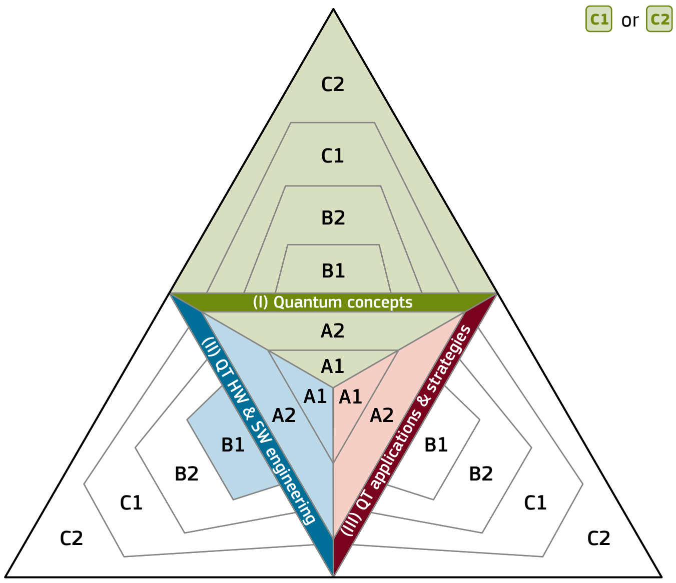
Suggested general conditions:

- Language: English
- Certificate: not applicable

Note: This profile was rarely discussed in the interviews, currently the QT analyst (P5) seems to be sufficient for most cases, or the development of strategies is done by senior QT engineers/QT architects or QT core developers. There may be only a few people in the beginning, e.g. in the big consulting companies, who transform real problems into QT use cases and also develop e.g. a software product roadmap that is implemented by other (classical and quantum) experts, engineers, etc.

QT proficiency for the **QT core innovator**

P9



C1 Specialisation: Refine and extend quantum methods to solve new problems
K: Highly specialised knowledge in one subdomain and critical awareness of connections between different subdomains.
S: Ability to refine or extend solutions for new problems (e.g., real-world use cases), using quantum physical and/or mathematical methods and incorporating methods from different subdomains to generate new methods.

C2 Innovation: Develop innovative solutions for critical problems
K: State-of-the-art knowledge in the subdomain and about connections with different approaches and (sub)domains.
S: Ability to find or develop innovative solutions for critical problems or real-world use cases; to evaluate and assess solutions (based on theoretical physics and mathematics), thus verify advantage; to extend and redefine knowledge or professional practice.

B1 Utilisation: Modify/apply a QT facet
K: Knowledge of a variety of parts for QT facets and their influence (e.g. what quantum effects may occur and have some influence) on other (classical or hybrid) parts/systems and QT facets; specialised knowledge on a selected QT facet (hardware and/or software).
S: Ability to adapt and test QT facets, interpret and compare results.

A2 Literacy: Identify value of QT
K: Knowledge of applications landscape (e.g. products on market) and use cases as well as expected technological development (impact, timelines) and ethical implications.
S: Ability to identify potential use cases (i.e. opportunities for value creation, where to seek expert assessment).

General description

The **QT core innovator** is, for example, a researcher like a quantum (physics) post-doc who has developed a new solution, e.g. a new ion trap approach to realise a qubit, or a new quantum algorithmic approach, who has:
- a very high level of expertise on the quantum concepts (physics, mathematics, …) for a specific subdomain and on the connections with different approaches and subdomain, also from 'classical' domains like computer science or chemistry,
- intermediate knowledge and experience around the related quantum engineering, in particular the influence that e.g. other (HW or SW) components may have, and
- an idea of potential use cases and impact of their work,

and (in industry) works closely with the **QT specialist(s)** P7 to ensure that the quantum core can be industrialised and integrated into the system/product, and with the **QT strategist** P8 (or at least **QT business analyst** P5) to ensure that the product meets market needs.

Example personas

Hardware research and development:
A **quantum physicist specialised on NV centers**, working in a quantum sensing start-up and in developing the 'heart' of the sensor, has research experience from an academic PhD or even post-doc period using NV centers for magnetic field measurement, now working with engineering experts (e.g. a systems engineer with experience in sensor development) to industrialise the academic lab set-up and turn it into an industrial product.

Quantum computing algorithm/software development:
A **quantum error correction researcher** in a quantum computing company, with state-of-the-art knowledge of the particular qubit type the company is using for its own computer, covering the physical and engineering challenges and working on software/algorithms to reduce the errors that affect the qubits due to their quantum properties.
An **algorithmic scientist** from the field of quantum information and/or mathematics who is researching new algorithmic approaches.

