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QUANTUM+

Uncovering technology for business

# D2.3 Stakeholders Focus Groups Conclusions

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# 1. Introduction

This report presents the key insights and conclusions derived from the focus groups organized by the Quantum+ partnership as part of the skills need analysis on quantum technologies. Specifically, the partners from each participating country (i.e. Finland, Spain, Italy and Greece) organized 8 focus groups with stakeholders from the industry and research. In total 42 stakeholders have been consulted regarding the quantum technologies skills needs, and the design of a higher education curriculum for quantum technologies and their business applications.

The following table presents the key information about the focus groups organized.

| Organizing partner | Profile of participants | Number of participants | Date |
|---|---|---|---|
| University of Vaasa | Researchers from Finland | 8 | 25.03.2025 |
| | Enterprises from Finland | 2 | 28.03.2025 |
| University of Patras | Researchers from Greece | 1 | 20.03.2025 |
| | Enterprises from Greece | 1 | 09.04.2025 |
| Università Cattolica del Sacro Cuore | Researchers from Italy | 6 | 28.03.2025 |
| | Enterprises from Italy | 10 | 28.03.2025 |
| GAIA | Enterprises from Spain | 9 | 28.03.2025 |
| Skills Divers | Researchers from Spain | 5 | 08.04.2025 |

*Table 1: Focus groups organized by the Quantum+ partners*

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# 2. Description and organization of the focus groups

The focus groups were conducted online between March and April 2025 to facilitate the participation of a broad range of stakeholders.

Aligned with the online survey conducted under Task 2.2, the target groups for the focus groups were:

- **Industry professionals** working in tech companies, startups active in the domain of quantum technologies, etc.
- **Academics and researchers** specializing in quantum physics, computer science, or related fields who are working with quantum technologies.

The focus groups aimed to:

- Identify the key skills and knowledge required in both research and industry for developing a relevant higher education curriculum.
- Explore the expectations and practical challenges faced by research and industry in quantum technology education.
- Strengthen collaboration between academia and industry to develop a practical, future-ready curriculum.

## 2.1 Discussion questions

The discussion questions explored during each focus group have been grouped into 3 sessions as follows:

**Session 1: Understanding the needs of research/industry in terms of required knowledge and skills on quantum technologies**

- What are the most critical knowledge areas that students/professionals should master in quantum technologies?
- Which specific skills related to quantum technologies are currently lacking among graduates entering the field?
- How do the knowledge and skill requirements differ between research and industry applications?
- What are the emerging trends in quantum technologies that should be incorporated into higher education curricula?

**Session 2: Bridging education on quantum technologies with real-life applications in diverse industries.**

- What are the biggest gaps between academic training and real-world industry needs?
- Can you provide examples of how quantum technologies are currently being applied in your research?
- What kind of hands-on or project-based learning experiences would be most beneficial for students?
- Are there specific tools, software, or platforms that should be included in a relevant curriculum on quantum technologies to improve industry readiness?

**Session 3: Recommendations for the development of a higher education curriculum.**

- What core courses should be included in a future-oriented curriculum on quantum technologies and their business applications?

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- How should quantum education balance theoretical concepts with practical applications?
- How can universities keep their quantum technology curriculum updated with fast-evolving industry needs?
- What are the key challenges in implementing a quantum-focused curriculum, and how can they be addressed?

## 2.2 Indicative agenda

Each focus group had a duration of 90 minutes. Below, we present the indicative agenda of each focus group.

- **Introduction (10-15 min):** Overview of the QUANTUM+ project and focus group objectives.
- **Discussion (60 min):**
  - **Session 1:** Understanding the needs of researchers/businesses in terms of required knowledge and skills on quantum technologies (20 min).
  - **Session 2:** Bridging education on quantum technologies with real-life applications in diverse industries (20 min).
  - **Session 3:** Recommendations for the development of a higher education curriculum (20 min).
- **Conclusion (10-15 min):** Wrap-up and key takeaways.

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# 3. Insights obtained from the focus group with stakeholders from Spain

Below we present the key insights derived from the focus groups with stakeholders from Spain.

## 3.1 Focus group with industry

| SESSION 1: UNDERSTANDING THE NEEDS OF BUSINESSES IN TERMS OF REQUIRED KNOWLEDGE AND SKILLS ON QUANTUM TECHNOLOGIES |
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| **RQ1. What are the most critical knowledge areas that professionals should master in quantum technologies?** |
| Professionals in quantum technologies should master quantum physics, alongside quantum computing and algorithm design, including hybrid classical-quantum models. Knowledge of specialized areas such as NV centers, Rydberg atoms, optoacoustics, and quantum sensing is essential. Skills in post-quantum cryptography, cloud-based quantum computing, and quantum machine learning are increasingly relevant. A solid background in statistics, advanced programming, software development, and operational research supports algorithm implementation and system modeling. Familiarity with telecommunications, materials science, and fundamental physics enables effective hardware and infrastructure development. Finally, the ability to work in multidisciplinary teams is crucial to be able to work in this evolving field. |
| **RQ2. Which specific skills related to quantum technologies are currently lacking among professionals working in the field?** |
| Among professionals working in the field of quantum technologies, there is a notable lack of up-to-date knowledge on the state of the art. Specific gaps include limited expertise in quantum cryptography and security, as well as insufficient integration of hardware and software know-how. There is also a lack of skills in quantum algorithm development and the use of specialized frameworks such as Qiskit, Cirq, Pennylane, and D-Wave. Professionals often struggle with process optimization and with evaluating the feasibility and cost of quantum solutions. Additionally, there is a shortage of solid-state physics knowledge and its application to electronic device development, along with limited understanding of quality management and testing in quantum contexts. Concerns about cybersecurity are rising, but there's still no understanding of cryptographic methods. |
| **RQ3. How do the knowledge and skill requirements differ between research and industry applications?** |
| The knowledge and skill requirements in research focus on advanced simulation, theoretical development, and early-stage experimentation, with growing attention to aligning investigations with real-world applications and industry needs. Researchers must consider working with a market-oriented perspective. In contrast, industry applications prioritize access to stable and affordable products, integration with classical software and production workflows, and the ability to implement and validate quantum solutions efficiently. While the distinction between academia and industry is still emerging, the main difference lies in research |

