Il Colle di Galileo

Dire l'indicibile, a quantum exhibition

November 20th to 27th 2023, Florence
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Abstract. The second Quantum revolution is expected to influence society as a whole thanks to the groundbreaking technologies it introduces. As part of its effort in the dissemination of Quantum Physics and Quantum Technologies, in November 2023, the National Institute of Optics (CNR-INO) in Florence organised "Dire l'indicibile: l'entanglement quantistico" an exhibition open to the general public with the aim of spreading knowledge of quantum Physics and quantum technologies. The goal of the exhibition was to boost awareness of these developing technologies in local communities, using interactive exhibits designed for the occasion, while also investigating the impact this event had on its visitors.

Keywords: exhibition, outreach, public engagement evaluation, Quantum Physics, Second Quantum Revolution.

1. A quantum exhibition

The need to educate society about Quantum Technologies (QT) is becoming increasingly significant for institutions involved in their development. It is expected that, within 10 years, QT will revolutionise our societies with the disruptive technologies that will be introduced. A particularly effective dissemination tool is the science exhibition. Over the past 20 years, examples of science education and dissemination in the form of exhibitions have multiplied within museums, science centres and in many different contexts. This format is particularly attractive for science institutions, as it enables contact with different kinds of audience. Moreover, it has been proven that interactivity in museums increases interest and engagement, leading to better results in learning processes [1] [4]. While with classical physics (and many other scientific fields) hands-on and interactive experiences are possible thanks to real-life experiments, the phenomena of quantum physics (QP) are hard to replicate outside a laboratory [3]. Therefore, to make QP accessible to society, we need to use alternative tools that bring the public closer to quantum phenomena. To increment quantum literacy among the general public in Europe, a dedicated day – World Quantum day (WQD) – was established. Sev-

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eral initiatives are held on WQD to promote quantum literacy all over the world, with outreach activities in different formats. The events are clustered around the 14th of April, which is the actual quantum day, but they are held on other dates too. In Italy, WQD activities are promoted by the Italian Quantum Weeks initiative, a three-year project launched in 2022 which coordinates outreach efforts at national level and supports the local initiatives. The Italian Quantum Weeks project involves several Institutions, Universities and research centres throughout the country. INO has been active in the project since the beginning. The activities organised within the Italian Quantum Weeks include a quantum exhibition entitled "Dire l'indicibile" to paraphrase the famous *Speakable and unspeakable in Quantum Mechanics* by John S. Bell. The planning and design of the exhibition was steered at national level, although local committees had complete freedom in the implementation. INO's approach in Florence in both the 2022 and 2023 editions, was to design exhibits that were clearly "non quantum", which would be symbolical representations of quantum principles. This approach intended to provide visitors with useful tools to visualise and interpret quantum concepts far removed from everyday experience.

2. Design and implementation in Florence

The 2023 exhibition in Florence took place from November 20th to 27th and was designed and planned by researchers of the National Institute of Optics with the help of a local professional curator and exhibition designer: Machina srl. Ten thematic rooms guided the visitor through the discovery of the basic principles of quantum mechanics and entanglement using interactive exhibits and visual representation [2]. Msc and PhD Students as well as researchers from the CNR-INO and Florence University acted as ambassadors and facilitators, guiding visitors through the exhibition. The venue was chosen because it was in the city centre, near to busy areas served by restaurants, clubs and bars, in order to attract a wider public and people who don't usually participate in the CNR-INO's activities.

The exhibition made use of pictures, written text, videos, interactive exhibits and visualisation tools that visitors could experience alone or with the help of one of the volunteers present. All volunteers were experts in quantum physics and related technologies, being CNR-INO researchers and students.

What distinguishes this exhibition from similar events is the focus on interactivity. Quantum Physics is often deemed difficult to teach and learn while its laws are well understood by the scientific community. The difficulties lie in the fact that its predictions are counterintuitive with respect to our daily experience. Outreach events tend to struggle to create a connection between the daily life of those who attend them and the subject [5]. "Dire l'indicibile" tried to fill this gap by designing experiences that visitors could engage in with their own hands and

