# Quantum technology impact: the necessary workforce for developing quantum software

Guido Peterssen 1,2

<sup>1</sup> aQuantum by Alhambra, Madrid, 28037, Spain <sup>2</sup> Alhambra-Eidos, Madrid, 28037, Spain guido.peterssen@a-e.es

**Abstract.** Quantum computing started recently from a historical point of view. This paper addresses the how quantum technology has impacted and will impact in society and, in particular, in quantum industry and academia. This study analyzes the necessary workforce for developing quantum software.

Keywords: Quantum Technology; development workforce; quantum software.

#### **1** Introduction

Quantum computing started recently from a historical point of view: 47 years ago if, as some do, we take as a reference the publishing of the article "Bounds for the Quantity of Information Transmitted by a Quantum Communication Channel" by the Mathematician Alexander Holevo [1] or 40 years ago if, as more frequently is done, we take as a reference the publishing of the article "The Computer as a Physical System: A Microscopic Quantum Mechanical Hamiltonian Model of Computers as Represented by Turing Machines" by the Physicist Paul Benioff [2]. Earlier or later, four decades of quantum computing progress in which we can initially highlight, in addition to those already mentioned, a handful of scientists: Charles Bennett (Physicist), Richard Feynman (Physicist), David Deutsch (Physicist), Peter Shor (Mathematician), Lov Grover (Computing scientist), etc.

Of those four decades, more than three have been practically exclusively dedicated to the search for solutions in laboratories, activities in which the majority of worldwide quantum science is still immerse. There have been very good even surprising results and, fruit of that activity, up to the date different types of quantum computers have been defined, of quantum computer models and of physical systems to create qubits.

Among the types of quantum computers, which differ in processing power (quantity of qubits), we can highlight the following between what in one way or another limits the type of applications that can be implemented in the same:

- Quantum Annealing
- Simulation or Analog Machines
- General o Universal Quantum Computers

Copyright © 2020 for this paper by its authors. Use permitted under Creative Commons License Attribution 4.0 International (CC BY 4.0).

Also, several models of quantum computers have been created, among these the main ones are:

- Quantum gate array
- One-way quantum computer
- · Adiabatic quantum computer, based on quantum annealing
- Topological quantum computer

And the following stand out among the many physical systems created to generate qubits:

- Superconducting quantum computing
- Trapped ion quantum computer
- Nuclear magnetic resonance quantum computer
- Diamond-based quantum computer
- Linear optical quantum computer
- Cavity quantum electrodynamics (CQED)
- Fullerene-based ESR quantum computer Optical lattices
- Quantum dot computer
- Bose-Einstein condensate-based quantum computer

For now, all the previously listed elements (and some others not included due to being less relevant or representative) show in laboratories (and very few in commercial inclusion), their worth as quantum technology, which manifests a not only very complex technological panorama due to the scientific and technical specifities of each one but also due to the variety of combinations that can be registered among them to allow a specific quantum computer. As if all this was not complex enough, technological research and development, throughout the years, has taken place in knowledge areas which are new for humanity.

In this sense Jeremy Hilton, D-Wave's Senior Vice President of Systems, with two decades of experience developing quantum, computing systems, summarises very well the previously mentioned system. "Since when Richard Feynman initially developed a practical quantum computer in 1982, the field has been marked by great diversity of opinions about hardware approaches, scientific theory, and the best way towards commercialisation and more. But one problem has united all: the lack of talent in quantum computing" [3].

If we consider that, of these four decades of quantum trajectory, more than three have been dedicated, above all, to laboratory research and activity, using for that a very limited qualified and usually previously not specialised workforce (this latter has characterised at all times the recent history of quantum computing), is surprisingly the progress achieved by quantum computing and the achievements up to the date.

Even more surprising is that, based on that state for the art, in 2011 the first commercial quantum computer made its worldwide appearance: D-Wave One de 128 qubits, sold to Lockheed Martin of Maryland, United States [4]. Only later, the sum of that sale was made public: about 10 million US dollars. Curiously, at the time of this sale, some 60 scientists and engineers worked in D-Wave, of which some 20 worked on the development of algorithms and 40 on the construction of hardware and, according to the same source, the research that gave way to that model of 128 qubits was conducted by 25 of the D-Wave employees together with researchers from the Agder University in Norway and the Simon Fraser University in Canada [5]. A small team, collaboration with other entities and countries for quantum development, an advance of the production organisation management that now is something quite frequent.

