Quantum Information Education

Subjects: Quantum Science & Technology

Contributor: Francisco Delgado

Quantum information is an emerging scientific and technological discipline attracting a growing number of professionals from various related fields. Although it can potentially serve as a valuable source of skilled labor, the Internet provides a way to disseminate information about education, opportunities, and collaboration.

research education | internet-supported education | blended learning | educational innovation | quantum information education

1. Introduction

Quantum mechanics, a science that emerged in the early twentieth century, underwent a slow incubation of concepts and development throughout the century. Its notable applications include transistors, lasers, magnetic resonance, and electronic microscopes, leading to remarkable technological developments as a result of the research. However, the field did not take a fundamental step toward technological development until Richard Feynman's statement [1] that quantum systems could perform a type of computational processing unachievable by classical systems. By exploiting the central properties of quantum mechanics, such as superposition and quantum entanglement, a new development trend has emerged, resulting in real-world applications ranging from cryptography, novel communication systems (teleportation), and quantum processors.

From Quantum Mechanics Toward a Quantum Industry

The emerging areas of quantum information, communication, and processing are no longer confined to physicists, mathematicians, and computational scientists. Instead, these fields increasingly influence various disciplines that address complex phenomena, including chemistry, biology, economics, and even sociology. As a result, a new generation of professionals with varied interests and an inclination toward innovative scientific solutions is being called upon to contribute to develop quantum technologies and solutions.

Based on a classification agreed upon by several authors for the evolution of quantum technologies and the role of education [2], **Figure 1** shows the three outstanding branches in applied quantum information, quantum processing (quantum computation and algorithmic processing), quantum sensing (measurement, metrology, and quantum sensor development), and quantum communication (quantum processes to generate, store, transmit, and receive quantum information). The diagram highlights emblematic applications in each branch and the classically associated disciplines where professionals are likely to originate.