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| focusing on exploration and potential, while industry demands readiness, scalability, and clear value propositions. |
| **RQ4. What are the emerging trends in quantum technologies that should be incorporated into higher education curricula?** |
| Emerging trends in quantum technologies that should be incorporated into higher education curricula include the introduction of quantum concepts at earlier educational stages, such as in high school, and the integration of foundational quantum technology knowledge across various university programs. Curricula should address new quantum architectures, classical-quantum hybrid computing, and hardware-aware programming that optimizes performance based on the backend system. It is essential to include topics like quantum machine learning, cybersecurity, and post-quantum algorithms within both science and engineering tracks. Given the rapid evolution of the field, education should prioritize solid, transversal foundations that can adapt as technology matures. |

| **SESSION 2: BRIDGING EDUCATION ON QUANTUM TECHNOLOGIES WITH REAL-LIFE APPLICATIONS IN DIVERSE INDUSTRIES.** |
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| **RQ1. What are the biggest gaps between academic training and real-world industry needs?** |
| The biggest gap between academic training and real-world industry needs in quantum technologies is the theoretical focus of university programs, which often lack practical training. This focus forces companies to rely on multidisciplinary teams to bridge the gap, which is not always efficient. Academic curricula rarely translate concepts into real-world implementations, leaving graduates unfamiliar with industry tools like Qiskit, Cirq, or Braket, and unprepared to tackle problems with real-world constraints. Physicists often lack programming skills and knowledge of software development life cycles, while computer scientists are unfamiliar with braket algebra and quantum theory. There is also a noticeable lack of connection between academia and industrial needs in areas like quantum sensing. Moreover, soft skills such as teamwork, communication across disciplines, and exposure to real business challenges are not developed, highlighting the need for more internships, collaborative projects, and practical experiences within academic programs. |
| **RQ2. Can you provide examples of how quantum technologies are currently being applied in your business?** |
| In one of the participant's company, quantum technologies are currently being applied through the design of specific devices tailored to client needs, offering technical solutions based on emerging capabilities. While the market is still developing and real-world cases are limited, another participant mentions that they are exploring applications in logistics optimization, such as route planning and the efficient management of containers and warehouses. In the field of communications, quantum tools are also being evaluated as potential resources for advanced cybersecurity testing, including simulated hacking scenarios to assess vulnerabilities. |
| **RQ3. What kind of hands-on or project-based learning experience would be most beneficial for your business?** |
| In general terms and based on what the companies tell us; it is indicated that in relation to sensors there are no points of union between the needs of industry and therefore they should be created. Also, there are few applicable real cases, this shows the need to have adequate |

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| laboratories to facilitate learning experiences in the appropriate academic areas where real industrial cases already solved can be implemented as learning models with the participation of people from this industry to awaken vocations.<br>In line with the latter, there is a lack of multidisciplinary professionals with industrial knowledge and quantum knowledge in the companies, since these types of profiles can respond to the type of learning experience and work on projects that are really beneficial for the companies.<br>To conclude, it is also commented that the theoretical framework is fundamental in the sensory areas to work in simulation, there are very few professionals and all of them are extremely busy. It is believed that university training in quantum is taught in a theoretical fundamental way and there is a lack of engineering and/or software knowledge. Multidisciplinary teams are required today to make up for this lack and it is not effective, as has been discussed. Last but not least, the disconnection with real business problems was mentioned together with the lack of professionals with soft skills. |
| **RQ4. Are there specific tools, software, or platforms that should be included in a relevant curriculum on quantum technologies to improve industry readiness?** |
| In relation to this issue, the companies commented that it would be of interest to focus on certain tools or platforms to be included in the curriculum on quantum technologies since they would serve to improve the processes and production of industrial companies.<br>Some of the tools -platforms that were mentioned were D-Wave, Quiskit, Q#, QASM, IBM Lab, Quirk, QuantumUnit, Shaded Tangles, Ocean SDK (D-Wave), Fujitsu Digital Annealer SDK, Pennylane (framework), Gurobi, CPLEX, OR-Tools, HexaLI.<br>Other ways to incorporate quantum technologies in companies that are working very well are the industrial doctorates because through them there are collaborations between Centers/Universities and companies. Once the doctorate is completed, the individual is transferred to the company at the end of the doctoral studies. This is also applicable to Master's projects. Finally, it is also commented that challenges such as hackathons with industrial datasets are also very useful to promote collaborations between Centers/Universities and companies. |

| **SESSION 3: RECOMMENDATIONS FOR THE DEVELOPMENT OF A HIGHER EDUCATION CURRICULUM** |
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| **RQ1. What core courses should be included in a future-oriented quantum technologies and their business applications curriculum?** |

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| In response to this question the companies indicate that it would be good to have a common core to develop a curriculum oriented to quantum technologies, among the disciplines to be addressed would be:<br>• Common core:<br>    o Fundamentals of quantum mechanics<br>    o Quantum algorithms (Grover, Shor, hybrid algorithms)<br>    o Introduction to quantum information theory<br>    o Quantum physics<br>    o Quantum machine programming<br>    o Optimization<br>    o Statistics<br>    o Advanced programming<br>    o Numerical analysis,<br>    o Specific hardware (providing access to tools from real vendors and access to appropriate laboratories)<br>    o Applied approach:<br>        ▪ Quantum programming with current frameworks.<br>        ▪ Workshops on use cases by industrial sector.<br>        ▪ Practical interdisciplinary projects.<br>    o Integration of hybrid classical/quantum software systems.<br>    o Design and modeling of quantum algorithms.<br>    o Software Quality Management<br>    o Life Cycles/ Multi-disciplinary development methodologies.<br>• Soft skills:<br>    o Technical/non-technical communication skills.<br>    o Collaboration between physics, computer science and engineering profiles.<br>Finally, it is also indicated that education should be seen as a means of expanding the technology, participating in internships and projects with companies that already have the technology and then participating in internships with companies that have the capacity to apply it. |
| **RQ2. How should quantum education balance theoretical concepts with practical applications?** |
| To date, the programs in the degree programs are more theoretical than practical. To reverse this and try to balance or even bet more on the practical part, a model such as this is proposed:<br>Adjusted 70-30 model:<br>• 70% practical-applied: solving real cases, use of frameworks, multidisciplinary projects.<br>• 30% theoretical: solid foundations in quantum mechanics, linear algebra, information theory.<br>This being so, it is commented that engineering careers would be the example to follow, and this type of learning models could be applied to other careers such as: chemistry, pharmacy, and medicine. |