## 2 Quantum research in the world

Research in quantum computing is still, for now, the most outstanding activity in the quantum field, and therefore concentrates most of the quantum workforce round the world and is where the incipient quantum workforce is more active.

Another of the relevant characteristics of the second quantum revolution is its marked international character, something that is fully manifest in the research field.

The quantum career is not limited, not even remotely, to the business world, it also concerns countries (read States) among which we can highlight, due to volume of investments and results obtained, the United States, China, European Union, Russia, Canada, Japan, and others.

The geographic map of the worldwide quantum research activity (see Fig. 1) shows its elevated concentration (numbers of persons and monetary quantities are not mentioned on the map, only the R&D activity), in the United States, Canada, Europe, Australia, Japan, China, and Russia [6]:



Fig. 1. Geographic map of the worldwide quantum research activity

I believe it is important to highlight that the level of activity represented by the map musty not necessarily be identified (it only indicates the location of the research organisations) with the level of leadership among other countries in worldwide quantum computing and, even less, with the scientific and technological branches in which there are clear advantages for one country or the other.

An example of that previously mentioned is China, with a discreet quantity of locations on the map, it is among the world leaders in quantum R&D investments [7], in results applied to communications, quantum computing and metrology, and also in the registry of patents related to quantum computing [8], only exceeded in this latter by the United States.

Another case in this sense is Russia, country in which, although only 2 locations in its extensive territory appear, it has a National Digital Economy Programme (known as Quantum technologies Route Map), with a budget for quantum technology projects for the next 5 years around one thousand million Euros [9].

Special attention should be paid in the coming years to the results of India in quantum research: National Mission on Quantum Technologies & Applications (NM-QTA) [10]. This country, which has enormous potential in physicists, mathematicians, computer engineers, has just announced an ambitious quantum R&D project with a budget of over one billion dollars. With this project, India joins the select group of countries or regions of the world with quantum research investments of more than one billion dollars to be executed in the next five years: the United States, the European Union, Russia and China.

Something similar occurs in Universities related to quantum computing research. At the time of writing this document I detected 130 universities with activity related in this field of the world distributed as follows:

- 115 according to this type of universities from the *Quantum Computing Report* [11], of which 102 are concentrated in: United States (46), European Union (24), United Kingdom (10), Canada (9), Japan (7) and Australia (6).
- 10 Russian universities [12], not one, as indicated by the *Quantum Computing Report* list and, therefore, this could mean some more centres more than those shown by the map).
- 4 Chinese universities [13], three more than those indicated by the previously mentioned list.
- 4 Spanish universities, one more than the 3 on the Report list, the Castilla La Mancha University (UCLM), the only one in Spain researching in the field of Software Engineering and Quantum Programming.

According to *The Quantum Daily* [14], the most outstanding 12 universities of the world in 2019, considering the criterion of their leadership in quantum computing research, were as follows:

- The Institute for Quantum Computing University of Waterloo
- University of Oxford
- MIT Centre for Theoretical Physics

- National University of Singapore and Nanyang Technological University Centre for Quantum Technologies
- University of California Berkeley
- University of Maryland Joint Quantum Institute
- University of Science and Technology of China (USTC) Division of Quantum Physics and Quantum Information
- University of Chicago Chicago Quantum Exchange (CQE)
- University of Sydney Australia
- Quantum Applications and Research Laboratory at LMU Munich (QAR-Lab)
- University of Innsbruck Quantum Information & Computation

In my opinion that list must include, among others, two European universities with relevant results in this field:

- Delft University of Technology
- Aalto University Quantum Computing and Devices (QCD)

We can see from the previous lists that globally the proposal is extensive, and it is, quantum activity is continuously increasing, and global universities are always being incorporated to scientific research. In most cases the focus, the fundamental objective of the research and, therefore, the academic proposal, is aimed at quantum computing and algorithmics.

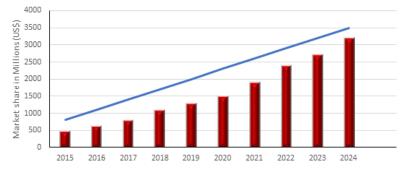
For the moment the academic offer, above all, is focussed on very important, low level quantum hardware and software, necessary for the development of quantum computing. Although, without doubt even though considering this to be logical, it is also logical to think that in the short term the academic training offer must be extended to applied sciences to satisfy the growing demand for quantum workforce of the emerging quantum industry.