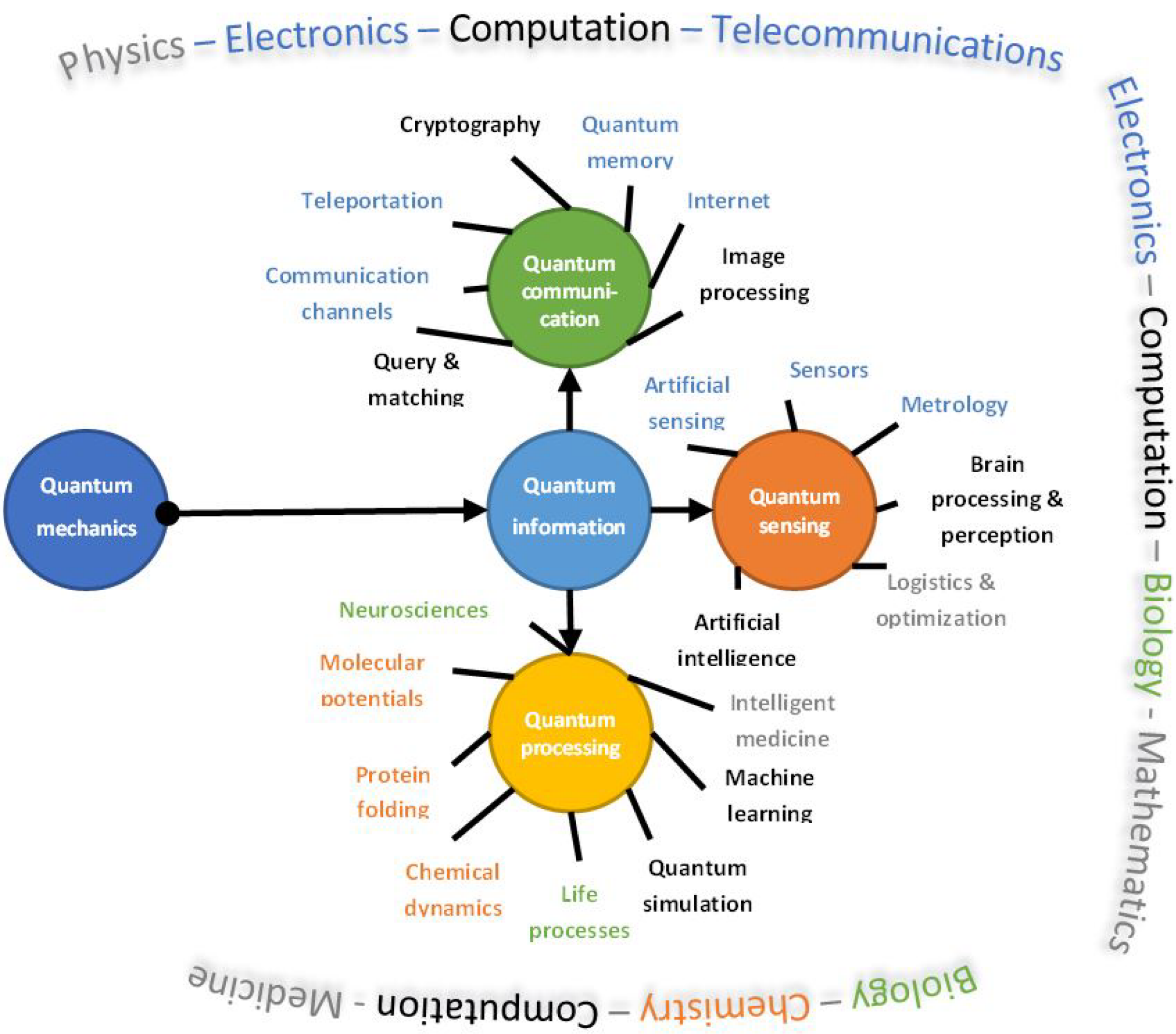

Figure 1. Three well-identified branches of quantum information science with some associated quantum emblematic technologies. The classical areas related to each branch are the same color as the corresponding emblematic application, framing the central diagram.

Nowadays, quantum mechanics courses for physicists and mathematicians have been transformed into a diversity of courses with remarkable specialization, such as Information, Communication, Measurement, and Processing [3]. The audience has also changed with students coming from several science and engineering programs, including Computer Science, Chemistry, Chemical Engineering, Material Sciences, Nanotechnology, and Electronic Engineering [4]. Another trend is an exponential increase in educative resources provided by the Internet, such as video conferencing systems, diversified digital learning resources, and specialized tools [5][6]. Due to these, science has a charming attraction that was hidden before. Those public and innovative resources are reaching young people interested in research, with different focuses based on their academic interests. Students' increasing interest in science has been sparked by the Internet and the perception of having greater job security than other sectors [7]. Unfortunately, students' interest in science does not guarantee their automatic selection of a career in Science or Technology, so additional interventions should be made [8]. In any event, it can be said that the Internet is facilitating things previously popularized in specialized books. Science is becoming more open and approachable.

2. Quantum Information as an Attractive Life Plan for the Development of Quantum Industry

The boom in quantum information development has been sparked by its perceived potential impact on human society and the undeniable boost that the Internet has provided through scientific dissemination to everyone using their devices. The Internet has generated an intangible impulse for scientific development in the last 25 years, attracting and involving new human resources in research [9].

After decades of theoretical and experimental work, quantum technologies are a reality, currently crossing a period of emerging growth in a well-identified global industry. Although the most notable goal is the creation of a quantum processing device emulating and improving the capabilities of current computing technologies, other developments are proceeding from different fronts, including quantum processing algorithms, user interfaces with these technologies, the development of quantum sensors, and the associated metrology to measure related systems [10]. These are commonly classified into three significant developments, computing and simulations, communication and networks, and quantum sensors and measurements. Blocks of countries in North America, Europe, and Asia, have detailed medium-term strategies, roadmaps, and prioritized investments in those technologies as a line of economic development [11].

