# Quantum Computing as Uprising Topic for Business Students in Higher Educational Institutions

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**Abstract**

*Quantum computing (QC) has recently seen significant developments, and its market is expected to reach $125 billion by 2030 [1]. In today's rapidly evolving world with vast and complex data, QC technology is increasingly becoming essential [2]. Despite its widespread applications in sectors such as financial services or life sciences, a noticeable gap exists in educational offerings tailored for a business audience. The integration of this critical subject into the business programs of Higher Educational Institutions (HEIs) remains an underexplored area, demanding more attention. We adopt a structured literature review approach to provide an overview of existing and potential applications of QC in selected business fields. We also explore existing educational offerings of QC for business students. Based on a small-scale survey conducted at the University of Applied Sciences and Arts Northwestern Switzerland FHNW, we provide preliminary insights into the interests of business students in the topic of QC. Finally, we provide recommendations for HEIs regarding teaching QC to business students. Our findings and recommendations serve as valuable guidelines for educators in HEIs seeking to integrate QC into their business programs.*

**Keywords:** *Quantum Computing, Quantum Computing Education, Higher Educational Institutions, Quantum Computing for Business*.

## 1. Introduction

In today's rapidly evolving economy, quantum computing (QC) is emerging as a highly promising technology with the potential to address some of society's most pressing challenges, including climate change and disease [3]. QC is defined as "*a new technology for computation, which leverages the laws of quantum mechanics to provide exponential performance improvement for some applications and to enable completely new territories of computing potentially*" [4].

QC has the potential to disrupt several business sectors and related industry value chains [5]. With its projected economic impact of up to $1.3trillion of economic value in sectors such as financial services, life sciences and others by 2035 [4], it is not surprising to find both the public sector (for example, the United States, China, and the European Union) and the private sector (for example, Google, Microsoft, and IBM) investing heavily in QC research [4].

Despite the anticipated economic impact and the predicted widespread application of QC in technology and business, the quantum industry faces a significant talent shortage [6]. As our literature review will reveal, current QC education at Higher Educational Institutions (HEIs) is primarily designed for students with a technical focus. However, to fully exploit the potential of QC, interdisciplinary expertise is essential. Today's business students – future decision-makers – are a highly relevant target group for fostering technology adoption. There is a notable lack of QC courses tailored for this audience. This gap underscores the importance of investigating existing educational offerings for business students.

This paper aims to achieve the following objectives:

- Underline the relevance of QC for business by providing an overview of QC applications in selected sectors;
- Identify the existing gap in educational offerings for business students by describing the state of QC education;
- Highlight the challenges hindering QC adoption in business and education.

Our findings could provide valuable insights for educators in HEIs on how to integrate QC into their business programs.

Our main method involves a structured literature review. The keywords used for the search included: "quantum computing" and "education", "quantum computing course", "quantum computing for business", and "barriers to quantum adoption". We selected relevant academic papers from platforms such as Scopus, IEEE Xplore, ResearchGate, ScienceDirect, Google Scholar, and Springer. Additionally, we drew insights from industry reports and analyses from reputable sources including IBM and McKinsey. We also utilized publicly available learning materials from platforms such as Udemy, Coursera, and LinkedIn Learning. To complement our literature findings, we conducted a small-scale study via an online survey to gauge the interest of business students at the University of Applied Sciences and Arts Northwestern Switzerland FHNW in a potential QC course at the School of Business. Given the exploratory nature of this study, it supports the literature research results and enriches the recommendations for HEIs.

The remainder of this paper is structured as follows: Section 2 presents the results from the literature review. Section 3 discusses the exploratory study on the interest of FHNW business students in a quantum computing course. Section 4 discusses the results and provides recommendations for HEIs. The paper concludes with a summary and an outlook for future research in Section 5.

## 2. Literature Review

In this section, we review studies on QC applications in selected sectors to underscore QC's potential impact on the business world. The selected fields — life sciences, financial services, ecology, and agriculture — offer a broad range of perspectives and cover sectors of high relevance in Switzerland [7] particularly in the Basel region where the FHNW School of Business is located. Subsequently, we examine the literature on existing educational offerings in QC, both at a general level and with a specific focus on offerings for business students. This review highlights the significant gap in QC education tailored for a business audience. The literature review concludes with an overview of factors hindering the integration of QC into HEIs' curricula and the adoption of QC in businesses. These findings inform the recommendations provided in Section 4.