Needs and suggestions

Suggested previous qualification:
- Masters in quantum physics, quantum science and technologies or similar, or at least **QT engineering professional** P6.

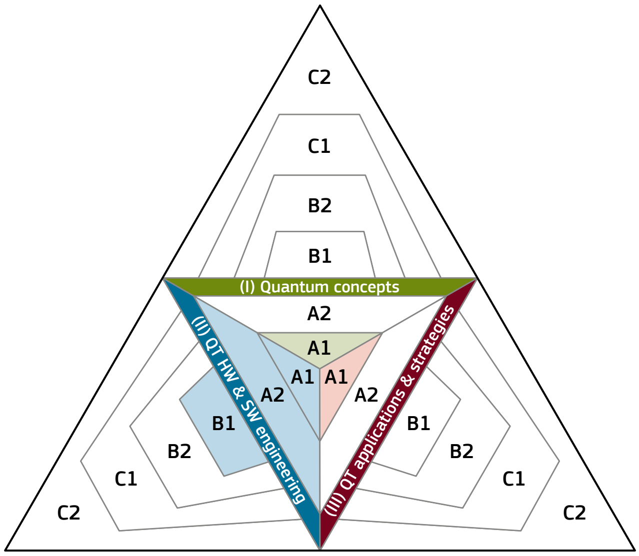
Suggested learning path:
- PhD, maybe post-doc experience, related to a quantum (physics) subdomain.
- Keep up to date with technology developments, stay in networks from PhD/post-doc period.

Alternative: Master in quantum science and long experience in research and development.
In industry, engineering aspects may become more important, some may become (additionally) a **QT (HQ or SW) specialist** P7.
Communicating with novices (or at least not quantum experts) about quantum concepts becomes more important in an (industrial) interdisciplinary team than in an academic research group, some may benefit from training in **public communication** and **education** 8.4.

Suggested general conditions:
- Language: English
- Certificate: rather scientific publications

Example:
Quantum control electronics practitioner for NV sensors

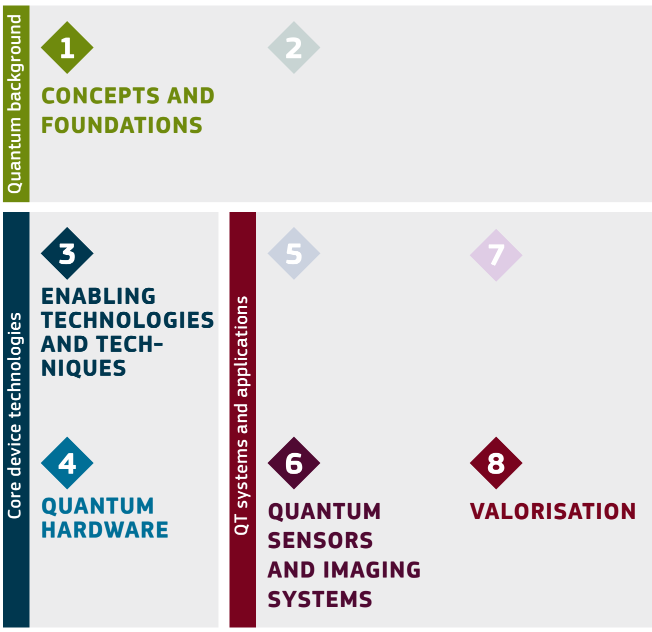
Profile P4 **QT practitioner** specification with content selection



A1 Awareness: Reproduce basic quantum concepts & terminology
K: Basic idea (phenomena-oriented) of elementary quantum concepts with the corresponding terminology.
S: Ability to identify basic quantum concepts and assign the appropriate term, e.g. to follow (media) conversations about quantum.

B1 Utilisation: Modify/apply a QT facet (core, component, system, application; HW/SW here: component: electronic control for an NV sensor)
K: Knowledge of a variety of parts for QT facets and their influence (e.g. what quantum effects may occur and have some influence) on other (classical or hybrid) parts/systems and QT facets; specialised knowledge on a selected QT facet (hardware and/or software).
S: Ability to adapt and test QT facets, interpret and compare results.