As a result, the quantum industry is growing exponentially, transitioning from quantum mechanics, as noted in several prospective references [4][11][12][13]. **Figure 2** schematically shows the exponential growth as a function of time, estimated by research discovery facts and data. The color code marks three different, well-stated developmental stages of that industry. The horizontal axis divides the quantum revolution since its dawn in 1900 (with the Max Planck hypothesis of quanta) as the beginning of quantum science (blue), going through the era of electronics with the development of the semiconductors around the 1960s marking the beginning of the quantum technology stage (orange). Then, the beginning of the quantum industry era (green) was marked by the first commercial quantum computer available, the D-Wave, and 2030 is a planned horizon in the roadmaps of several countries blocks [12]. Vertical legends refer to applications that appeared or are expected to appear in each stage [4][11][12][13]. The vertical axis indicates the number of quantum scientists involved in the field; mainly, the number of new employments related to quantum information in the current decade ranges in the tens of thousands yearly [14]. Otherwise, the leading global industries currently have employees ranging in the millions [15]. Those values barely set the number of people involved for each stage of the vertical axis, especially for the quantum industry.

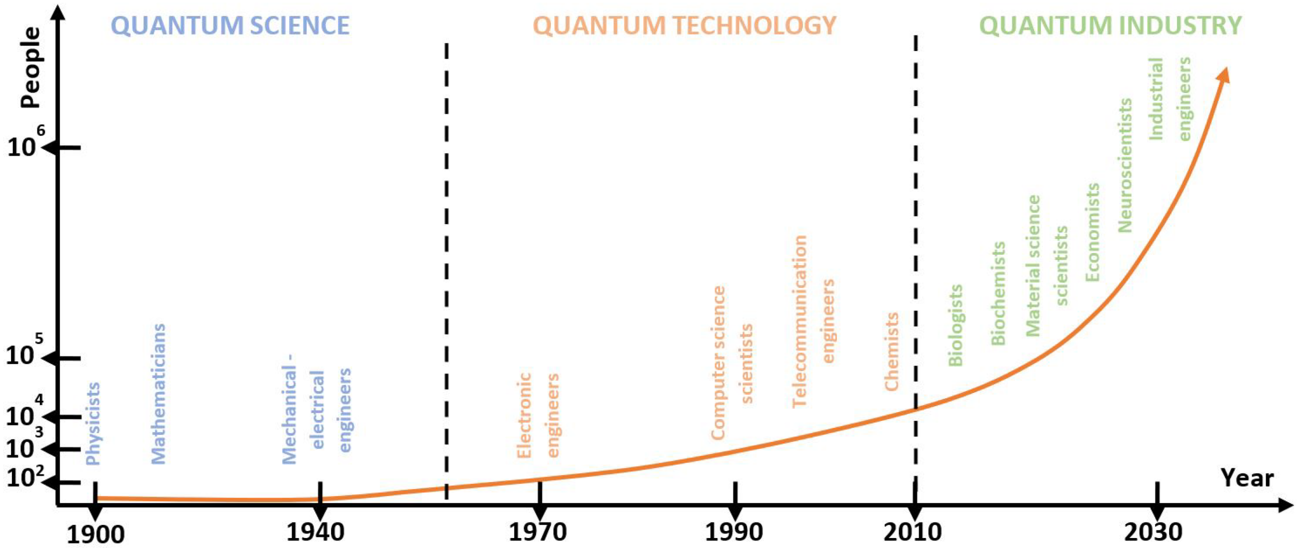

Figure 2. Evolution in quantum science applications through disciplines involved and the number of professionals to trigger an impact on global transitions quantum industry.

Thus, by surpassing the theoretical and basic experimentation of the last century, quantum science is evolving first in the current intermediate stage of quantum technologies to arrive in the following decades in a global industry of quantum applications [13]. In the future, several applications are expected to be developed involving an increasing number of professionals [16].

3. Quantum Information Education: A Wider Initiative around the World

The attraction of new human resources to forge and promote disciplines, such as quantum information, requires early actions. Thus, STEM (Science, Technology, Engineering, and Mathematics) educative initiatives provide early approaches for their inclusion [12]. Those initiatives seek to include, attract, and train students in scientific research first, and then the areas of quantum information as motivating life plans. Quantum information can promote and contribute to scientific interest because it is a disruptive discipline [2]. Nowadays, specialized groups and institutes use this approach to introduce this discipline in early courses, attracting students through workshops, professional stays, scientific graduate courses, and academic degrees [3][4][12].