### *2.1 Quantum Computing Applications in Selected Sectors*

One sector expected to benefit significantly from QC is the **life sciences**. Computationally complex calculations are fundamental to genomic analysis and drug design. Currently, the level of complexity in these areas exceeds the capabilities of classical computers; however, QC has the potential to be a game-changer [8]. Quantum technology is poised to become a key enabler for progress in precision medicine, aiming to keep individuals healthy through proactive medical care and personalized guidance. For instance, quantum sensing could enhance diagnosis and treatment through highly sensitive measurements [9]. Initiatives such as QuantumBasel, a Center of Competence for Quantum and Artificial Intelligence, focus on the life sciences and provide access to QC resources for companies, startups, and leading research institutions [10].

[11] reviewed how QC could disrupt the **financial services** industry. Their paper highlighted quantum algorithms applicable to financial problems, such as Grover's algorithm and the Harrow, Hassidim, and Lloyd (HHL) algorithm. The authors also identified the potential of QC to address supply chain management issues, optimize dynamic portfolios, and enhance credit scoring. While they affirmed that QC could revolutionize quantitative finance, they emphasized that experimental breakthroughs are necessary before a universal quantum processor capable of surpassing present-day supercomputers can be developed. In addition to its numerous potentials, QC poses significant risks to cybersecurity due to its potential capability to implement Shor's algorithm, which could render much of current-day cryptography obsolete [12].This presents an urgent challenge for all industries, particularly the finance sector, which must proactively ensure the trustworthiness of their services in the face of these emerging threats.

Several studies have examined QC applications in the field of **ecology.** QC could provide several opportunities like increased realism in ecological modelling, solutions to complex ecological challenges, the readiness of fundamental approaches to quantitative ecology, and an opportunity to shape the future [13]. The potential of QC to address serious ecological issues, such as the impacts of climate change through enhanced simulation capabilities, is supported by industry players such as [14] and [15]. However, [13] emphasized existing challenges. For instance, the applicability of QC to solve ecological problems may be limited by the current capabilities of today's hardware. Additionally, while ecologists can understand and apply quantum approaches, further education and training are required. Another challenge is that ecologists will likely compete with other sectors, such as financial services and advanced manufacturing, for access to quantum computing hardware.

[16] explored the application of QC in (smart) **agriculture** practices to enhance sustainable crop management and increase yield. They employed a narrative literature review approach, identifying 650 articles, of which 43 were deemed relevant to their research question and included in the study. They found that quantum technologies could significantly influence regulated farming practices, optimize outputs, and achieve high crop yields. By leveraging the inherent computational speed of quantum systems, farmers could gain actionable insights and recommendations for maximizing yield and minimizing environmental impact. In the same light, variational quantum algorithm can be used to classify soil samples based on their fertility and even provide higher classification accuracy [17]. The study also validated quantum algorithm's effectiveness in separating samples based on their characteristics. Despite the potential of QC in smart agriculture, one major challenge is the need for more expertise and infrastructure because QC is a highly specialized field [16].There is also limited availability of hardware and software globally, making it difficult to test and optimize quantum algorithms in smart agriculture and other fields. Moreover, quantum methods need high computing power and special hardware [17].

### *2.2. Overview of Quantum Computing Education*

[18] researched the possibility of introducing QC to a new audience using a computer-science-oriented approach. The authors adopted the approach of presenting QC as a generalisation of probabilistic and classical computing and abstracting the physical concepts through linear algebra. The approach excluded any complex numbers and mainly focused on real numbers, hence not requiring any digression into complex numbers. [18] tested their content in 22 two- to three-day workshops held in ten countries. Each workshop featured instructors and mentors, with a total of 430 participants from diverse backgrounds, including computer science, engineering, physics, and high school students. Their findings indicated that this teaching method effectively increased the basic knowledge of QC among participants, including those without a physics background. The authors concluded that this approach is particularly appealing to individuals who do not wish to learn quantum physics or do not require such understanding. Furthermore, [6] developed several educational offerings, including an eight-month program for undergraduate students that integrated high-impact learning methods, industry insights, and real-world QC opportunities; the profile of the target group was not specified. Their research found that students struggled to gain an in-depth understanding of QC fundamentals, necessitating the presentation of quantum concepts in a more approachable manner. Despite higher-than-expected interest in subsequent cycles, student retention until the end of the program remained an issue.