| **RQ3. What types of industry partnerships (e.g., internships, joint research projects) would enhance professionals learning?** |
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| The first thing that stands out is to carry out internships in companies; also, it is stated that holding Forums of encounter between University/Center Company in the field of quantum would help to balance the theoretical concepts with the practical applications demanded by the companies, and, finally, industrial doctorates are once again valued. |
| **RQ4. How can universities keep their quantum technology curriculum updated with fast evolving industry needs?** |
| Some of the experts participating in the Focus Group indicated that a relevant point would be to create Advisory Councils with the industry to:<br>• Include representatives from companies, startups and technology centers.<br>• Make periodic meetings to review trends and emerging needs.<br>• Impact: adjust contents, competencies and projects according to real demand.<br>Also, there is a perceived need for universities to get closer to companies in order to awaken vocations and to understand the needs of companies. In order to implement this type of action, it is highlighted as a problem that there are few professionals with knowledge in quantum technologies, which implies always having the same ones and because of the time they have and have little time to share, besides, this implies a high cost.<br>Other lines of action could be:<br>• Review annual curricula (annual review of the curriculum with business feedback) and participation in company/university projects to keep up to date.<br>• Encourage mixed teaching staff (academic + professional).<br>• Establish regular feedback mechanisms with industrial partners/spinoffs.<br>• Open university departments to projects with companies.<br>• Establish ongoing relationships with technology centers and companies.<br>• Master degrees with the participation of companies and technology centers. |

| **FINAL REMARKS ON THE FOCUS GROUP'S FEEDBACK** |
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| **Inclusive Access to Master Programs in Quantum Technologies**<br>Master programs in quantum technologies should not be limited to students from specific academic backgrounds such as physics or engineering. Instead, they should be designed to welcome anyone with an interest in the field, even those without prior knowledge. To achieve this, the curriculum should include introductory courses that provide foundational knowledge and ensure that all students, regardless of their previous studies, can build a solid understanding of quantum principles. These preparatory modules would help balance the knowledge level across the group, making the program accessible and effective for a broader range of learners.<br>**Developing Experts to Teach, Research, and Apply Quantum Technologies**<br>It is essential to train professionals who specialize in quantum technologies with a dual focus: on one hand, they should be prepared to contribute to academic research and teaching; on the other, they should be equipped to apply their expertise in industrial contexts. These specialists will act as a bridge between the academic and business worlds. |

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| **Promoting Industrial PhDs for Knowledge Transfer**<br>Encouraging more industrial PhD programs is key to ensuring that the knowledge and innovations developed in academic settings are effectively transferred to industry. In these programs, doctoral students work in close collaboration with companies throughout their research, focusing on real-world challenges. Upon completing their PhD, these professionals can transition into industry roles, bringing with them the advanced expertise and innovation capacity needed to drive quantum technology adoption and development in business environments. This model promotes a full-cycle transfer of knowledge from research to application.<br>**University-industry working method**<br>The need to generate internships in companies, promote teamwork and address real problems of companies is emphasized. It is also important to collaborate in process and product technical teams, as well as to maintain a continuous relationship with technology centers and companies.<br>By way of summary, it is commented that in academic training there is not so much work on concepts aimed at real implementations or applications such as hacking tools based on existing real experiences, in addition, there are few applicable real cases. A solution to this could be to create suitable laboratories in academic areas where real industrial cases already solved can be implemented to awaken vocations. |

## 3.2 Focus group with research

| **SESSION 1: UNDERSTANDING THE NEEDS OF RESEARCHERS IN TERMS OF REQUIRED KNOWLEDGE AND SKILLS ON QUANTUM TECHNOLOGIES** |
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| **RQ1. What are the most critical knowledge areas that students should master in quantum technologies?** |
| Quantum technologies fields are very diverse and depend on the subcategory where it falls. In general, strong STEM profiles are required by the enterprises and then they are skilled by the experience in specific enterprises/sectors. Some of the most required topics are quantum mechanics, programming, electronics and signal digital process, optics and ICT in general. Commonly, physicians have programming and ICT skills gap. So, 3 legs are important: programming, quantum mechanics and ICT. |
| **RQ2. Which specific skills related to quantum technologies are currently lacking among graduates entering the field?** |
| Scientists are lacking programming skills while programmers / engineers are lacking skills in quantum physics and mathematics. Students nowadays don't have the experience to work with AI. For Hardware, the graduates lack software skills. |

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| **RQ3. How do the knowledge and skill requirements differ between research and industry applications?** |
| The basic skills can vary depending on whether the workers are going to work in R&D or on the productive side (despite of the fact that production is new in this field).<br>On the side of quantum technologies (sensing, communication, imaging), 90% electronic engineering and optics is required. Engineers can provide very good solutions to problems. Wave theory is important to understand quantum as well. Basic knowledge of size scales.<br>In industry, a problem-solving approach is required. In scientific and research, strong skills in the fundamentals of quantum are required. The skills of scientists are not orientated to production. Specifics skills in sensing and communication are needed, but it is necessary to define if the goal is R&D (as long-term vision industry) or more short-term industrial applications. At general level, programming skills, electronics and photonics and waves (physics).<br>In addition, depending on the specific industry and research field, different skills are additionally required: physics or chemistry/materials or photonics (for certain sensors). In Spain, the part of Quantum sensors is limited to less than 20 enterprises. |
| **RQ4. What are the emerging trends in quantum technologies that should be incorporated into higher education curricula?** |
| It was mentioned many times, the importance of knowing how AI can support the different fields of quantum as supporting tool. E.g. Co-Pilot for Quantum Computing. It was also mentioned the promotion of blended master's degrees, for example, on topics in Machine Learning with quantum technologies. |

| **SESSION 2: BRIDGING EDUCATION ON QUANTUM TECHNOLOGIES WITH REAL-LIFE APPLICATIONS IN DIVERSE INDUSTRIES** |
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| **RQ1. What are the biggest gaps between academic training and real-world industry needs?** |
| There is a gap between university and research from real life applications. From research to production. There is also a gap in capacities for prototyping and gathering requirements of customers and creating and applying solutions to problems. Apart from sensors (which is a small niche), the industry is still in the research stage and the gap is big, but it is different from one type of enterprise to the other. Profiles with strong base in STEM are needed.<br>Some of the participants appointed that it is easier to move from a strong base in physics and mathematics to programming. On the other hand, others say that in many fields, the required skills in science are very specific and not necessarily broad. Students need guidance to understand that working in quantum isn't just about doing calculations alone. It's about solving real problems and collaborating within an industry context. They need to see how quantum technologies are applied in the real world. Industry operates at high TRLs, while academia usually focuses on much earlier stages. |
| **RQ2. Can you provide examples of how quantum technologies are currently being applied in your research?** |
| For instance, in methods for protection of code, or also topics of quantum networks and |