Also, it is very curious that among these 130 universities, only the Castilla La Mancha University has publicly declared a clear specialisation in the research for quantum programming and software.

#### **3** The workforce needed by the quantum industry

As I have previously highlighted, all that achieved in those four decades in the evolution and development of quantum computing has been done by a limited, very limited, quantity and variety of quantum workforce: first as a result of the activity of that handful of scientists and engineers that, progressively grew to consist of some decades later by a few hundred scientists and engineers and currently by a few thousand distributed around the world [15].

The results accumulated over such a short period of historic time are so surprisingly good, that today they allow projecting a significant growth of the quantum market for the coming years, something nearly unimaginable only five years ago. As can be seen in the following graphs (see Fig. 2), the economic previsions of the quantum market for



the coming years are really good, with an excellent estimation of sustained growth for a decade.

Fig. 2. Quantum technology market evolution [16].

Another interesting detail of this quantum market growth provision is the role that quantum services (QCaaS) has in the same, which in my opinion, means the existence of a market for solutions and practical applications that recently is beginning to take its first steps (see Fig. 3).

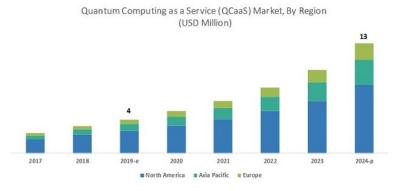


Fig. 3. Quantum computing as a service evolution

Without the intention of questioning the value of these growth projections (nothing further away from my imagination), I do believe we must give attention to the following: these predictions will only be reasonably materialised if they are urgently and creatively resolved, one of the main obstacles which have affected the emerging quantum industry: availability of qualified and trained workforce in the quantum employment market.

The limited quantity of workforce that has made quantum computing possible, as we know it now, is surprisingly small. This data that on one side shows the greatness of the work done and glorifies the actors because of the enormous and unquestionable results achieved, has a less attractive face: confirming the extreme, and critical lack of

the quantum workforce required for the growth or research and, even as more worrying or more than this, is that with that lack of quantum workforce the estimated growth of the quantum industry is not viable. Therefore, as we will see later, this is one of the most pressing problems to be approached by those committed to the quantum industry as a motor for the growth of economies.

Development of the quantum industry not only requires the indispensable physicists and mathematicians, it also demands a growing number and variety of scientists, engineers, and specialists in the multiple fields of indispensable sciences and technologies, both for research and development and for the emerging quantum industry. The great problem is that, increasingly, types of specialists with knowledge and skills that are yet to be created are in demand.

The rupture between the offer and demand of quantum workforce, that currently is disproportionate and chronic, in my opinion manifests the embryonic state of the employment market of the quantum industry. And this is so even in the select group of countries leading the second quantum revolution. To talk of a true quantum workforce market first the quantum workforce mut be created, that needed by the quantum industry.

In this state of the quantum workforce, there is fierce competition due to the great lack of quantum workforce with skills, both at national level as international level. And, even including the total current number of the qualified quantum workforce in the world is still insufficient.

In this context there is something positive to be highlighted: the maturity state of quantum technologies and the lack of specialised work force, in some measure, has stimulated an unusual collaborative attitude among institutions, companies and even countries, to accelerate results sharing efforts.

A couple of manifest examples of the tendency to quantum collaboration among companies are:

- *Partner with IBM Quantum* [17]. Global community of visionary companies, academic institutions, start-ups and national research laboratories working together to advance in quantum computing.
- *Microsoft Quantum Network* [18]. Community of pioneers collaborating with Microsoft to learn, research and launch quantum computing applications and hardware.

Beyond the attractive way of declaring the collaboration objective, at least outside of the United States that is the experience to make this comment, the requests for adhesion to those networks are not rapidly attended to, therefore one has to insist to achieve it.

In the case of international collaboration, the recent *Tokyo Statement on Quantum Cooperation* signed between Japan and the United States kin which this question is explicitly declared, is a good example: "The declaration encourages greater participation in Quantum Information Science and Technology (QIST) through conferences and international events; supporting the cooperative efforts to prepare the next generation of QIST scientists and engineers; and promoting the interchange of research methodologies, infrastructure and data" [19].

### 4 Needs of the quantum workforce

Working in quantum computing requires knowing, understanding and knowing how to apply the basic principles of physics, mathematics, algebra and other sciences that, until now, the educational community has been teaching us for a binary application, not a quantum one.

