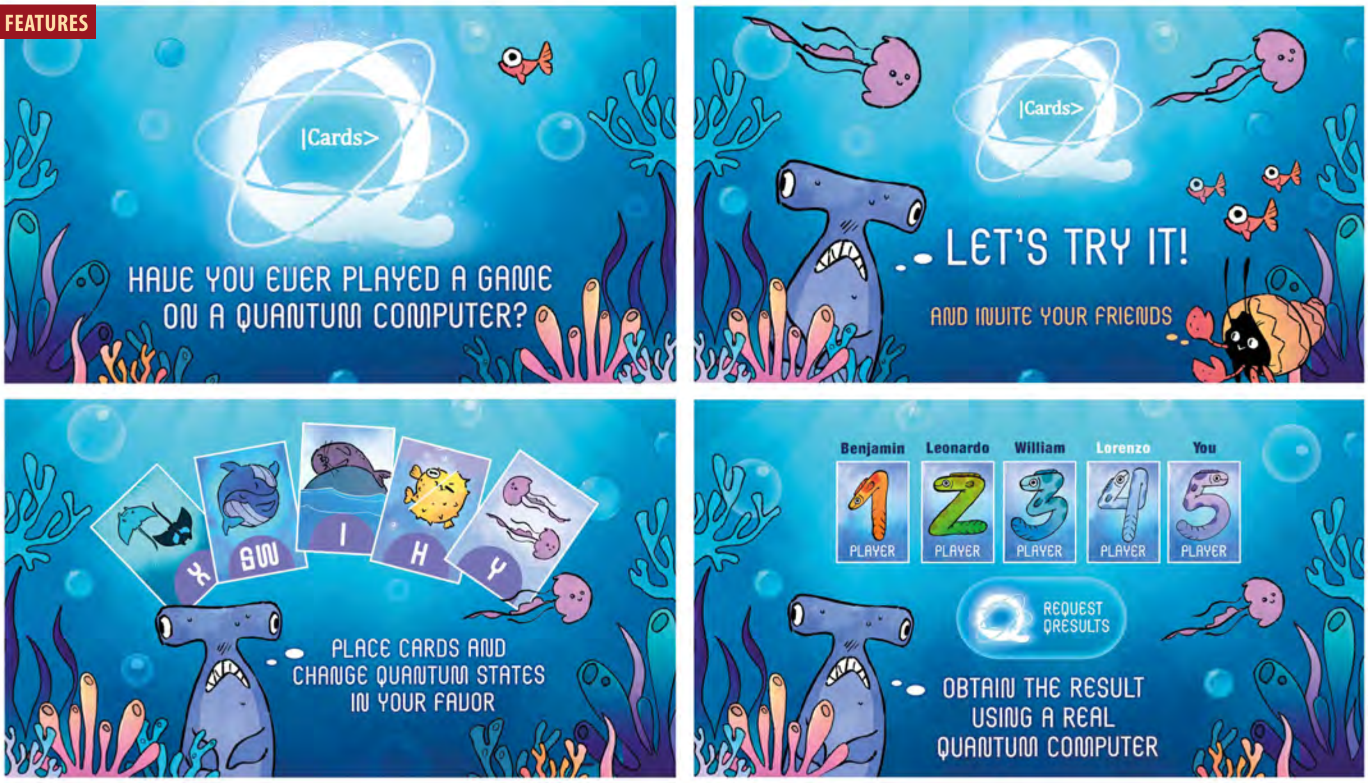

QUANTUM GAMES - A WAY TO SHED LIGHT ON QUANTUM MECHANICS

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Today the term 'quantum' is often encountered in the media, not only in connection with scientific research and technology, but also in combination with almost anything that may come to mind. You can find quantum chocolate, the quantum car, soap, love, the mind, the soul, etc. This reflects, on one hand, how the notion of quantum physics is somehow associated to efficiency and technological power, but also how the counter-intuitive behaviour of quantum mechanics remains elusive to most people. As we are entering an era of quantum technologies, it is essential to shed some light on the basic principles of quantum physics. Games can provide a versatile and fun way to immerse people from all backgrounds to the counterintuitive rules of the quantum world.

▲ Q|Cards> Online is a game introducing and teaching the basics of quantum computing, without requiring previous experience in quantum physics.

First of all, why popularise quantum physics?

Today, when people speak or write of quantum technologies, they mean a broad range of devices that function, in their essence, by exploiting quantum effects. These new quantum technologies are related to the recent ability to control and observe matter at the level of individual quantum particles. It has been discovered, for instance, that entanglement enables completely new ways of manipulating and transmitting information, and that superposition of quantum states and interference can bring a great advantage in certain algorithms.

Among quantum technologies (QT), the holy grail is certainly the quantum computer, which promises to solve problems that are intractable today. Quantum computers are expected to profoundly affect life sciences, robotics, artificial intelligence, data storage and security, and potentially every field that relies on computing power. It is believed that they will help us solve many of the great challenges of our century, from healthcare to energy and the environment.