[19] researched the need to build QC capacity in engineering education. The study aimed at proposing a starting point for QC education in higher education. The authors evaluated third-party educational approaches to teaching emerging technologies to develop a teaching model for QC. [19] proposed a model that distinguishes between the teaching of core QC technology and the exploration of its socio-cultural applications. They advocated for the customization of a single QC course specifically designed for engineering students, with the primary objective of cultivating new use cases. In another study, [20] presented a case study of an undergraduate QC course tailored for students in Fundamental Sciences and Engineering disciplines. Employing a blended learning approach and utilising the IBM Qiskit framework as a teaching resource, the course required no pre-knowledge. The authors concluded that most students successfully completed the course. Several other publications have delved into the realm of QC education for engineering students, including works by [22] [23] [24].

Furthermore, there are educators who have ventured into teaching QC at the high school level. [25] shared their experience with the Quantum Computing, Math, and Physics camp (QCaMP), aimed at introducing QC to high school students and teachers. [26] elaborated on a full-year course in optics-based QC conducted at the high-school level, with coursework tailored to engineers. Considering the complexity of QC, the didactical concept of inquiry-based learning — where students engage in collaborative and self-directed learning — may pose challenges when transferred to non-technical students. [27] also described their one-day workshop organised for high-school students, designed without the expectation of prior knowledge. The workshop utilised various interactive learning methods, including games, unplugged activities, practice sheets, and programming exercises to teach basic quantum principles. Finally, [27] shared that a successful QC workshop requires diverse participants in terms of age and activities that foster interaction among the participants. Another lesson learned from the authors is the need for props and handouts. While this approach shows promise, its theoretical focus may not align well with the needs of business students, lacking consideration of financial aspects and real-world applications in business contexts.

### *2.3. Quantum Computing Education for Business Students*

During our search for existing QC courses suitable for business students, we found a notable absence of institutions offering QC as a dedicated course tailored to a business audience. This observation is further corroborated by the study conducted by [28], which surveyed educational initiatives contributing to the development of a quantum workforce. Their listing of university programs consists of institutions in technical fields such as physics or engineering. However, we identified short-term QC courses tailored to beginners, students, and business professionals on platforms such as LinkedIn Learning and Udemy. For instance, the course on LinkedIn Learning introduces QC, classical computing, and explores applications in QC, as well as associated risks and opportunities [29]. Similarly, the Udemy course covers foundational concepts such as QC basics, vector and matrix quantum states, qubits, and logic gates [30]. In addition, MIT xPRO offers a course aimed at beginners and business professionals, introducing them to QC fundamentals, as well as quantum algorithms relevant to cybersecurity, chemistry, and optimization [31]. Furthermore, there is a beginner-level course on Coursera tailored to students with some background in linear algebra, probability theory, and information theory [32].

A common feature among these online courses is the use of videos and practical exercises to enhance understanding. Additionally, organizations such as IBM and CERN provide online materials, including case studies and lectures on QC tailored for business professionals, students, and technology enthusiasts [33] [34].

While business students, particularly those at the undergraduate level have limited QC course offers in HEIs, there are advanced level courses on QC tailored towards engineering students or those with a science background in general in institutions like ETH [35] and Constructor Institute [36]. These courses are tailored towards master’s students [36] or students with a bachelor’s in electrical engineering or physics.