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| Quantum Algorithms for Machine Learning. |
| **RQ3. What kind of hands-on or project-based learning experiences would be most beneficial for students?** |
| The ones related to quantum computing. FPGAs can also help to solve complex and emerging problems. |
| **RQ4. Are there specific tools, software, or platforms that should be included in a relevant curriculum on quantum technologies to improve industry readiness?** |
| • AI tools for supporting coding and programming and testing.<br>• Software tools (design, testing, documentation) such as: Qiskit (IBM), or PennyLane (Python - AI).<br>• Code protection methods pill would be good.<br>• For hardware: the tools for object-oriented programming for test in laboratories. Interfaces to interact with hardware. |

| **SESSION 3: RECOMMENDATIONS FOR THE DEVELOPMENT OF A HIGHER EDUCATION CURRICULUM** |
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| **RQ1. What core courses should be included in a future-oriented quantum technologies and their business applications curriculum?** |
| University of Mondragón includes in physics engineering: mathematics, AI, and quantum physics, optics, programming, among others. For quantum sensors, specific pills of chemistry or physics. |
| **RQ2. How should quantum education balance theoretical concepts with practical applications?** |
| There is a need to be more oriented on hands-on learning in quantum technologies education. Right now, many students finish their studies knowing theory, but they can't solve real-world problems or understand how companies work. The world isn't purely quantum—it's hybrid. And students should be prepared to navigate both. |
| **RQ3. How can universities keep their quantum technology curriculum updated with fast-evolving industry needs?** |
| There should be a general course on quantum technologies to give students a broader, big-picture understanding. If they have a strong grasp of the fundamentals, they'll be able to adapt as the field evolves. But from a tech perspective, it's crucial to always stay updated—this space is moving fast. |
| **RQ4. What are the key challenges in implementing a quantum-focused curriculum, and how can they be addressed?** |
| The degrees now are very applied in Spain and lack a strong base in physics which is needed for this field. Quantum tech is a very diverse world, and it would be a challenge and opportunity to create a course about it with a general overview of all the fields allowing the student to decide where to move and progress. |

| FINAL REMARKS ON THE FOCUS GROUP'S FEEDBACK |
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| There are some initiatives such as Quantum Competence Framework that will allow the project to validate its results. Other initiatives are doing similar to Quantum+: https://www.qureca.com/es/<br>It is very difficult to find the perfect job profile as it is a hybrid profile (scientific and engineer). For a realistic and applied course, it is important to focus not only on quantum computing as this world will be hybrid combining traditional computers with quantum computers.<br>The usefulness of a course on quantum technologies that addresses all the sub-themes was also discussed, enabling the student to study in depth the ones that interest him/her most in future training courses. |

# 4. Insights obtained from the focus group with stakeholders from Italy

We would like to mention that for the case of Italy the discussion during the focus groups followed a freer style.

## 4.1 Focus group with industry

The main feedback collected from the stakeholders coming from industry is the following.

| **From your perspective, what topics should be addressed, and what skills should be developed within Quantum+?** |
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| • Developing a foundational knowledge of major quantum programming languages (e.g., Qiskit by IBM, now the industry standard).<br>• Introducing basic quantum mechanics concepts, particularly discrete states, qubits, and entanglement.<br>• Providing an overview of the quantum technology ecosystem, including business models and funding opportunities.<br>• Exploring different hardware platforms (solid-state, trapped ions, photonics) and their respective pros and cons.<br>• Emphasizing quantum readiness: Even if clear quantum advantage does not yet exist, businesses must prepare for its eventual realization.<br>• Starting from real business needs (case studies) and demonstrating how quantum computing can address them.<br>• Positioning quantum technologies within the broader Deep Tech landscape, addressing both technical-scientific risks and market risks.<br>• Providing a broad overview of quantum fields (computing, cryptography, sensing) and their opportunities.<br>• Offering a scientific communication course focused on quantum technologies to bridge the gap between R&D and business needs.<br>• Teaching foundational skills in at least one quantum software platform (preferably Qiskit).<br>• Addressing the disconnect between industry needs and quantum research outputs by involving end-users in training programs.<br>• Including training on open-source analysis tools.<br>• Exploring ethical implications of quantum technologies.<br>• Providing guidance on Intellectual Property (IP) protection, given the overlap between business and cutting-edge research.<br>• Discussing interdisciplinary approaches and scalability of quantum solutions.<br>• Offering basic training on major quantum software platforms.<br>• Reviewing solid-state physics and electronics fundamentals to understand quantum hardware potential. |

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| • Presenting case studies on quantum-powered pricing models and risk evaluation, comparing advantages over classical methods (e.g., Monte Carlo simulations).<br>• Ensuring participants have basic algebra, probability, and optimization knowledge.<br>• Clarifying the break-even point where quantum technologies become economically viable.<br>• The need for skilled personnel with both specialized and transversal competencies to navigate the quantum ecosystem.<br>• Encouraging flexibility in professionals to tackle real-world problems.<br>• Prioritizing practical case studies and industry collaborations.<br>• Error management (classical and quantum), including error mitigation and quantum error correction.<br>• Developing vertical technical expertise while understanding use cases across industries.<br>• Equipping business professionals with a general understanding of quantum potential rather than deep technical skills.<br>• Teaching linear algebra and classical/quantum optimization basics. |
| **What are potential collaboration opportunities with the Quantum+ project?** |
| • Willing to co-develop micro-courses on real-world problems (e.g., option pricing, logistics, energy).<br>• Open to hosting internships and supporting thesis projects.<br>• Available for collaborative projects, including internships and long-term initiatives.<br>• Willing to develop hands-on modules and virtual labs involving classical and quantum programming. |
| **Conclusions** |
| The focus group highlighted growing industrial interest in quantum computing but underscored the need for foundational knowledge to address current technological and operational challenges. |

## 4.2 Focus group with research

The main feedback collected from the stakeholders coming from research is the following.

| **Feedback collected** |
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| • It is essential to implement coordinated national actions on quantum technologies during this transitional phase.<br>• Spoke 9 of NQSTI is dedicated to dissemination and training aimed at businesses, high schools, etc.<br>• The training process requires highly complex actions: they must adopt an interdisciplinary approach, significantly different from the academic one, and involve collaboration with companies of varying scales and interests. |

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| • Target profiles for the project should be identified, such as:<br>i) Workers and managers in high-tech companies who need to understand the potential of quantum technologies.<br>ii) Higher education to enable quantum-related activities within companies.<br>• Corporate training is crucial to building an Italian quantum ecosystem.<br>• In many cases, companies themselves can act as facilitators to engage other businesses.<br>• There is often an absolute dichotomy between basic research and industrial innovation.<br>• There is a need to develop training programs on quantum technologies for professionals who may not work directly in the field but must understand its potential and make strategic decisions.<br>• Part of the training should focus on defining the limits of applicability of quantum technologies, clarifying realistic expectations and distinguishing them from problems solvable with traditional methods.<br>• Interaction with companies through networking events between academia and industry is key. Collaborative university-industry funding schemes also play a significant role.<br>• It is necessary to spread knowledge of quantum technologies in non-technical communities (e.g., economics, finance, business) to highlight their potential without creating unrealistic expectations.<br>• The focus should not be on technical details but on understanding and leveraging the opportunities.<br>• The joint PhD program in Quantum Technologies between the University of Naples Federico II and the University of Florence has been instrumental in preparing students with a broad vision of the field.<br>• Training Quantum Engineers is critical so that industries can hire qualified personnel capable of leading the transition to these technologies. |
| **Conclusions** |
| The focus group demonstrated strong interest from the National Quantum Science and Technology Institute in QUANTUM+, with a willingness to collaborate on both material preparation and course dissemination once finalized. |

