Quantum technology education: projects, research, and a reference framework for Europe and beyond

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A variety of coordinated efforts across Europe are advancing quantum education and workforce development. One such effort is the EU's Quantum Flagship initiative, under which the European Competence Framework for Quantum Technologies (CFQT) was developed to serve as a reference for defining and comparing quantum-related education and qualifications. Several projects in Europe and beyond have used the CFQT to support curriculum development, qualification profiling, and job market analysis. This talk will introduce key educational initiatives and outline the development of the CFQT through iterative research and stakeholder consultation, as well as provide examples of its application.

2025 PERC Proceedings edited by Pawl, Zwolak, and Leak; Plenary, doi.org/10.1119/perc.2025.plenary.Greinert

I. INTRODUCTION

The emerging field of secondary generation quantum technologies (QTs) spans areas such as quantum computing, quantum communication, and quantum sensing. To realize its potential, (not only) Europe requires a coherent education and training ecosystem. Traditional university curricula do not fully prepare learners for interdisciplinary careers in the quantum industry. There is a growing demand of professionals with diverse qualification profiles such as quantum technicians or quantum software developers.

This paper provides a brief overview on three aspects of quantum education in Europe: (1) workforce requirements and the European Competence Framework for Quantum Technologies (CFQT), (2) European initiatives, with a focus on the QTEdu CSA, DigiQ and QTIndu projects, and (3) QT as a context for teaching fundamental quantum physics using the "reasoning tools".

II. WORKFORCE NEEDS AND THE COMPETENCE FRAMEWORK

An iterative study with experts from academia and industry revealed the complexity of future quantum workforce needs [1]. Beyond scientific expertise, quantum professionals must combine interdisciplinary knowledge, practical experience, and business skills.

The study provided input to the *Competence Framework for Quantum Technologies (CFQT)* [2], the official reference framework published by the publications office of the European Union (EU). The CFQT supports different stakeholders, such as educators, learners, professionals, and recruiters. It can be used, for example, to specify learning objectives or required qualifications.

Iterative updates from 2021 to 2025 integrates community feedback, expert consultations, and especially results from 34 interviews with professionals from industry with a follow-up surveys [3]. The framework is used and adapted in Europe and beyond, e.g. in Latin America [4]. This underscores its potential as a global reference.

The CFQT comprises three main elements:

- the *Content Map* with eight domains and 42 subdomains structuring QT concepts and topics,
- the *Proficiency Triangle* with six proficiency levels in three proficiency areas, shown in Fig. 1 and
- nine *Qualification Profiles* that describe prototypical QT-related qualifications for industry roles.

The CFQT with all versions and related publications and materials, such as a certification scheme for QT proficiency providing sample tasks, is available via Zenodo [5].

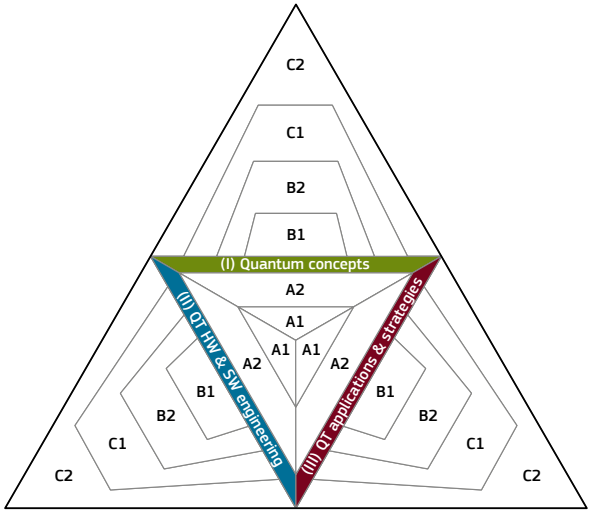

FIG. 1. The Proficiency Triangle of the CFQT: six proficiency levels across three proficiency areas (I) Quantum Concepts, (II) QT Hardware & Software Engineering, (III) QT Applications & Strategies), reproduced from [2].

III. EUROPEAN INITIATIVES

The development of the CFQT was initiated in the EU project *QTEdu CSA* [6] (2020–2022). Furthermore, the project did foster community building and pilot projects in quantum education. Eleven pilot projects explored various dimensions, such as the community-based development of a Quantum Concept Inventory (QCI) [7].

The activities on the EU level have been continued in the QUCATS project (2022-2025) with the *European Quantum Readiness Center* [8], aiming to establish best practices, provide open resources, and connect educators and industry stakeholders across Europe. They represent an ecosystem approach that goes beyond individual curricula and contributes to a shared European education strategy.