A1 Awareness: Recognise potential of QT
K: Basic idea of the potential of QT systems and applications, overview of possibilities, challenges and limitations.
S: Ability to follow public media and discussions with critical awareness of hype



Focus contents (for specialisation)

3.4 CONTROL TECHNOLOGIES

- Electronics, microwave and RF (radio frequency) technologies, frequency conversation, modulation and generation
- Opto-electronical and opto-mechanical systems

4.2 SPIN-BASED SYSTEMS

- Electron-spin qubits, nitrogen-vagancy (NV) centres in diamond

6.2 ELECTROMAGNETIC FIELD SENSORS

- NV centres, Rydberg atoms, superconducting sensors

Example description

A **quantum control electronics practitioner for NV sensors** is, for example, an engineer with expertise in 'classical' electronics etc and with additional qualifications in quantum hardware (NV centres), and the associated electronic control requirements, which electrical components may influence the quantum core, etc., working on a sensing device (full industrial product) with an integrated quantum core.

QT specific qualification

A1: Awareness ...

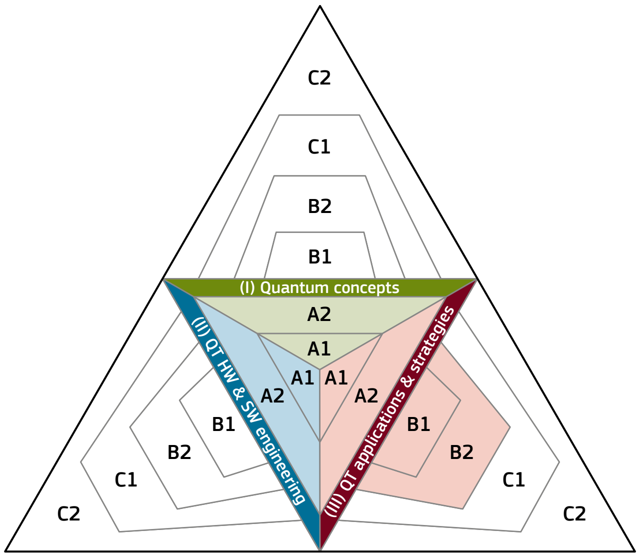
- of quantum concepts to be able to follow team discussions and instructions from the quantum experts;
- of how the product they are working on can be used, what the challenges are, see the relevance of their own work.

B1: Utilisation: Basic knowledge of a variety of components for the sensing device and how they influence the quantum core (here NV centres), specialising in the electronic control relevant to the specific device, being able to modify and test the electronics related to the quantum core.

Qualification by training, e.g. a few days in a university lab for the foundations, including the variety of components and influences, internal training or learning on the job for the specialisation on the concrete device.
Alternative: an elective lecture on the fundamentals within the electrical engineering degree program.

Example:
Quantum optimisation in logistics & production analyst

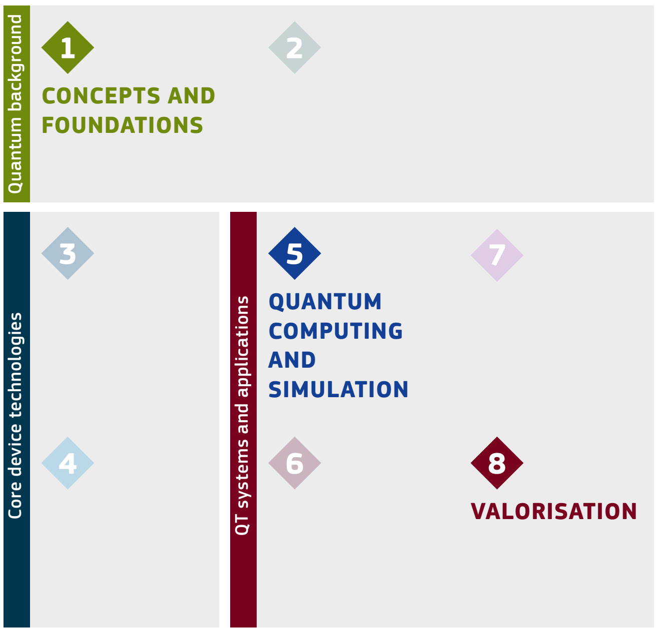
Profile P5 **QT business analyst** specification with content selection



A2 Literacy: Describe fundamental quantum concepts with appropriate terminology, e.g. in conversations
K: Knowledge of fundamental quantum concepts with underlying mathematical formalism and/or representations.
S: Ability to explain basic quantum concepts and describe them using basic mathematics and/or representations as well as appropriate terminology, e.g. to communicate with quantum experts and novices.