Without doubt this focus must change because, otherwise, having a quantum workforce in the future will be very difficult if, from average teaching, or even before, teaching is given with a traditional viewpoint (classic, binary), not quantum, of application of physics, mathematics, algebra, ,,, life analysis.

Of course, in no case, does this mean that initially we pretend to convert society into a nursery of quantum physicists, mathematicians, etc. What it means is that from now on, teaching methods or subjects that until now have been used are changed, above all, from a theoretical point of view, and must be rethought for the quantum interpretation of life. Therefore, paraphrasing the famous words of Richard Feynman: "*iNature is quantum, damn it! So, if we want...*" quantumly understand it, we need a different basic education that prepares us for quantum computing.

Due to the above, preparation of the necessary workforce for developing the quantum industry must cover, pre-university education, engineering, software programming and a long list of sciences. This change in the educational model is essential so the students can reach universities with the domain of the necessary principles to study the required quantum careers, and which the world of quantum work will increasingly demand.

We are faced with one of the scientific advances and the most disruptive modern technology, where everything is presented as new, not only because it is, but also because all must be analysed from a perspective that until recently was simply a theory for a few experts.

Quantum computing, something in advance of prognostic studies and previsions, is here and therefore we have realised that we do not have the knowledge or reasonable skills to approach it on a social scale. Now it is about starting to apply quantum computing to the daily routine, but mainly humanity does not how to approach this task, how to interpret it because, dude to its newness, we are in the condition *of quantum illiteracy*. This the current situation, the greater part of the second quantum revolution for the debut, in the market of quantum computing. Therefore, there is no time to lose to start educating the future quantum workforce.

To start working to educate the future quantum workforce there is one very serious problem: the level of quantum illiteracy is so great that there not enough professors to teach it. Therefore, educating quantum teachers is a strategic task in this complex situation.

Current concern for the development of quantum workforce is such, that its starts to appear among the important elements for analysing the risks of the emerging quantum industry, as indicated in the *Quantum Computing Report*: "There are non-technical factors which we will hear more of in 2020. There is constant concern that we are not a quantically qualified workforce as quickly as we should. Measures are being taken to

improve educational programmes and training, but it is not clear that this is enough" [20].

In countries where the adoption of quantum computing is most advanced (United States, Canada, Germany, France, United Kingdom, Netherlands, Russia, China, South Korea and Japan [21]), the States have become aware of the criticalness of the quantum workforce employment market and are developing national programmes that included strategies for the training of the quantum workforce at a forced rate. Among them, there are some programmes worth highlighting and, in order to not spending too much time, I limit this to the cases of the United States and the Netherlands.

The United States government has defined a notional quantum project for worldwide quantum leadership through its National Quantum Initiative, NQI [22], that in the coming years will provide 1.2 million dollars, mainly for quantum research. Among other objectives of this initiative, is the *creation of an intelligent quantum workforce for to-morrow*, through this ambitious action plan:

- Encourage the industry and academical institution to create convergent and transsectoral approaches for the development of a diverse quantum workforce.
- Use and improve the existing programmes to increase the quantum workforce.
- Encourage academical institutions to consider quantum science and engineering as a different discipline, with the need of new teachers, programmes, and initiatives.
- Approach education in the quantum science field from an early stage, including the level of primary, intermediary and secondary education.
- Reach an increasingly greater public, working with the agencies and industry involved to increase their investments, together with innovative or non-conventional approaches.
- Encourage the quantum community to trace and estimate the future needs of the quantum industry workforce.

To create the quantum workforce needed by the employment market in the United States, the National Quantum Initiative considers that profound changes must occur in the educational system and, therefore, proposes the association of government agencies, industry and institutions.

This revolutionary view considers that basic research is the main mechanism to generate a QIS (Quantum Information Science) qualified workforce and, therefore, the focus of research in training is essential for the success of the initiative, which also considers transforming the primary and secondary education programmes as necessary to stimulate interest in scientific, computer technology, and physics thinking from those educational stages.

The objectives are enormous and the task for reaching them are titanic, because they aim at transforming cultural aspects of society. Therefore, the Initiative considers the creation of the U.S. Quantum Consortium between industry, academical institutions and Government (see following diagram) to prognosticate and establish consensus about the needs and the obstacles, coordinate efforts in the precompetitive research, approach concerns about intellectual property and rationalise technology transfer mechanisms (see Fig. 4).