Until recently, QT were the preserve of a small number of scientists. However, the skills required to address the big challenges are diverse, and concern not only quantum physicists, but also professions such as engineers, computer scientists, mathematicians, business and marketing experts. Taking into account the stakeholders of potential QT applications, we should add to the list also chemists, biologists, natural and material scientists, medical doctors, economists, brokers, analysts, traders. It is clear that the development of multifaceted quantum literacy, capable of adapting to different languages, is crucial to the emergence of the quantum ecosystem.

In this context, education and training is *a priori*ty, and specific curricula to address this transformation are being designed all over the world. At the same time, in order to build a society capable of making responsible decisions, it is important that a broader cohort than just school and university students is informed about quantum science and technology.

QPlayLearn: quantum physics for everyone, with games

To address the challenges and opportunities of a widespread quantum literacy, the collaborative online platform QPlaylearn (https://qplaylearn.com) was conceived and implemented, with the aim of teaching quantum science and informing about the impact of QT to everyone, regardless of their age or background.

The QPlayLearn (QPL) online platform offers tailored contents for different target groups, focusing on the following: i) Teachers, students and curious learners; ii) Corporate executives, employees, policy makers and journalists; iii) Artists, curators and cultural managers.

Despite diversification following the different needs of each audience, the core of our approach is that different types of intelligence dominate the learning process of each individual. In this regard, QPL develops and curates various multimedia contents to build intuition and engagement through games and videos, grasp physical concepts through easy-to-follow explanations, acquire the formal understanding through the mathematics. An essential ingredient in QPL's approach is playfulness. Fun and interactivity increase the effectiveness of the learning process and make concepts less intimidating. In this, games can play a relevant role.

The application of game elements and digital game design techniques to non-game problems has gained much attention in recent years and applications have been successfully implemented in various contexts, from real, • • •

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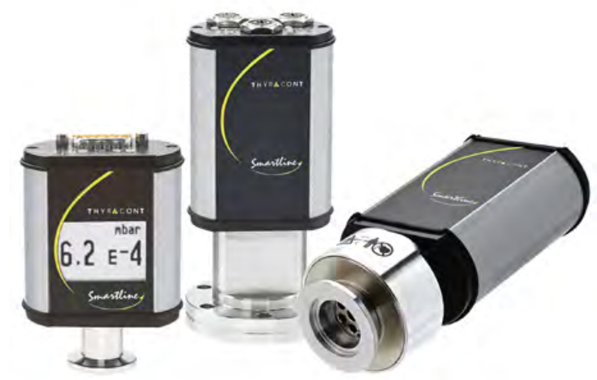

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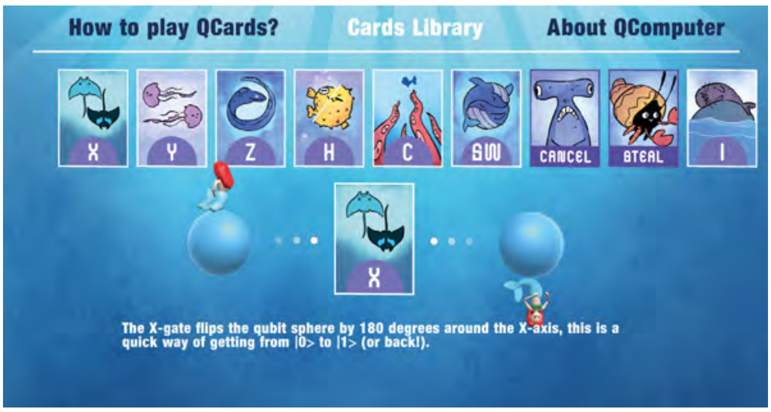
more 'serious' games related to business and social impact challenges, to games exploited as an educational strategy.

Cognitive neuroscience has provided considerable empirical evidence on how our brains are positively affected by games from a learning perspective. Games are an effective way to learn because, increasing attention and focus levels, keeping our brains engaged and happy, they create favourable biochemical conditions for synaptic networks to be created and learning to happen. In fact, not only game-based learning (GBL) can help especially children to develop a set of skills that are considered to be essential in their future jobs: critical thinking, problem solving, resilience, collaboration, analytical skills, but as they allow gamers-learners to enjoy challenges and play, which increases the willingness and excitement to take risks and even accept failing as part of improvement and learning processes, whereas risk-taking is otherwise a step people typically tend to avoid. More in general, GBL allows people of all ages to approach learning with a hands-on, inquiry-driven, game-based sets of activities which hard-wire knowledge, skills and competences in our brains.

Indeed, given the pressing need to make QT accessible to a wider audience and to facilitate the inclusion of stakeholders in the debate on the topic, learning quantum concepts through games has gained prominence as an approach to support the quantum community at large in its outreach and education efforts [1]. Quantum phenomena and problems require imagination, thinking outside the box and exploring broad solution landscapes. GBL could therefore be a valuable resource for both real games and learning.