A2 Literacy: Perform basic tasks on a QT facet (core, component, system, application; HW/SW here: SW systems and applications: quantum optimisation algorithms with use cases)
K: Knowledge of fundamental working principles of different parts in the context of a QT facet and how they can be used (technically), focusing on the difference to classical counterparts.
S: Ability to perform practical tasks (operate) with the QT facet (work in a lab or with software).

B2 Investigation: Analyse QT market and opportunities
K: Advanced knowledge of a QT application and the related industry landscape and business models, including critical awareness on risks and potential consequences.
S: Ability to identify promising QT use cases with advances and risks; relate strategic QT reports to own business.



Example description

A **quantum optimisation in logistics & production analyst** is, for example, a mathematician or data scientist in a company's department responsible for improving logistics and production, looking at quantum computing and in particular quantum optimisation and machine learning approaches in logistics and production, such as traffic flow optimisation and routing, loading and sizing, or production planning (e.g. matrix production, job shop scheduling problems).

QT specific qualification

A2: Literacy ...
- in quantum concepts to be able to follow research papers and strategy reports, explain ideas to quantum experts and colleagues,
- in the fundamental working principles of quantum computing, what advantage they (might) bring to classical computing, and have tried some basic quantum programming on their own, e.g. on graphical platforms or with prebuilt subroutines.

B2: Investigation: Knowledge of the possibilities and limitations of quantum computing, specialising in quantum optimisation and optimisation through quantum machine learning in logistics and production, what approaches are available with pros and cons, including risks and consequences (impact, ethics), analysing e.g. strategic reports for potential use in the own company.

Qualification by self-study or upskilling, e.g. one week in a university labor continuous seminars over some months to become literate in quantum optimisation, with further reading and searching for new approaches, new research results, new use cases, staying up to date, also attending conferences and exchanging in networks.

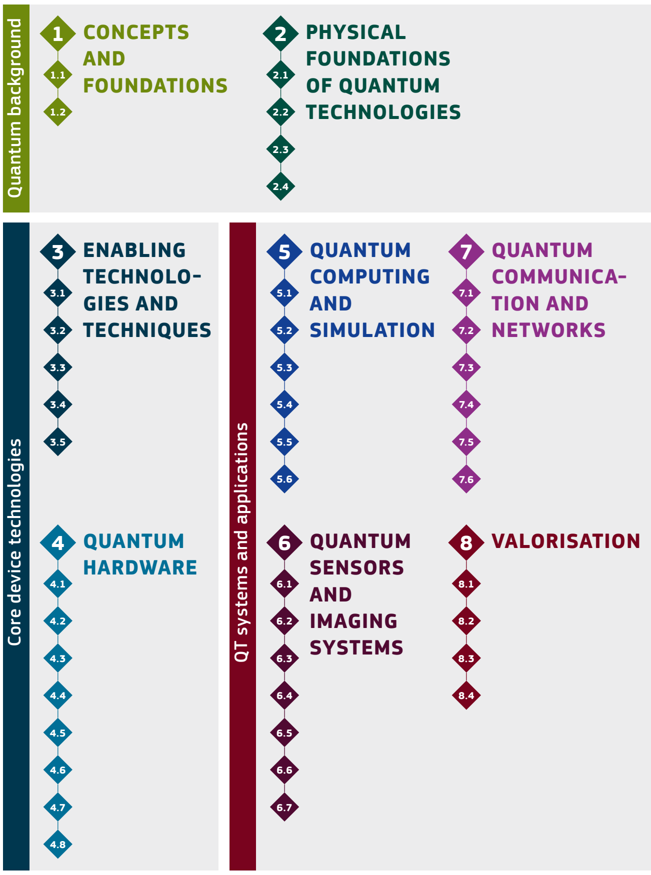
Focus contents (for specialisation)