# 5. Insights obtained from the focus group with stakeholders from Finland

## 5.1 Focus group with industry

| **SESSION 1: UNDERSTANDING THE NEEDS OF BUSINESSES IN TERMS OF REQUIRED KNOWLEDGE AND SKILLS ON QUANTUM TECHNOLOGIES** |
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| **RQ1. What are the most critical knowledge areas that professionals should master in quantum technologies?** |
| The most critical knowledge areas that professionals should master in quantum technologies are:<br>• Basic understanding of quantum computing and programing principles<br>• Comparison with existing computing capabilities<br>• Integration of quantum and classical systems<br>• Algorithms and use cases programing principles. |
| **RQ2. Which specific skills related to quantum technologies are currently lacking among professionals working in the field?** |
| The specific skill that needs to perform but currently lacking among professionals working in the field are the following:<br>• Specific math objects,<br>• Specific programing languages,<br>• Performance evaluation tools. |
| **RQ3. How do the knowledge and skill requirements differ between research and industry applications?** |
| The main and only few points that were highlighted are the following:<br>• Research focuses on physics while industry focuses on the user expertise that means how to maximize performance for a given application.<br>• Researchers emphasize the general workflow where Industry integrates application with general workflow. |
| **RQ4. What are the emerging trends in quantum technologies that should be incorporated into higher education curricula?** |
| The respondents have no clear idea about higher education curricula, but there were mentioned a few points such as error mitigation and error correction, parallelism, circuit knitting, and integration. |

| **SESSION 2: BRIDGING EDUCATION ON QUANTUM TECHNOLOGIES WITH REAL-LIFE APPLICATIONS IN DIVERSE INDUSTRIES.** |
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| **RQ1. What are the biggest gaps between academic training and real-world industry needs?** |

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| The widest gap between what is taught and what is truly needed by industry changes with each business application involved. The industry needs to understand quantum and classical computing, as well as learn how to select the right use cases and implement the algorithms. |
| **RQ2. Can you provide examples of how quantum technologies are currently being applied in your business?** |
| • Marine and energy sector<br>• IBM works with the whole quantum stack from basic physics to business use cases. |
| **RQ3. What kind of hands-on or project-based learning experience would be most beneficial for your business?** |
| A practical demonstration regarding the future of industry and what quantum technology is going to contribute to it. Industry-Specific Use Cases: Companies will most benefit from software development exercises that align with their industry use cases. |
| **RQ4. Are there specific tools, software, or platforms that should be included in a relevant curriculum on quantum technologies to improve industry readiness?** |
| Our respondents are not so much aware of any specified tools, software or platforms that should be included in a relevant curriculum on quantum technologies to improve industry readiness except Qiskit. |

| **SESSION 3: RECOMMENDATIONS FOR THE DEVELOPMENT OF A HIGHER EDUCATION CURRICULUM** |
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| **RQ1. What core courses should be included in a future-oriented quantum technologies and their business applications curriculum?** |
| The following courses should be included as per respondents' suggestion:<br>• Basic quantum computing and technology<br>• Math and programing<br>• Any course for a quantum computing application. |
| **RQ2. How should quantum education balance theoretical concepts with practical applications?** |
| • A balanced approach, such as 50-50 is sound.<br>• Start with the theoretical foundations but immediately connect them to real-world use case examples to reinforce practical understanding. |
| **RQ3. What types of industry partnerships (e.g., internships, joint research projects) would enhance professionals learning?** |
| • Internships would be great if can be arranged<br>• Visitor lectures<br>• Student projects: getting an application challenge from industry and building a proof-of-concept. If successful, industry gets an answer to a problem and students get an opportunity to maybe start-up a company. |
| **RQ4. How can universities keep their quantum technology curriculum updated with fast evolving industry needs?** |

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| It depends on the industry. Below are some ideas:<br>• Industry-specific pace (the IT industry may evolve rapidly, while traditional industries may have a slower pace)<br>• Addressing challenges for slower industries (slower industries to secure a market for new quantum applications)<br>• External Resources (IBM provides courses and tutorials)<br>• Ongoing development. |

| FINAL REMARKS ON THE FOCUS GROUP'S FEEDBACK |
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| • Specialists in the field emphasized the need to study both quantum and classical computing, with a focus on selecting appropriate use cases and implementing algorithms.<br>• Practical demonstrations and hands-on learning were highlighted by participants.<br>• The need for focused training in niche areas.<br>• The need for industry-academia collaboration for real-world industry.<br>• Utilizing outside resources, such as IBM's quantum tutorials, was also highlighted as beneficial to stay current.<br>• Respondents recommended that higher education curricula should focus on emerging trends. |

## 5.2 Focus group with research

| SESSION 1: UNDERSTANDING THE NEEDS OF RESEARCHERS IN TERMS OF REQUIRED KNOWLEDGE AND SKILLS ON QUANTUM TECHNOLOGIES |
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| **RQ1. What are the most critical knowledge areas that students should master in quantum technologies?** |
| Quantum technologies encompass a broad range of disciplines, making the specifics dependent on the field of study. The most critical knowledge areas that students should master in quantum technology are:<br>• Quantum computing and technology<br>• Quantum information theory<br>• Computing algorithm and quantum mechanics<br>• Quantum superposition and entanglement<br>• Mathematical literacy (Linear algebra, differential equation,<br>• Quantum hardware and cybersecurity<br>• Quantum cryptography, business communication (Data Management)<br>• Qubits vs. classical bits<br>• Single-qubit gates (Pauli gates, Hadamard, Phase, T, etc.) vs. multi-qubit gates (CNOT, SWAP, Toffoli, Fredkin)<br>• Acquiring hands-on-knowledge<br>• Implication of socio-technical, ethical and legal issues etc. |
| **RQ2. Which specific skills related to quantum technologies are currently lacking among graduates entering the field?** |