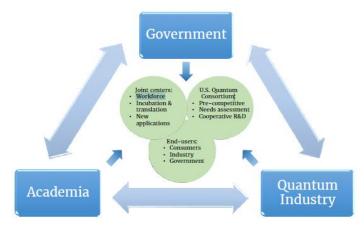


Fig. 4. Actors in the Quantum Technology context

Undoubtedly it will be very interesting to observe, over the coming years, the evolution of the execution of the tasks provided for in the Initiative. We will be seeing the results through the media and detailed studies, after consolidating some processes and data, this will not take long.

In the case of the Netherlands the national quantum programme has defined through the National Agenda For Quantum Technology [23], that has a budget of 102 million Euros per year, and which, in my opinion, is the most advanced plan of Europe to prepare the future quantum workforce because, to achieve it, it also proposes inculcating society with quantum culture, something necessary to create a sustainable quantum workforce, strong in quality and sustainable in quantity.

This mega project, harmoniously developed with European quantum programmes in which it participates (in many of the case as leaders), consists of three ambitious unifying catalysing programmes (referred to as CAT from National Catalyst Programmes), and four main lines of action with a clearly defined objective: to position the Netherlands over the coming years as a worldwide centre for quantum research and development, thanks to which it will become the worldwide leader of quantum technologies. And, to achieve that, also 2 lines dedicated to preparing society to create the quantum workforce have been defined (see Fig. 5):

Action line 3 | Human capital: education, knowledge and abilities.

- Strengthening of education, collaboration and interchange of knowledge.
- Attraction and retention of talent form the Netherlands and other countries.
- Community construction, conferences, summer schools and interchange of students.

Action line 4 | Promotion of social dialogue about quantum technology.

- Initiation of dialogue (international) about quantum technology.
- Training of a national ELSA (Ethical, Legal and Social Aspects) committee and professors.
- Development of legal and ethical frameworks for quantum technology.

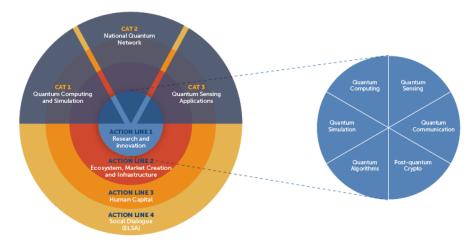


Fig. 5. Action lines in quantum workforce

I believe it is important to highlight that the United States and the Netherlands programmes, despite the evident differences because of the obvious social-cultural differences, share the view, firstly, from the complexity of creating a sustainable quantum workforce and, secondly that the quantum industry future necessarily requires a quantum culture to analyse life and its processes, for which, a change of conception in teaching and coordinated and active participation of society is essential.

In both cases, the solution for creation of a solvent and sustainable quantum workforce is evident and requires starting the teaching from early ages, to change the ways of learning and applying education to all stratum of society, to guarantee a worldwide leadership position in quantum science and industry.

I consider that this multilateral and cultural view is equally valid to approach the very complex task of creating the quantum workforce, and that both can be useful for extending, after adaptation (never as a simple copy), to many other places in the world. Duly applied to socio-cultural, economic, and technological realities, this can be a good pattern for those who still cannot visualise quantum industry being able to do so because of having a national potential for that), and strategically for a new type of social and economic growth.

Although I will not go into detail, due to the so radically different views and realities of China and Russia to approach the preparation of the quantum workforce, because of the importance of these two countries in the worldwide quantum map I believe making some references to their methods of approaching this problematic is opportune.

China, started to work on large-scale quantum projects in the eleventh "Five Year Plan", that is to say, from 2006 to 2010, with a budget of 150 million dollars [24]. The results of the research in quantum communities stimulated to continue with the effort, therefore support to quantum research was strengthened in the twelfth "Five Year Plan", that is to say, from 2011 to 2015. As in other "quantum" countries, the increase of the budget collided with the limited available quantum workforce, with the aggravation that the language and State policies conditioned the search for solutions to within

the country. The solution to the problem they approached was created, in the Mediumand Long-Term National Talent Development Plan framework of the Chinese government (2010-2020). This plan contemplated a national training strategy to develop quantum talent and, simultaneously, they created special conditions to attract those Chinese quantum scientists that, if they wanted to, could return from abroad. The training program is still being conducted and as part of the national quantum strategy, they are working to inaugurate this year the largest quantum research laboratory of the world (the National Quantum Information Science Laboratory, near Hefei), at an estimated cost of 10 thousand million dollars.