The quantum industry comprises an emerging, commercial, and scalable development of quantum technologies [2]. The industry has produced massive products and services, such as quantum cryptography devices. Such an effervescent development of potential products and services requires a plethora of qualified human resources for their development and implementation [17][18]. Today, many commercial initiatives are already developing and improving existing quantum technologies in fierce competition. Thus, IBM, Google, D-Wave, and Amazon Braket are emerging pioneers in developing quantum processors. Meanwhile, MagiQ, AgilPQ, Anametric, and QuantumXchange develop applications and quantum encryption devices. In a disruptive direction, Atom Computing, EeroQ, and IonQ develop solid-state-based processors. ColdQuanta develops various quantum devices for communications and storage. Those companies are examples of quantum products' accelerated development and commercialization as part of an emerging market on which several developed countries partially bet their global leadership and economy [11][16].

Those opportunities in the scientific profession have motivated the development of this type of learning experience and training in research for Higher Education students [19]. However, in each country, it is usual that only a few university education institutions or research centers offer such a possibility, being regularly far from potential candidates. How to attract them? Which initiatives can be formulated to make this opportunity equitable? We can appreciate quantum information's importance as a discipline in different countries in many educative initiatives implemented in several levels of education. For instance, some experiences introducing the teaching of quantum optics have been reported in secondary education [20], together with more theoretical approaches teaching Dirac notation [21]. In high school, an experience teaching quantum computation has been reported [22], just in the preamble of higher education. Interestingly, such experiences also include technical education regarding Photonics [23].

Higher Education has many examples of educational initiatives in quantum information and Photonics. Creation of complete educative modules or courses has several implementation examples [24][25], or at least its inclusion in other courses [26]. Photonics initiatives are an essential applied area of education, with centers created for the discipline [27][28][29][30]. All those efforts are directed towards developing leadership in quantum technologies [31].

References

1. Feynman, R.P. Quantum mechanical computers. Found. Phys. 1986, 16, 507–531.
2. Fox, M.F.J.; Zwickl, B.M.; Lewandowski, H.J. Preparing for the quantum revolution: What is the role of higher education? Phys. Rev. Phys. Educ. Res. 2020, 16, 020131.
3. Cervantes, B.; Passante, G.; Wilcox, B.; Pollock, S. An Overview of Quantum Information Science Courses at US Institutions. In Proceedings of the 2021 Physics Education Research Conference, Virtual, 4–5 August 2021; 2022; pp. 93–98.
4. Jeremy, H. Building the Quantum Workforce of the Future. Forbes Technology Council. 19 June 2019. Available online: https://www.forbes.com/sites/forbestechcouncil/2019/06/19/build-ing-the-quantum-workforce-of-the-future/#3daf7d26fa47 (accessed on 5 January 2023).
5. Turkle, S. Falling for Science: Objects in Mind; MIT Press: Cambridge, MA, USA, 2011.
6. Hasni, A. Student's Interest in Science and Technology and its Relationships with Teaching Methods, Family Context and Self-Efficacy. Int. J. Environ. Sci. Educ. 2015, 10, 337–366.
7. OECD. Evolution of Student Interest in Science and Technology Studies. In Proceedings of the of Global Science Forum, Maastricht, The Netherlands, 12–14 September 2006.