### 2.4 *Barriers Hindering the Implementation of Quantum Computing*

In the realm of education, particularly for students from non-science backgrounds, one significant obstacle hindering the teaching of QC is the inherent complexity of the subject [37]. Mastery of QC demands a multidisciplinary understanding encompassing chemistry, quantum physics, mathematics, and a high level of problem-solving proficiency. [19] further underscored the challenges in integrating quantum computing into engineering education, citing the lack of well-established knowledge, skills, and use cases associated with the technology. Moreover, this knowledge, skills, and use cases are subject to rapid evolution, compounding the barrier to adoption. To design a curriculum conducive to QC learning, [38] acknowledged that the absence of a strong physics background often dissuades computer science and students from other disciplines. Lastly, when examining the difficulties educational institutions encounter in incorporating rapidly changing technologies into business curricula, [39] identified several key elements. Time constraints pose a significant challenge, as institutions struggle to allocate adequate time to cover both the practical and theoretical aspects of emerging technologies within their syllabi. Additionally, the diverse array of technologies tailored to specific industries and organizations complicates the implementation of a particular emerging technology in business curricula.

In the realm of business, [40] delineated the barriers to the adoption of quantum computing within the software industry, spanning institutional, managerial, organisational, and technological levels. The study underscored the lack of technical expertise, limited understanding of market demands for quantum applications, and the scarcity of engineering talent as prominent impediments. Similarly, [41] revealed skill gap as a challenge of adopting quantum computing in business. The technology demands a blend of skills from physics, computer science, and mathematics. Another challenge highlighted by [41] is the difficulty in transitioning from quantum to classical systems after achieving a superior quantum solution, as most businesses predominantly utilise classical systems. This underscores the necessity for quantum-classical algorithms, facilitating computation to occur partially in both quantum and classical realms. Furthermore, technological immaturity presents a significant barrier, with quantum technology still in its nascent stage relative to classical computing. Even advanced quantum computers, such as Noisy Intermediate-Scale Quantum (NISQ) devices, are susceptible to errors due to inherent noise within the systems. Additionally, quantum computers necessitate new algorithms and programming paradigms distinct from those used in classical computing. Considering the future trajectory of QC, [42] identified key factors such as the absence of a coherent business strategy and an ecosystem for co-creation as barriers to adoption within businesses. The absence of a well-defined business strategy impedes organisations from creating commercially viable QC solutions, exacerbating business reluctance. The concept of co-creation underscores the necessity for a network of collaborative partners to foster application and hardware development in quantum computing. While such an ecosystem may expedite time-to-market, mitigate risks, and augment revenue, maintaining it poses long-term challenges. Additionally, unsupportive organisational structures, characterised by a lack of top management support, further hinder QC adoption, as outlined by [42].

## 3. Flanking Exploratory Study

In this section, we delineate the methodology and outcomes of a small-scale exploratory study undertaken at the FHNW School of Business, administered as an online survey. The primary objective of the survey was to identify a potential optimal course design, identify areas of interest, elucidate expectations, and gauge the level of interest among business students regarding a QC course.

### *3.1 Survey Methodology*

To gather preliminary insights complementing our research, we aimed for a minimum of 50 survey participants. The sample comprised bachelor-level business students at the FHNW Business School. Utilizing the survey program provider Tivian [43], we designed the survey in English and distributed it via email to the students. The survey remained accessible for over 8 weeks during the winter of 2023. Comprising seven sections, the survey covered the following areas: 1) Demographics, 2) Prior knowledge of quantum computing, 3) Interest in a potential quantum computing course, 4) Preferred course style, 5) Perception of quantum computing's relevance, 6) Preferred communication channels, and 7) Contact information. The survey included an introduction and conclusion, with eight questions being mandatory out of a total of 17. Despite the survey's limited outreach and duration, the results yielded preliminary insights, augmenting the findings from our literature review.