A. DigiQ: Digital and inclusive quantum education

The *DigiQ* [9] project (2023–2025) develops digital courses, internships, and networking opportunities for students and young researchers. Led by Jacob Sherson and Simon Goorney with more than 20 partner institutions, DigiQ addresses two major needs:

- lowering barriers for students entering the QT field,
- building a sustainable European network for quantum education.

Its outputs include online lectures accessible across Europe, structured internship programs that connect students with industry and academia, and digital platforms that support personalized learning. By focusing on accessibility and inclusiveness, DigiQ ensures that the quantum workforce is not only highly skilled but also diverse.

B. QTIndu: Training for industry professionals

The *QTIndu* [10] project (2023–2025) addresses a different audience: professionals who need to adapt to quantum technologies within industrial environments. With ten partner institutions, QTIndu develops courses for engineers, IT specialists, and managers who wish to acquire targeted QT expertise.

The program emphasizes:

- hands-on training with hardware and software platforms,
- modules tailored to industrial applications (e.g., quantum sensing, quantum communication),
- flexible learning formats, including blended and online learning.

The courses cover, for example:

- Quantum Computing – the Soft Way (University of Helsinki),
- Quantum Myths (Technical University Braunschweig)
- Introduction to Quantum Communication and Quantum Network Explorer (QNE) (Delft University of Technology)
- Introduction to the Quantum Ecosystem (QURECA)

Together, DigiQ and QTIndu illustrate how European projects address the full spectrum of workforce development—from students entering the field to professionals in mid-career.

IV. QUANTUM TECHNOLOGIES AS A CONTEXT FOR TEACHING QUANTUM PHYSICS

QT is not only relevant for professional training but also provides a meaningful context for quantum physics education. Using quantum technologies in the classroom helps students connect abstract concepts to real-world applications.

The *milq* approach [12] formulates four qualitative rules of quantum physics, known as *reasoning tools*: indeterminism, interference, definite measurement results, and complementarity. These rules offer learners a verbal framework that supports qualitative discussions of quantum phenomena, helps anticipate possible effects, and reduces common misconceptions.

The comprehensive high school teaching concept *milq* is available online [13]. Over the past 25 years, it has evolved into a widely adopted approach in German secondary education, with large parts also translated into English. Building on this foundation, we have adapted the reasoning tools for use in the context of QTs, where they provide a didactical bridge for engineers and other professionals without a prior quantum physics background [11]. The four basic rules in this adapted form are depicted in Fig. 2.

Hands-on learning scenarios, such as the *Quantum Penny Flip* game [14] or the implementation of interferometers on quantum computers, demonstrate how quantum advantages can already be experienced through simple examples. In the Quantum Penny Flip, a winning strategy arises from exploiting superposition, with the players' moves implemented as quantum gates so that the game itself becomes a quantum algorithm. Likewise, the Mach–Zehnder interferometer can be translated into a quantum circuit (see Fig. 3), where optical components are represented by gates. These scenarios link abstract principles to concrete algorithms, combining conceptual understanding with playful experimentation and making quantum physics tangible and accessible across different learning levels.

V. CONCLUSIONS

Europe is making significant progress toward a coordinated quantum education landscape. The CFQT provides a common language for competencies, while projects such as DigiQ and QTIndu implement concrete training opportunities for students and professionals. At the same time, QT contexts enrich the teaching of fundamental quantum concepts.

By connecting workforce research, frameworks, projects, and educational practice, Europe builds a sustainable foundation for preparing the next generation of QT professionals.

Rule 1:	*Indeterminism and statistical predictability* Single events are not predictable, they are random. Only statistical predictions (for many repetitions) are possible in quantum physics.
Rule 2:	*Interference of single quantum objects* Interference occurs if there are two or more "paths" leading to the same experimental result. Even if these alternatives are mutually exclusive in classical physics, none of them will be "realized" in a classical sense. Quantum states showing interference are called superposition states.
Rule 3:	*Definite measurement results* Even if quantum objects in a superposition state need not have a fixed value of the measured quantity, one always finds a definite result upon measurement.
Rule 4:	*Complementarity* Exemplary formulations are: "Which-path information and interference pattern are mutually exclusive" or "Quantum objects cannot be prepared for position and momentum simultaneously".

FIG. 2. Basic rules of quantum physics in Ref. [11, p. 39].

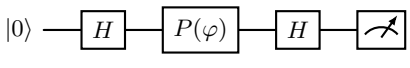

FIG. 3. Building a Mach-Zehnder-Interferometer as a quantum circuit with variational phase shift in one path of the interferometer.

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