8. Sáinz, M.; Fàbregues, S.; Romano, M.J.; López, B.S. Interventions to increase young people's interest in STEM. A scoping review. Front. Psychol. 2022, 13, 954996.
9. Riffe, D.; Lacy, S.; Varouhakis, M. Media System Dependency Theory and Using the Internet for In-depth, Specialized Information. Web J. Mass Commun. Res. 2008, 11, 1.
10. Wang, Y.; Song, X. Quantum Science and Quantum Technology. Stat. Sci. 2020, 35, 51–74.
11. Acín, A.; Bloch, I.; Buhrman, H.; Calarco, T.; Eichler, C.; Eisert, J.; Esteve, D.; Gisin, N.; Glaser, S.J.; Jelezko, F.; et al. The quantum technologies roadmap: A European community view. New J. Phys. 2018, 20, 080201.
12. NSF. Quantum Leap Challenge Institutes (QLCI). National Science Foundation: Alexandria, VA, USA. Available online: https://www.nsf.gov/pubs/2019/nsf19559/nsf19559.htm (accessed on 5 February 2023).
13. Dowling, J.; Milburn, G. Quantum technology: The second quantum revolution. Ser. Math. Phys. Eng. Sci. A 2003, 361, 1655–1674.
14. Vuleta, V. Quantum Computing Statistics: Benefits and Negative Effects. SeedScientific. 2023. Available online: https://seedscientific.com/quantum-computing-statistics/ (accessed on 14 March 2023).
15. Statista. Total Employed Persons in the United States in 2022 by Industry. Available online: https://www.statista.com/statistics/200143/employment-in-selected-us-industries/ (accessed on 14 March 2023).
16. Peterssen, G. Quantum technology impact: The necessary workforce for developing quantum software. In Proceedings of the QANSWER 2020 International Workshop on the QuANtum SoftWare Engineering & Programming, Reina, Spain, 11–12 February 2020; pp. 1–20.
17. Curioni, A. Why Education must take a Quantum Leap. In World Economic Forum: The Digital Transformation of Business; IBM Research Europe: Albany, NY, USA; World Economic Forum: Cologny, Switzerland, 2022.
18. Gunashekar, S.; d'Angelo, C.; Flanagan, I.; Motsi-Omoijiade, D.; Virdee, M.; Feijao, C. Using Quantum Computers and Simulators in the Life Sciences; Novo Nordisk Foundation: Hellerup, Denmark, 2022.
19. Asfaw, A.; Blais, A.; Brown, K.R.; Candelaria, J.; Cantwell, C.; Carr, L.D.; Singh, C. Building a Quantum Engineering Undergraduate Program. IEEE Trans. Educ. 2022, 65, 220–242.
20. Bitzenbauer, P. Practitioners' views on new teaching material for introducing quantum optics in secondary schools. Phys. Educ. 2021, 56, 055008.
21. Michelini, M.; Stefanel, A.; Tóth, K. Implementing Dirac Approach to Quantum Mechanics in a Hungarian Secondary School. Educ. Sci. 2022, 12, 606.

22. Hughes, C.; Isaacson, J.; Turner, J.; Perry, A.; Sun, R. Teaching Quantum Computing to High School Students. Phys. Teach. 2022, 60, 187.
23. Massa, N.; Donnelly, J.; Hanes, F. Student reactions to problem-based learning in photonics technician education. In Education and Training in Optics and Photonics; Optica: Washington, DC, USA, 2013; p. 928918.
24. Tang, H.; Wang, T.; Shi, R.; Jin, X. Teaching quantum information technologies and a practical module for online and offline undergraduate students. arXiv 2021, arXiv:2112.06548v1.
25. Filali-Meknassi, O.; Semlali, M. Optics and photonics in the education system of the Kingdom of Morocco. In Proceedings of the 19th Congress of the International Commission for Optics: Optics for the Quality of Life, Firenze, Italy, 25–30 August 2002.
26. Feenstra, L.; Julia, C.; Logman, P. A Lego Mach–Zehnder interferometer with an Arduino detector. Phys. Educ. 2021, 56, 023004.
27. Hull, D. Optics and photonics education centers of excellence: An opportunity for international collaboration. In Education and Training in Optics and Photonics: ETOP; Optica: Washington, DC, USA, 2015; Volume 9793, p. 97930A.
28. Friedman, J.; Diaz, A.; Saltares, R.; Luciano, S.; Molina, N.; Martinez, S.; Hernandez, A.; Rivera, J.; Capeles, A.; Alvear, F.; et al. Photonics outreach and education through partnerships in Puerto Rico. In Education and Training in Optics and Photonics: ETOP; Optica: Washington, DC, USA, 2015; p. 97932X.
29. Helgert, C.; Nolte, S.; Pertsch, T. Internationalized and research-oriented photonics education: Abbe School of Photonics. In Education and Training in Optics and Photonics: ETOP; Optica: Washington, DC, USA, 2015; p. 979305.
30. Siddiq, N.A. Teaching optics in Covid-19 pandemic through project-based learning. Phys. Educ. 2021, 56, 035020.
31. Singh, C.; Asfaw, A.; Levy, J. Preparing students to be leaders of the quantum information revolution. arXiv 2021, arXiv:2111.06438.

Retrieved from https://encyclopedia.pub/entry/history/show/99864