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| • General understanding of the key principles of quantum technology.<br>• Hands-on experience with quantum hardware, error correction techniques, and optimization.<br>• Quantum physics and how to use quantum computing in parallel with supercomputers.<br>• Understanding the business potential of the quantum technology and ability to monetize it.<br>• Interdisciplinary knowledge to bridge quantum technologies with other fields. |
| **RQ3. How do the knowledge and skill requirements differ between research and industry applications?** |
| Quantum computing remains largely in the research phase, with only a few preliminary applications beginning to emerge. Knowledge and skill requirements differ between research and industry as research focuses on theoretical advancements, algorithm design, advancing hardware technologies, requiring strong mathematical and physics skills; whereas industry emphasis is on practical implementation, optimizing existing quantum algorithms for real-world applications and integrating quantum systems with traditional computing frameworks, which demands programming skills, problem solving and business awareness. |
| **RQ4. What are the emerging trends in quantum technologies that should be incorporated into higher education curricula?** |
| • Ensure concepts of quantum computing must be a part of elementary computer science courses, then confirm the application of quantum computing technology into higher education curricula.<br>• Introduce basic but most used statistical skills in machine learning and quantum computing optimized machine learning.<br>• Include quantum AI & machine learning like quantum neural networks, generative models, and quantum-enhanced learning techniques.<br>• Quantum error correction, quantum in cyber security, hybrid quantum-classical algorithms must be added in higher education curricula.<br>• Quantum networking: Development of quantum repeaters and secure quantum communication protocols. |

| **SESSION 2: BRIDGING EDUCATION ON QUANTUM TECHNOLOGIES WITH REAL-LIFE APPLICATIONS IN DIVERSE INDUSTRIES** |
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| **RQ1. What are the biggest gaps between academic training and real-world industry needs?** |

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| • From the industrial engineering perspective, the main gap is the lack of application in academia, particularly technology companies developing hardware and cloud-based services.<br>• In the academic field, insufficient software training and lack of hands-on exposure to real quantum hardware make a significant gap with industry use cases.<br>• The monetization challenges like quantum computing are addressing industry fields which are not well addressed in academic settings.<br>• There is a lack of interdisciplinary collaboration in academia which is most important to industrial commercialization.<br>Academic courses cover the theoretical part well, but fail in providing practical knowledge of real-life applications for which students are not prepared when they are going to work in the industry. |
| **RQ2. Can you provide examples of how quantum technologies are currently being applied in your research?** |
| • VRP solving and scheduling problems<br>• Portfolio optimization<br>• Quantum simulations<br>• Interdisciplinary projects integrating quantum with AI and cybersecurity<br>• Improving efficiency and energy savings in training large language models<br>In the field of earth Observation and satellite remote sensing, quantum sensors or detection methods may be used soon. |
| **RQ3. What kind of hands-on or project-based learning experiences would be most beneficial for students?** |
| • Quantum solver & optimization problems<br>• Building and testing quantum circuits<br>• Collaborating on interdisciplinary case studies<br>• Internships with industry partners<br>• Implementing quantum algorithms & cloud access<br>• Hackathons & industry collaboration<br>• Quantum computing enhanced machine learning and stochastic modelling using quantum computing<br>• Integrating quantum with fields like AI and cybersecurity.<br>• Financing and modelling, as well as special cases of machine learning. |
| **RQ4. Are there specific tools, software, or platforms that should be included in a relevant curriculum on quantum technologies to improve industry readiness?** |
| • Python<br>• IBM quantum academic<br>• Qiskit<br>• Cirq<br>• QuTiP<br>• Quantum cloud services (e.g., IBM Quantum, AWS Braket)<br>• Quantum hardware emulators<br>• Helmi & Lumi super- & quantum computers. |

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| SESSION 3: RECOMMENDATIONS FOR THE DEVELOPMENT OF A HIGHER EDUCATION CURRICULUM |
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| **RQ1. What core courses should be included in a future-oriented quantum technologies and their business applications curriculum?** |
| • Introduction to quantum computing & mechanics<br>• Quantum information & cryptography<br>• Quantum algorithms & programming<br>• Quantum machine learning<br>• Quantum business & commercial applications<br>• Applications in optimization and machine learning<br>• Quantum hardware<br>• Quantum business strategy |
| **RQ2. How should quantum education balance theoretical concepts with practical applications?** |
| Here all respondents emphasized the important of balance of theoretical concepts with practical applications through:<br>• Strong theoretical foundation by integrating lab-based learning, industry projects, and real-world case studies.<br>• Combining fundamental theory with practical coding and experimentation (Project-based learning).<br>• Incorporating real-world use cases and applications from the industry.<br>• Providing access to quantum systems for hands-on experience by using Qiskt, IBM quantum.<br>• General Computer Science Integration that emphasizes selecting appropriate technological solutions. |
| **RQ3. How can universities keep their quantum technology curriculum updated with fast-evolving industry needs?** |
| • Industry partnership (tech companies based on quantum technologies),<br>• Incorporate feedback from various stakeholders,<br>• Incorporating emerging topics & certificate programs<br>• Collaborations & research opportunities with CSC<br>• Internships & guest lectures<br>• Investigating quantum computing resources available from businesses (IBM, etc.).<br>• Integrating open-source research developments into coursework. |
| **RQ4. What are the key challenges in implementing a quantum-focused curriculum, and how can they be addressed?** |

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| **Key challenges in implementing quantum-focused curriculum:**<br>• Faculty shortage (finding people who are skilled in this domain)<br>• Hardware access (high-cost quantum hardware)<br>• Rapid technological evolution (challenging to keep course materials up to date)<br>• Complexity of the subject (understand where quantum computing excels and where traditional computing solutions are better)<br>• Lack of practical applications in business<br>• Student and faculty knowledge gaps<br>**Address These Challenges**<br>• Faculty training & industry collaboration<br>• Remote access to hardware & industry partnerships<br>• Building a strong foundation in quantum fundamentals<br>• Modular and adaptable course structures<br>• Interdisciplinary collaboration & minor programs<br>• Industry-academia collaboration & guest lectures |
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| **FINAL REMARKS ON THE FOCUS GROUP'S FEEDBACK** |
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| 1. The focus group's comments are particularly rich insights into the existing gaps and potential opportunities in quantum education.<br>2. Emphasis on feedback of focus groups on interdisciplinary collaborations, experiential learning, incorporation of emerging trends, industry-led project and internship and faculty development.<br>3. Overcoming adversity by industry collaboration, learning by experience, and continuous curriculum updating.<br>4. Ongoing feedback from industry partners, alumni, and researchers, and engagement with technology companies.<br>5. Identified as key topics that need to form part of future curricula (Quantum AI & ML, quantum error correction, and hybrid quantum-classical algorithms). |