This way China has overcome up to now, apparently successfully, the precarity of its quantum employment market, but sincerely I doubt that this experience is extendable to the other countries in the world.

As previously explained, Russia also has its programme for quantum computing, the Quantum Technologies Route Map, with a budgetary provision for five years (already underway) similar to that of the United States Quantum Initiative or the European Quantum Flagship, that includes a large and growing network of research centres and universities.

To resolve the limitations of the quantum workforce Russia is committed, above all, to training young quantum researchers in both public and private centres. A good example of those is the Russian Quantum Centre (RQC), a private research group with the intention of competing with Google, IBM and Microsoft in the global search for a quantum computer. Since its creation in 2010, it has rapidly expanded and in 2019 it had about 200 employees with an average age of 34 [25]. Russia has a great diaspora of quantum scientists, but it does not have, at the moment, a programme for stimulating the return of quantum specialists.

In my opinion, the model could be viable to satisfy the needs of the quantum workforce in Russia, but this model is not extendable to other countries.

Unlike other European countries, Spain does not have a national quantum programme, and therefore there are no official programmes for the preparation of a quantum workforce. This situation is not conditioned by the fact that there is no national quantum potential (with enough activity especially in Barcelona) which, basically, is channelled through:

- Participation, above all of research and academic centres, in European research projects.
- Quantum talent with great potential. The country has a significant quantity of quantum physicists, although it is also true that in this sense, we have a large diaspora distributed around the world in relevant quantum centres and companies.
- The activity conducted by some transnational companies on the national scene (IBM, Microsoft, Atos, others)
- The most important banks of the country have started to conduct their own research activities applied to their financial activity.
- Over the last years a group of national and foreign companies dedicated to research, development, and services in the quantum fields have appeared.

- The number of centres, research groups and universities dedicated to quantum technologies continues to grow.
- Although limited, there is a training offer for quantum computing and quantum software programming in universities and some IT training companies.

# 5 The workforce specialised in quantum programming and software engineering

The development of the quantum industry would not have any future if it only depended on quantum scientists and physicists, like the classic computer technology industry would not have had any future if it had only depended on cybernetic engineers. Like what happened with classic computers, the software engineers and programmers interacting with users and the market are those that, mainly, will finally define how and for what quantum computers will be used to develop practical applications that contribute to the same, firstly usefulness and, progressively, universality.

But, to achieve the critical mass of software applications for end users that increases the growth of the quantum industry, much commercial software will have to be produced, necessarily needing an "army" of quantum programmers and software engineers that does not currently exist.

As all that has to do with quantum computing, the initial complexity stems from that we are faced with a new technological and programming paradigm, for which necessarily we have to approach, right now, the preparation of quantum programmers and software engineers.

Like what has occurred with the technology of quantum computers, in the scope of quantum software development there is wide range of programming languages (*QCL; Quantum pseudocode; Q/SI>; Q language; qGCL; QMASM; QFC y QPL; QML; LIQUi/>; Quantum lambda calculi; Quipper; PyQuil, Q# and others)*.

Also the quantity of development environments for quantum programming is varied (normally very linked to the types of quantum computers), that are usually presented as SDKs with access to quantum processors (*Ocean , ProjectQ; Qiskit; Forest; t/ket>*), SDKs based on quantum simulators (*Cirq; Strawberry Fields, Microsoft Quantum Development Kit*), or SDKs with access to quantum simulators and hardware (*t/ket>*) [26].

Evidently there are not only languages and environments to programme quantum software, but that also allow us to select among such a varied range. But, as we know, only having languages, development environments and even free or very economic access for tests and practice with quantum computers is not enough to produce quality software for quantum computers: the new programming paradigm also has to be known and understood.

The radical change in the way of visualising and working of quantum software is meridionally expressed by Will Knight when he refers to the differences between classic and quantum programming: "quantum computers not only require different programming languages, they also need a different approximation to the concept of programming" [27].

As if the change of paradigm was not enough, the quality software required by the quantum industry also requires a new methodological and technological environment, typical of *Quantum Programming and Software Engineering*, which allows visualising, estimating, designing, developing, and maintaining quantum software solutions with the guarantees that the architecture, development, security, scalability, and quality of the same is equivalent to that offered by good classic software.

The quantum industry cannot expect to conduct the cultural transformation of companies to assume the quantum complexities like what occurs with the applications of the classic or binary environments. The urgency for growth requires some accelerators in the preparation of the quantum workforce and one of them could be the training of engineers and programmers as specialists in Quantum Programming and Software.