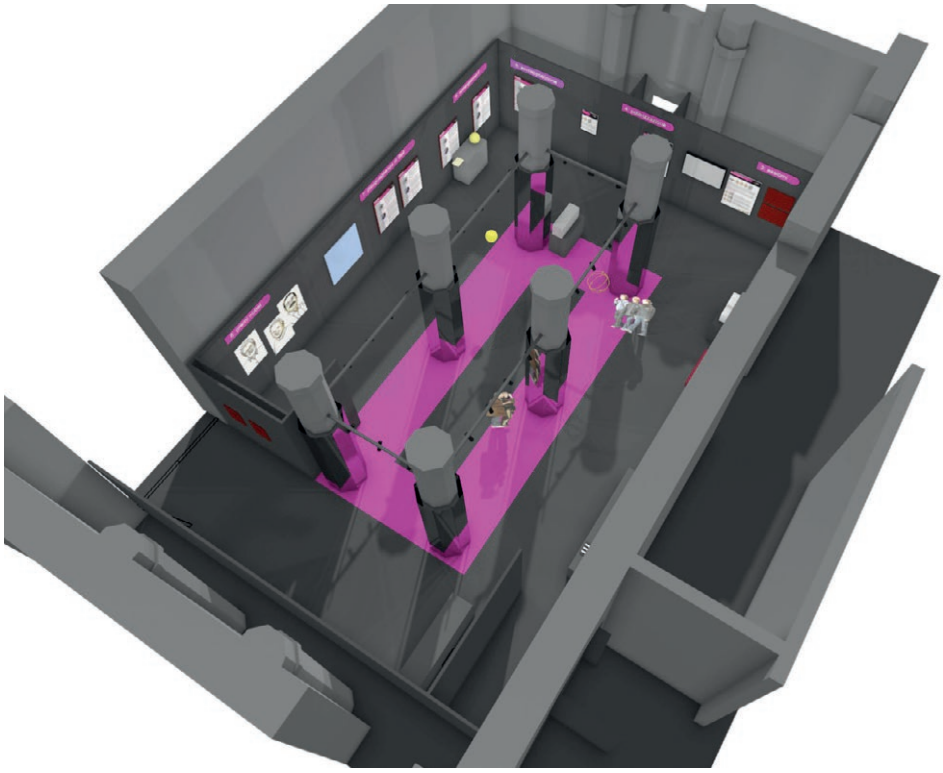

Figure 1. Rendering of the exhibition "Dire l'indicibile: l'entanglement quantistico" held in Florence in November 2023.

which would help create a mental framework, a representation, a new intuition, of the quantum principles. Another element that makes the exhibition an interesting case is the collaboration between CNR-INO, promoter and organiser of the event, and local organisations. The event venue was an historical landmark in the UNESCO heritage area of the city. "Il complesso delle Murate", built in the 15th century as a cloistered monastery which was subsequently transformed into a prison, has undergone a redevelopment process and now been returned to the public. In addition, the setup company, contracted to provide support, is a well-known business, regularly involved in the events organised by the local fashion industry. The ambition was not only to organise an outreach event of scientific value but also to create connections with the area where the Research Institute is located. Lastly, the exhibition is an experiment in its own right. Engagement evaluation surveys were designed and distributed among visitors who voluntarily filled them in. From the answers to those questionnaires, CNR-INO researchers hope to investigate the landscape of the public's interest in Quantum Technologies, along with their perceptions of their development and potential applications. The results of the analysis of the data gathered will be addressed in another dedi-

Figure 2. Overview of the exhibition on its opening day.

cated paper. Here, we intend to illustrate the exhibits and the ideas behind their use as tools for the visualisation of specific quantum principles.

3. The exhibition

The exhibition was structured according to a didactic perspective. First, we introduced the most basic concepts, to help understand the more advanced topics that follow. Ten sections numbered from 0 to 9 guided the visitor during the thematic path.

The visit began with an introductory section, where a series of pictures accompanied the visitor to the scales of dimensions where quantum phenomena cannot be neglected.

After this first section, visitors were shown examples of quantum systems. Using simple spectrometers, visitors were able to observe the radiation spectra emitted by several light sources. The aim was to show the differences between continuous and discrete emission lines. This very simple exhibit showed how close quantum physics actually is to our daily experience. Even with the naked eye, the quantised energy levels of atoms in a neon lamp can be appreciated through light, which

Figure 3. Light sources generating continuous and discrete emission spectra, observable using portable spectrometers.

turns out to be a fantastic carrier of information mapped in its visible spectrum from the microscopic world (Fig. 3).

The next section covered the different models developed to describe the atom. The peculiar behaviour of quantum systems was then illustrated comparing three versions of Young's double slit experiment [6]: a classical one using some sand; one showing the diffraction patterns of a laser beam and, lastly, a video showing the results of a double slit experiment performed using an electron beam.

Subsequently, visitors were presented with the superposition principle and the issue of measurement in QP. These concepts were presented with the help of some optical illusions. Written text on panels and guidance from the experts gave visitors the information needed to contextualise what they saw. The brief introduction to quantum measurement and superposition was consolidated with an interactive activity meant to give an intuition of what it means to perform a measurement in quantum physics with the help of polarisation. A lamp and three polarising filters showed the changes in the radiation transmitted with the variation of the filters' relative angles. Even though no quantum effect was involved, this activity created some useful parallelisms with pure quantum behaviour.

At this point, the exhibition progressed more into the concept of superposition, introducing Bloch's Sphere and how it can be used to represent quantum states. The next step was then a representation of the concept of entanglement.