# 6. Insights obtained from the focus group with stakeholders from Greece

## 6.1 Focus group with industry

| SESSION 1: UNDERSTANDING THE NEEDS OF BUSINESSES IN TERMS OF REQUIRED KNOWLEDGE AND SKILLS ON QUANTUM TECHNOLOGIES |
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| **RQ1. What are the most critical knowledge areas that professionals should master in quantum technologies?** |
| Applications of quantum computing for AI training to make it faster as well as applications of quantum cybersecurity in cryptocurrencies/blockchain. |
| **RQ2. Which specific skills related to quantum technologies are currently lacking among professionals working in the field?** |
| Basic understanding of quantum physics principles. |
| **RQ3. How do the knowledge and skill requirements differ between research and industry applications?** |
| In research people are slower compared to industry and their main focus is on making publications. In industry you need to be faster and get results. You need to apply the knowledge you are learning in business applications. Better communication and collaboration skills are also essential for enterprises. |
| **RQ4. What are the emerging trends in quantum technologies that should be incorporated into higher education curricula?** |
| Quantum computing for AI, cybersecurity and blockchain. |

| SESSION 2: BRIDGING EDUCATION ON QUANTUM TECHNOLOGIES WITH REAL-LIFE APPLICATIONS IN DIVERSE INDUSTRIES. |
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| **RQ1. What are the biggest gaps between academic training and real-world industry needs?** |
| Universities lack a practical knowledge approach. Students should have some hands-on experience to enter the job market. |
| **RQ2. Can you provide examples of how quantum technologies are currently being applied in your business?** |
| No feedback as the company does not currently exploit quantum technologies. |
| **RQ3. What kind of hands-on or project-based learning experience would be most beneficial for your business?** |
| Mix of theoretical and practical courses. E.g. how AI can be applied using quantum computing. More focus on business applications. |
| **RQ4. Are there specific tools, software, or platforms that should be included in a relevant curriculum on quantum technologies to improve industry readiness?** |
| No feedback as the company does not currently exploit quantum technologies. |

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<table>
<tr><th>SESSION 3: RECOMMENDATIONS FOR THE DEVELOPMENT OF A HIGHER EDUCATION CURRICULUM</th></tr>
<tr><td>RQ1. What core courses should be included in a future-oriented quantum technologies and their business applications curriculum?</td></tr>
<tr><td><ul><li>Fundamental principles of quantum physics.</li><li>Business applications of quantum technologies.</li><li>Skills for managers in quantum technologies integration in innovation and management.</li></ul></td></tr>
<tr><td>RQ2. How should quantum education balance theoretical concepts with practical applications?</td></tr>
<tr><td>Online theoretical lessons, but for practical knowledge students should have the opportunity to visit some companies to get experience with practical applications.</td></tr>
<tr><td>RQ3. What types of industry partnerships (e.g., internships, joint research projects) would enhance professionals learning?</td></tr>
<tr><td>Internships and study visits to enterprises.</td></tr>
<tr><td>RQ4. How can universities keep their quantum technology curriculum updated with fast evolving industry needs?</td></tr>
<tr><td>Establishing partnerships with enterprises.</td></tr>
</table>

<table>
<tr><th>FINAL REMARKS ON THE FOCUS GROUP’S FEEDBACK</th></tr>
<tr><td><ul><li>Industry prioritizes knowledge in quantum computing for AI, cybersecurity, and blockchain.</li><li>Professionals often lack a basic understanding of quantum physics fundamentals.</li><li>Research environments focus on theory and publications; industry demands fast, applied results.</li><li>Communication and collaboration skills are more critical in enterprise settings.</li><li>Academic training lacks hands-on, practical experience needed for job readiness.</li><li>A mixed approach of theory and practice is needed, especially for business applications.</li><li>Suggested core curriculum includes quantum physics, business applications, and managerial integration.</li><li>Online theory courses should be complemented by in-company practical exposure.</li><li>Internships and joint industry projects are vital to bridge the education-industry gap.</li><li>Continuous industry collaboration is necessary to keep curricula up-to-date.</li></ul></td></tr>
</table>

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## 6.2 Focus group with research

| SESSION 1: UNDERSTANDING THE NEEDS OF RESEARCHERS IN TERMS OF REQUIRED KNOWLEDGE AND SKILLS ON QUANTUM TECHNOLOGIES |
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| **RQ1. What are the most critical knowledge areas that students should master in quantum technologies?** |
| There should be more emphasis on quantum computing as well as on how to use and where we can use the quantum physics rules. Other critical areas are quantum machine learning (the best machine learning algorithms are those that utilize in parallel classic and quantum machine learning). |
| **RQ2. Which specific skills related to quantum technologies are currently lacking among graduates entering the field?** |
| Quantum computing is the core domain of skills needs, together with cybersecurity and machine learning applications. |
| **RQ3. How do the knowledge and skill requirements differ between research and industry applications?** |
| Industry emphasizes more business applications while academics give more focus on research. In Greece, there are no appropriate higher education courses - just 4-5 in all Greek universities. Moreover, only PhD students are going to work on QTs at industry |
| **RQ4. What are the emerging trends in quantum technologies that should be incorporated into higher education curricula?** |
| • Quantum machine learning<br>• Quantum cybersecurity<br>• Quantum communications |

| SESSION 2: BRIDGING EDUCATION ON QUANTUM TECHNOLOGIES WITH REAL-LIFE APPLICATIONS IN DIVERSE INDUSTRIES |
|---|
| **RQ1. What are the biggest gaps between academic training and real-world industry needs?** |
| As the industry is still at the research phase there are no gaps especially for PhD students working on the same domain. |
| **RQ2. Can you provide examples of how quantum technologies are currently being applied in your research?** |
| • Quantum machine learning for drug development<br>• Quantum machine learning for smart materials and chemistry<br>• Post quantum cryptography |
| **RQ3. What kind of hands-on or project-based learning experiences would be most beneficial for students?** |
| • Python projects running at simulators<br>• Real-life experimentation |

| RQ4. Are there specific tools, software, or platforms that should be included in a relevant curriculum on quantum technologies to improve industry readiness? |
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| • IBM quantum computing<br>• Desktop real quantum computers for testing (Chinese quantum computer for offices up to 3 qbits) |

| SESSION 3: RECOMMENDATIONS FOR THE DEVELOPMENT OF A HIGHER EDUCATION CURRICULUM |
|---|
| **RQ1. What core courses should be included in a future-oriented quantum technologies and their business applications curriculum?** |
| • Introduction to quantum physics<br>• Introduction to mathematics<br>• Quantum computing<br>• Quantum machine learning<br>• Quantum communications and internet<br>• Quantum cryptography |
| **RQ2. How should quantum education balance theoretical concepts with practical applications?** |
| In a postgraduate program, students must acquire hand-on experience through real life projects (e.g. quantum machine learning programming). |
| **RQ3. How can universities keep their quantum technology curriculum updated with fast-evolving industry needs?** |
| Engaging with partners from industry, e.g. pharmaceutical for drug development and financial institutions for quantum cryptography). |
| **RQ4. What are the key challenges in implementing a quantum-focused curriculum, and how can they be addressed?** |
| The background of students as they commonly lack relevant skills. Convince students that is worth to study quantum technologies. |