5.6 APPLICATION OF QUANTUM COMPUTING AND SIMULATION

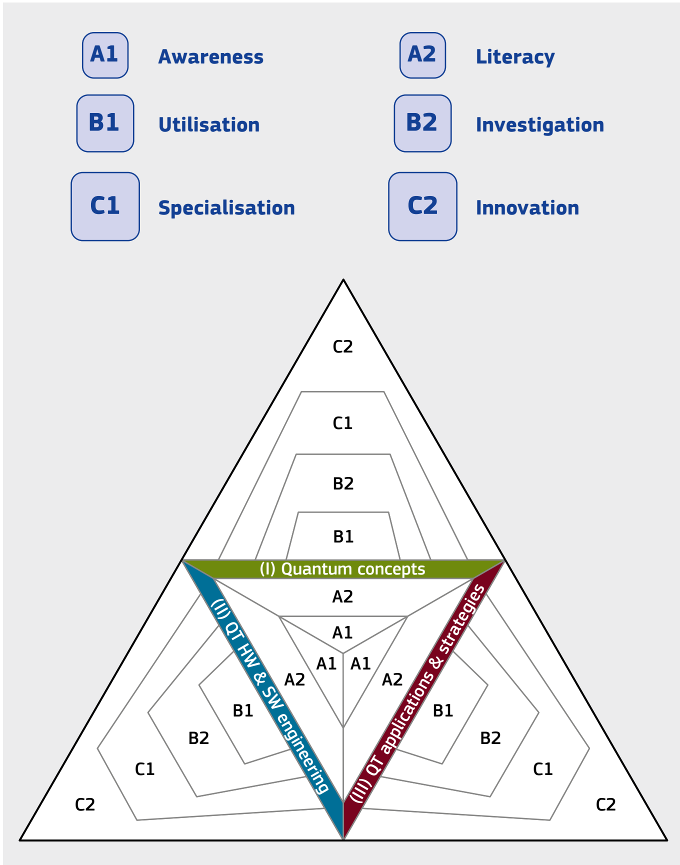
- Optimisation in finance, production, network and logistics
  - Routing
  - ...

8.2 BUSINESS STRATEGY, ENTREPRENEURSHIP AND MANAGEMENT (BUSINESS LEVEL)

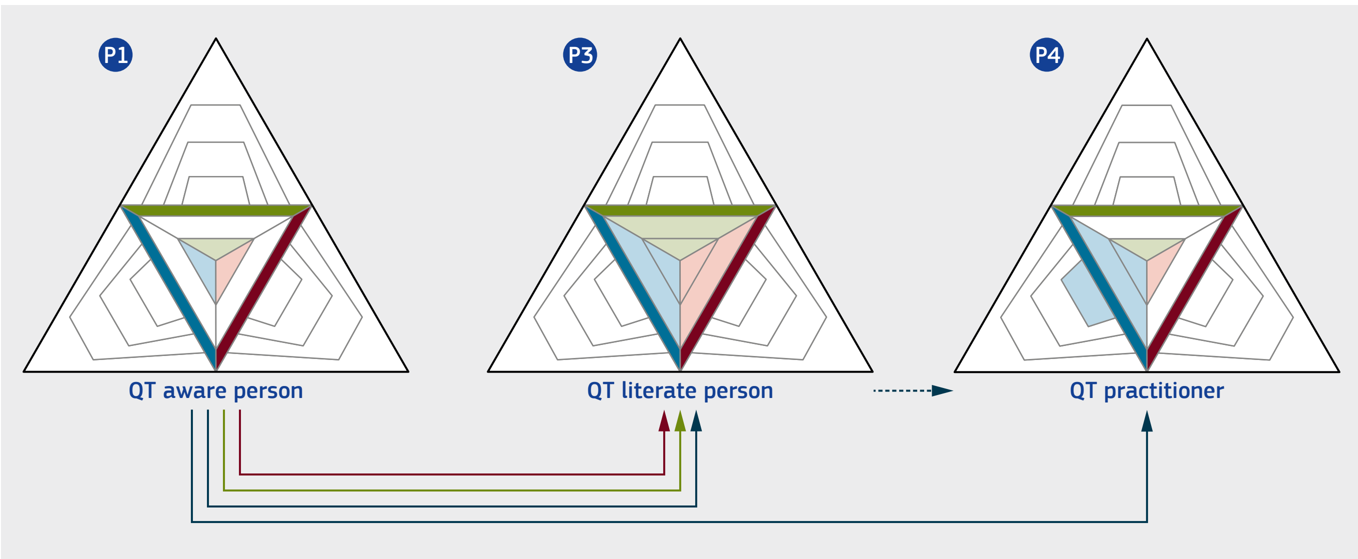
European Competence Framework for Quantum Technologies Summary



Content Map: 8 domains with 42 subdomains (p. 5), detail pages for each domain with topics and subtopics (p. 6–13).



Proficency Triangle visualising **6 proficiency levels** for the **3 proficiency areas** (p. 14), with in-depth level descriptions and more (p. 15–17).



9 Qualification Profiles overview (p. 18) and detailled descriptions incl. example personas and (training) suggestions (p. 19–27).

Extra: two **examples** how to combine a profile with a content selection (p. 28–29).

Version 3.0 (April 2025) compiled by Franziska Greinert and Rainer Müller
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