### *3.2 Survey Results*

The surveyed cohort of business students encompassed 652 participants, with 78 individuals completing the survey, equating to a 12% completion rate. Among the respondents, the largest proportion hailed from the Business Administration program (55%), followed by Business Information Technology (29%), International Business Management (12%), and other fields. Notably, most respondents were enrolled in part-time study programs (63%). A considerable 68% of respondents indicated a lack of prior knowledge regarding QC. In alignment with this finding, 60% expressed uncertainty regarding the importance of QC to them, while one-third considered it important. Regarding other areas of expertise, respondents rated their proficiency in computer science and mathematics as basic. In terms of physics knowledge, respondents were primarily split between having no knowledge and possessing a basic understanding. Nonetheless, 67% of respondents expressed interest in learning more about QC, with the highest interest observed in gaining a general overview of the subject and understanding its applications in businesses. Regarding preferred learning styles, practical exercises or laboratory sessions were favoured, with group work being the least preferred. A hybrid learning approach combining both on-site and online classes emerged as the preferred mode of instruction. When it comes to assessment methods, presentations and exercises were preferred over written exams. Additionally, email was the preferred channel for staying informed. In summary, students at the FHNW School of Business demonstrate an interest in learning about QC and perceive the topic as important, despite the majority lacking prior knowledge in the field. This study underscores that QC remains an emerging technology that has yet to effectively reach its target audience.

## 4. Discussion and Practical Recommendations

Our research underscores the significance of QC within the business landscape. The substantial investments pouring into QC-oriented startups reflect the optimism among investors regarding the technology's future returns. Nevertheless, our findings also shed light on the challenges impeding the swift adoption of QC by businesses. A significant challenge is the shortage of skilled talents in the field. The multidisciplinary nature of QC necessitates expertise in physics, computer science, and mathematics, posing difficulties for businesses in acquiring the requisite talent. Moreover, the current stage of QC, where the transition from quantum to classical systems remains unclear, alongside the absence of a defined business model, contributes to the hesitancy surrounding QC adoption.

Some of the barriers to QC adoption in the business realm are intertwined with challenges within the educational sector. The prerequisite knowledge in chemistry, physics, and mathematics may deter students, particularly those with backgrounds predominantly in business or economics. Furthermore, institutions may face budget constraints hindering their ability to hire experts capable of teaching QC to business students. [19] noted a dearth of well-established skills and use cases, partly attributable to the nascent stage of the technology and its limited application in business contexts, further complicating QC education within business schools.

Despite these challenges, it is imperative to introduce business students to the realm of QC to expedite its adoption in businesses. In the absence of QC courses within institutions, educators can encourage students to enrol in online courses offered by platforms like Udemy and LinkedIn Learning tailored for beginners. These courses offer accessible entry points for business students to grasp QC fundamentals, enabling them to contribute to developing suitable business models and making informed investment decisions.

To enhance QC accessibility for business students, we advocate for a curriculum that transcends technical basics, focusing instead on practical application cases and socio-cultural implications as advocated by [18] and [19]. Relating concepts to everyday events can heighten student engagement. Additionally, organising QC courses as short-term workshops with diverse participants and interactive sessions can sustain student interest, as lengthy, complex courses may deter participation. Finally, businesses should leverage collaborations with scientific sectors to foster QC development and expedite technology adoption.

## 5. Conclusion, Limitations, and Areas for Further Research

By synthesising pertinent literature, our study has illuminated various applications of QC within both the business realm and educational settings. Through our findings, we have elucidated the barriers hindering the integration of QC into business education and its adoption by businesses at large. To surmount these obstacles, we advocate for HEIs to incorporate QC into their business curricula, providing students with foundational knowledge that empowers them to develop QC-centric business models and make informed investment decisions. Our research contributes to the ongoing discourse surrounding QC's applications in both the business domain and educational institutions, with a particular focus on business schools — an area that has received limited attention in existing literature.

Despite the value of our contributions, it's essential to acknowledge the limitations of our study, primarily rooted in its reliance on secondary data and a small-scale survey. There remains a pressing need for more extensive investigations into the integration of QC within business school curricula. Future research endeavours should delve deeper into this domain, conducting thorough examinations of how and to what extent QC is integrated into business education programs.

Moreover, we recommend that subsequent research endeavours incorporate interviews with QC experts. Such interviews would serve to highlight optimal methodologies for introducing QC courses to business students, as well as identifying key areas of focus within these educational initiatives. By leveraging qualitative insights from experts in the field, future studies can enrich our understanding and inform best practices for integrating QC education into business curricula.

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