| FINAL REMARKS ON THE FOCUS GROUP'S FEEDBACK |
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| • Quantum computing, machine learning, and cybersecurity are the most critical knowledge areas and skills needed in quantum technologies.<br>• Graduates often lack practical skills, especially in quantum computing and its real-world applications.<br>• Academic programs need to balance theory with hands-on experiences.<br>• Tools such as IBM Quantum and small-scale quantum computers should be integrated into curricula.<br>• Industry collaboration and updated, interdisciplinary courses are essential to address the evolving landscape and skill gaps in quantum technologies. |

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## 7. Discussion and conclusions

The insights gathered from the eight focus groups conducted across Spain, Italy, Finland, and Greece reflect a shared urgency and opportunity to reshape quantum technologies education in Europe. Stakeholders from both academia and industry consistently expressed that current higher education offerings do not fully meet the evolving demands of the quantum technologies sector. While individual countries are at different stages of adoption and engagement, several overarching themes and conclusions have emerged from the discussions.

### 7.1 Bridging the theory-practice divide

Across all sessions, participants agreed that quantum technologies curricula are disproportionately theoretical. While a strong foundation in quantum mechanics, mathematics, and information theory remains essential, students often graduate without the necessary practical experience to contribute effectively to industrial environments. Companies emphasized the importance of hands-on learning through simulators, real quantum devices, and project-based modules using frameworks such as Qiskit, Cirq, Pennylane, and IBM Quantum Experience. Industry partners noted a persistent mismatch: physicists often lack software development experience, while engineers and computer scientists lack foundational knowledge in quantum theory. This imbalance undermines readiness and employability.

To address this, a rebalancing of curricula is needed. Stakeholders advocated for a "70-30" or "50-50" split—favoring practical and applied content over purely theoretical instruction. Internships, hackathons, industry-led challenges, collaborative projects, and industrial PhD programs were repeatedly mentioned as essential mechanisms to foster experiential learning and embed students in real-world problem-solving environments.

### 7.2 Emphasizing interdisciplinarity and hybrid profiles

The inherently interdisciplinary nature of quantum technologies was a recurrent theme. Quantum technologies operate at the intersection of physics, computer science, engineering, and increasingly, business and management. Effective education must cultivate "hybrid professionals" with competencies that span these domains. This includes knowledge of quantum algorithms, signal processing, hardware-software co-design, optimization techniques, and cybersecurity.

Particularly in Italy and Spain, there was an emphasis on expanding curricula to non-STEM learners—such as business students, economists, and entrepreneurs—who will play key roles in quantum commercialization. In this regard, introductory "pill" modules and foundational preparatory courses could democratize access to quantum technologies education, allowing a wider group of students to engage with the topic and support broader ecosystem development.

### 7.3 Industry readiness and curriculum responsiveness

A clear priority voiced by stakeholders was the need for curricula to keep pace with technological evolution. Quantum technologies are advancing rapidly, and universities often lag behind industry in adapting their content. Participants proposed several solutions, including:

- Advisory councils with industry representatives to provide regular input on curriculum development.

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- Annual curriculum reviews informed by business feedback and emerging trends.
- Mixed teaching teams comprising both academics and practitioners.
- Open-source integration, allowing students to engage with up-to-date tools and datasets.
- Partnerships with technology companies, such as IBM and Fujitsu, to provide cloud access to quantum systems and educational materials.

Countries like Finland and Italy highlighted the value of co-developing micro-courses, contributing to lifelong learning pathways and supporting both current students and working professionals.

### 7.4 Identified emerging trends

Several key domains were identified as critical to incorporate into future-oriented QT education:

- Quantum Machine Learning: Combining quantum and classical approaches for more efficient learning models.
- Quantum Cybersecurity and Post-Quantum Cryptography: Essential for protecting data in a quantum-enabled future.
- Hybrid Classical-Quantum Computing Architectures: Needed for realistic implementation of quantum algorithms.
- Quantum Communications and Sensing: Although niche, their importance is growing, especially in defense, health, and environmental monitoring.
- AI for Quantum: Using AI tools to optimize quantum algorithm design and coding.
- Error Correction and Mitigation: An essential area as current devices remain noisy and prone to faults.

Additionally, soft skills—especially interdisciplinary communication, project management, and entrepreneurial thinking—were highlighted as increasingly vital to enable professionals to work effectively across diverse teams.

### 7.5 Challenges to implementation

Despite the enthusiasm, several barriers to effective quantum technologies curriculum reform were identified:

- **Faculty shortage:** The limited pool of quantum technologies specialists restricts course delivery and innovation.
- **Access to infrastructure:** Many institutions lack quantum hardware or simulators to support hands-on learning.
- **Student preparedness:** Incoming students often lack strong backgrounds in mathematics or physics, making advanced quantum technologies topics inaccessible.
- **Cost and scalability:** Scaling up interdisciplinary, lab-based, and industry-integrated models poses financial and logistical challenges.

These challenges require coordinated policy responses at institutional, national, and European levels. Proposals included incentivizing industrial PhDs, funding collaborative university-industry labs, and supporting faculty training and recruitment.

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### 7.6 Toward a holistic quantum curriculum

The feedback strongly supports the development of a modular, interdisciplinary, and industry-connected curriculum framework that:

- Integrates **core theoretical foundations** (quantum mechanics, linear algebra, information theory).
- Offers **specialized and applied modules** (quantum machine learning, quantum cryptography, optimization, quantum software development).
- Embeds **practical experience** (labs, simulators, hackathons, internships, case studies).
- Fosters **collaboration across domains** (science, engineering, business).
- Is **inclusive and accessible** to a broad range of students and professionals.

The curriculum should not only produce researchers but also skilled practitioners who can lead quantum innovation in startups, corporations, and public sector organizations.

In conclusion, the Quantum+ focus groups have surfaced a coherent and urgent call for action. There is widespread consensus that the future of quantum technologies in Europe depends on a new generation of professionals who are not only technically proficient but also agile, interdisciplinary, and deeply connected to real-world applications. The development of a responsive, inclusive, and practical higher education framework is both a necessity and an opportunity. The insights presented here offer a roadmap for educational innovation that can ensure Europe remains competitive and visionary in the quantum era.

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