To describe what entanglement is, first we introduced correlation. To repre-

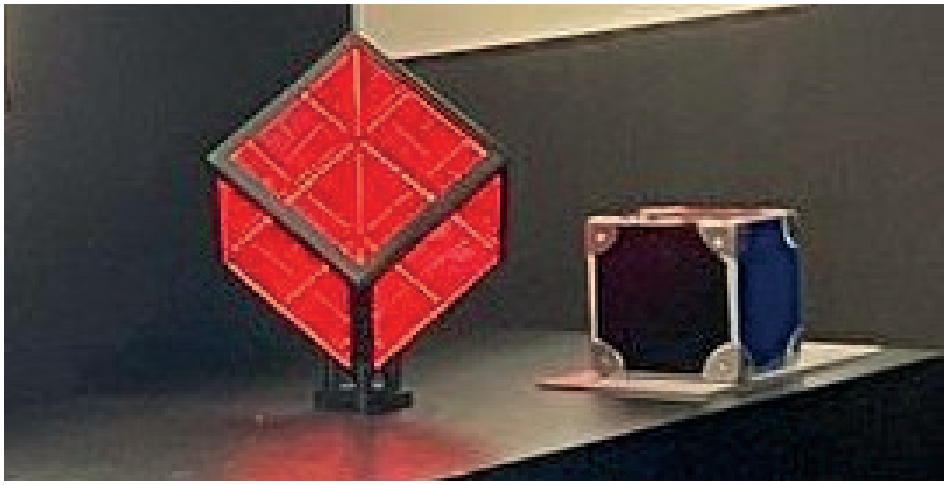

Figure 4. Entanglement exhibit: a dice and a cube are "entangled" so that the face the dice falls on determines the colour of the cube.

sent the non-locality principle of quantum mechanics, we created an exhibit that showed two "entangled" objects: a coloured dice and a cubic lamp which changed colour to the colour of the dice's face. We were able to use this to highlight the fact that, even if two entangled quantum objects are very far from each other, the collapse of the wavefunction is instantaneous. While the dice is rolling, the cube assumes all the colours, symbolising a superimposed state. The design of this exhibit was inspired by a previous exhibition designed by ETH in Zurich [2].

Once the concept of entangled states had been displayed, the exhibition progressed with Bell's Inequalities. An illuminated display and a set of polarising filters allowed visitors to perform Bell's inequality calculations under the hidden variables hypothesis. Finally, the experiments that proved the probabilistic approach to QP were introduced to the visitors using the words of the three 2023 Nobel prize laureates in Physics: Anton Zeilinger, Alain Aspect and John Clauser.

The exhibition closed with some examples of second quantum revolution technologies that used some of the principles introduced during the exhibition. Quantum key distribution and examples of quantum computer hardware were introduced to the visitor.

4. Conclusions

Events like the one described here are a powerful tool to reach a diverse audience, ranging from high school students to adults who have finished their education, with different interests. It also provides an opportunity to open the doors of research Institutions like INO to innovative ways of communicating science and

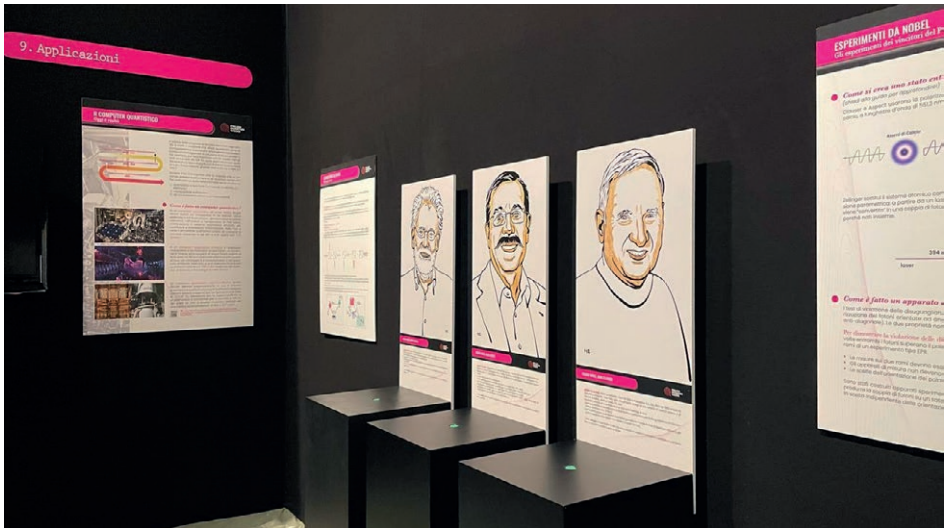

Figure 5. Last sections of the exhibition: 2023 Nobel laureates in Physics and examples of quantum technologies.

creating connections with local communities and pre-existing projects. This exhibition clearly benefited from the interdisciplinary team that came together in its design. Interdisciplinarity not only makes it possible to create more rounded and complete events and activities, it also has the bonus of attracting a diverse audience that might usually be the target for just one of the disciplines involved in the event. This experience opens new possibilities for more daring collaborations.

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