Among the resources offered by QPL, QUEST consists of a quantum dictionary containing a list of key quantum concepts. Each entry is explored using a methodology based on the different approaches to learning described above, from intuition to formalisation. In particular, all the various QUEST entries include a 'Play' section in which proprietary games, developed by the QPL team, are combined with games developed by other stakeholders and collaborators as part of the QPL network, carefully selected from the available games. Some of the games were born in the context of the Quantum Game Jams we co-organised, as in the case of the board game Q|Cards> developed during the Quantum Game Jam 2019 by some of the authors and other collaborators, or the more recent Potatoes Quest, developed during the IF Quantum Game Jam 2020 by two students at the University of Pisa.

In QPL, all games are used with the aim of helping learners develop insight into the 'strange' (to the human eye) behaviours of QP. Therefore, games are used as educational tools, hence all falling under the umbrella of the GBL. Currently, concepts explored through the games published on the QPL platform are: quantum physics, quantum state, qubit, superposition, entanglement, quantum measurement, wave-like behaviour, tunneling, quantum technologies. In the following section, we will present one of these games.



▾ In the tutorial of Q|Cards> Online qubits are represented as merpersons sitting on a ball. In the 'Cards Library' the players/learners can find a description of the action performed by each card/gate and play with the input state to see how the output changes.

Q|Cards> Online: a new video game to learn about quantum computation

Q|Cards> started as a prototype board game developed during the Helsinki-based Quantum Game Jam 2019 'Quantum Wheel', later refined and co-produced together with the Finnish company MiTale. In Summer 2021, QPL launched the mobile game Q|Cards> Online, a fully digital and online multiplayer version of its tabletop ancestor Q|Cards> [2].

As in the board game Q|Cards>, each player starts with a qubit in the |0> state and the goal during the game is to maximise the probability that, at the end of each turn, their qubit goes from |0> to |1>. During their turn, players can apply their cards to any player's qubit line, which corresponds to applying single- or two-qubit gates and forming a quantum circuit together with the cards/gates placed by the other players.

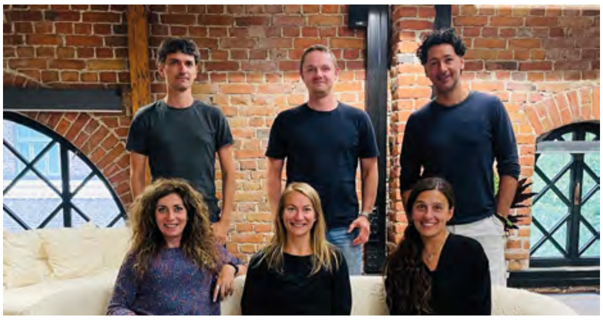
There are multilevel ways to play the game, just for fun or for delving into the physics behind it. Either way, to win or at least play consciously, players need to understand even roughly what a qubit is, how to manipulate it through gates and also why probabilities are involved. Therefore, Q|Cards> can be exploited as an educational resource to teach the basic notions of quantum information and computing, but also QP concepts such as superposition, entanglement, and quantum measurement.

In addition, the game runs on a real quantum device. The 2- to 5-qubit quantum circuit resulting from the game is automatically translated into IBM Qiskit and the corresponding circuit is simulated or executed on a real IBM Q cloud quantum computer.

Q|Cards> Online is accompanied by a tutorial explaining rules and actions of the various cards/gates, where qubits are pictorially represented as merpersons sitting on a ball. The imaginative pictures allow for a level of explanation that can be adapted to the audience. Hence, it is sufficient for pupils and young learners to think about the upright and upside down configuration of the seated merperson representing the qubits' basis states |1> and |0>; for high-school students it is easy to explain the Bloch sphere, which of course lies behind the representation of the merpersons; for a more mathematically advanced audience, density matrices can also be introduced, since in the tutorial mixed substates are also visualised as merpersons falling into their own ball, while the entangled Bell states are visualised as merpersons connected by branches still sitting on the surface of their own ball.

The idea of educational and popularisation resources offering the possibility of multilevel education is the mission behind each and every content and project developed by QPlayLearn. Regardless of the expertise of the target audience, there is always a solid scientific background behind images and examples used to popularise QP and QT. Multilevel educational resources can help avoiding misleading analogies and oversimplified explanations, a risk in quantum popularisation especially in contexts where the proper mathematical formalism cannot be used. ■

About the Authors



SM is Professor of Quantum Information, Computing and Logic at the University of Helsinki, vice-director of InstituteQ, the Finnish quantum institute, CEO and co-founder of Algorithmiq, a startup developing quantum algorithms for life sciences. EB, DC, CF, BS have PhDs in quantum physics and are all part of the Algorithmiq staff. RM holds a PhD in Educational Sciences and has worked in policy making in the EU and OECD. All authors are members of the QPlayLearn team and are passionate about innovative educational and outreach projects, particularly related to quantum science and technology.

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References

[1] Zeki C. Seskir *et al.*, *Opt. Eng.* **61 (8)**, 081809 (2022) https://doi.org/10.1117/1.OE.61.8.081809

[2] Available for download at Play Stores: Apple: https://apps.apple.com/fi/app/qcards-online/id1575238389
Android: https://play.google.com/store/apps/details?id=com.DefaultCompany.qcards2d