Universities and IT training centres must take the initiative and improve their quantum software programming courses for the production of commercial software. Training in quantum software programming is beginning to appear in the offer of some universities, some of them independently, others in collaboration with large manufacturers.

One of the cases of this type of collaboration that has been divulged by the media is that of Washington University with Microsoft to give an introductory course about quantum computing and programming. The course, directed by Dr. Krysta Svore, General Manager of Microsoft Quantum Systems, was focussed on the practical implementation of quantum algorithms and programming with Q#. After this experience, Microsoft has established curricular associations with more than 10 institutions around the world with the object of advancing in the closing of gap of abilities in the development of quantum software and the design of quantum algorithms [28].

The participation of Microsoft in those collaborations is coherent with the analysis that the company has been divulging about the need of quantum workforce and the need for training the same. Krysta Svore has been warning and divulging in the media about the challenges and opportunities that the engineers and programmers that want to enter the quantum industry have: "quantum computer technology will open a completely new economy and will need persons that are quantum programmers, developers and algorithm engineers" [29].

The increase of training offer in Software Engineering and Quantum Programming is essential and will be determinant for, in the short term, starting to increase the critical mass of quantum programmers that will be demanded by the quantum workforce. In this sense I consider the work being done by the Castilla La Mancha University in this matter is outstanding.

#### 6 Conclusions

Quantum computing represents a new paradigm for software programming. The rapid irruption of quantum computing has revealed, on worldwide level, a large-scale problem for successfully approaching it. *quantum illiteracy*.

*Quantum literacy*, a process in which some countries around the world is currently involved, requires strategic programmes and creative action plans to revert the situation

as soon as possible, which will allow to increase the workforce that is demanded and will be increasingly demanded by the emerging quantum industry.

From the software programming perspective, in quantum programming all is new and, although already having quantum hardware, quantum programming languages and development environments, quantum illiteracy limits to insignificant figures the quantity of engineers and quantum software programmers to work with all those tools.

Research in the new quantum methodological and technological environment, typical of Software Engineering and Programming, is determinant to produce quality quantum software.

Training of engineers and quantum programmers must be urgently approached by manufacturers, universities, and technical teaching to provide the quantum employment market with the essential qualified workforce.

The development of a sustainable quantum employment market depends on the capacity for cultural transformation of society that are in condition of understanding, approaching, and dominating the quantum complexities as a result of any other training and teaching process.

#### References

- 1. Холево, А.С., Некоторые оценки для количества информации, передаваемого квантовым каналом связи Пробл. передачи информ., 1973, том 9, выпуск 3, 3–11
- Benioff, Paul. The Computer as a Physical System: A Microscopic Quantum Mechanical Hamiltonian Model of Computers as Represented by Turing Machines" by the Physicist Paul Benioff. 22, No. 5, 1980
- Hilton, Jeremy. Building The Quantum Workforce Of The Future. Forbes Technology Council. June 19, 2019. https://www.forbes.com/sites/forbestechcouncil/2019/06/19/building-the-quantum-workforce-of-the-future/#3daf7d26fa47
- D-Wave Systems sells its first Quantum Computing System to Lockheed Martin Corporation https://www.dwavesys.com/news/d-wave-systems-sells-its-first-quantum-computingsystem-lockheed-martin-corporation
- Johnston, Hamish. Quantum-computing firm opens the box. May 12, 2011. https://physicsworld.com/a/quantum-computing-firm-opens-the-box/
- 6. World Map of Quantum Activity, Quantum Computing Report, September 3, 2019, https://quantumcomputingreport.com/our-take/world-map-of-quantum-activity/
- Qiang Zhang, Feihu Xu, Li, Nai-Le Liu and Jian-Wei Pan. Quantum information research in China. Quantum Science and Technology, IOP Publishing, 8 November 2019, https://iopscience.iop.org/article/10.1088/2058-9565/ab4bea
- Number of quantum computing patent applications worldwide from 1999 to 2017, by country/geography, Statista, Technology & Telecommunications, Hardware, https://www.statista.com/statistics/948019/quantum-computing-patent-applications-by-country/
- Fedorov, AK., Akimov, AV., Biamonte, JD., Kavokin. AV., Ya Khalili, F., Kiktenko, EO., Kolachevsky, NN., Kurochkin, YV., Lvovsky, AI., Rubtsov, AN, Shlyapnikov, GV., Straupe, S., Ustinov, AV. And Zheltikov, AM. Quan-tum technologies in Russia. Quantum Science and Technology, page 3, IOP Publishing, 16 October 2019, https://iopscience.iop.org/article/10.1088/2058-9565/ab4472

- Budget 2020 announces Rs 8000 cr National Mission on Quantum Technologies & Applications. https://dst.gov.in/budget-2020-announces-rs-8000-cr-national-mission-quantumtechnologies-applications
- 11. Universities, https://quantumcomputingreport.com/players/universities/
- Fedorov, AK., Akimov, AV., Biamonte, JD., Kavokin. AV., Ya Khalili, F., Kiktenko, EO., Kolachevsky, NN., Kurochkin, YV., Lvovsky, AI., Rubtsov, AN, Shlyapnikov, GV., Straupe, S., Ustinov, AV. And Zheltikov, AM. Quan-tum technologies in Russia. Quantum Science and Technology, IOP Publish-ing, 8 November 2019, https://iopscience.iop.org/article/10.1088/2058-9565/ab4472
- Qiang Zhang, Feihu Xu, Li, Nai-Le Liu and Jian-Wei Pan. Quantum information research in China. Quantum Science and Technology, IOP Publishing, 8 November 2019, https://iopscience.iop.org/article/10.1088/2058-9565/ab4bea
- Swayne, Matt. The World's Top 12 Quantum Computing Research Universities. The Quantum Daily, November 18, 2019, https://t hequantumdai-ly.com/2019/11/18/the-worlds-top-12-quantum-computing-research-universities/
- 15. There is no specific data about the quantity of scientists and technicians occupied in all quantum computing activities. The existing information is not very precise at the company, university, institute level, etc., which evidently makes the conducting of specialised studies of the employment of the workforce difficult.
- 16. Quantum Physics 2020. https://quantumphysics.physicsmeeting.com/
- 17. https://www.ibm.com/quantum-computing/
- 18. https://www.microsoft.com/en-us/quantum/quantum-network
- U.S. and Japan Sign Landmark International Quantum Statement. U.S. Embassy & Consulates in Japan. The White House. Office of Science and Technology Policy. December 19, 2019. https://jp.usembassy.gov/us-japan-landmark-quantum-statement/
- 20. Quantum Computing Outlook for 2020. Quantum Computing Report. https://quantumcomputingreport.com/our-take/quantum-computing-outlook-for-2020/
- Miller, Ryan. Revealed: Top 10 countries leading the race of quantum computing technology. Stats Gate, CEOWORLD magazine, December 14, 2019 https://ceoworld.biz/2019/12/14/revealed-top-10-countries-leading-the-race-of-quantum-computingtechnology/
- National Strategic Overview For Quantum Information Science. Product of the Subcommittee on Quantum Information Science Under the Committee on Science of the National Science & Technology Council. https://www.whitehouse.gov/wp-content/uploads/2018/09/National-Strategic-Overview-for-Quantum-Information-Science.pdf
- 23. National Agenda For Quantum Technology. September 2019 (https://qutech.nl/wp-content/uploads/2019/09/NAQT-2019-EN.pdf)
- Qiang Zhang, Feihu Xu, Li, Nai-Le Liu and Jian-Wei Pan. Quantum information research in China. Quantum Science and Technology, IOP Publishing, 8 November 2019, https://iopscience.iop.org/article/10.1088/2058-9565/ab4bea
- 25. Vernon, Jamie L. The Scientific Research Honour Society, Sigma Xi, 2019. https://www.americanscientist.org/article/restructuring-science-in-russia
- 26. A reasonable list of quantum languages and SDKs, with a good description of their characteristics can be consulted at https://en.wikipedia.org/wiki/Quantum\_programming#Imperative\_languages
- Knight, Will. Quantum computers are already here, what will we do with them? MIT Technology Review, 05 March, 2018, https://www.technologyreview.es/s/10018/los-or-denadores-cuanticos-ya-estan-aqui-que-haremos-con-ellos

- Developing a quantum-ready global workforce. Microsoft Quantum. December 18, 2019. https://cloudblogs.microsoft.com/quantum/2019/12/18/quantum-ready-global-workforcemicrosoft-universities/
- 29. Svore, Krysta. Quantum computing searches for new languages that will programme it in the future. MIT Technology Review, 03 January 2018. https://www.technologyreview.es/s/9890/la-computacion-cuantica-busca-los-nuevos-lenguajes-que-la-programaran-en-un-futuro