Bringing Quantum to the Masses

by Martin Laforest and the Communication and Strategic Initiatives Team

We are at the cusp of a technological revolution – the quantum information revolution. Technologies harnessing the counter-intuitive behaviour of atoms and molecules, such as the powerful quantum computer, unbreakable quantum cryptography and quantum sensors for medical, geological and chemical applications, are poised to get out of the labs, and into people's lives. The majority of the population does not realize that the first quantum revolution gave us devices including computers, cell phones, LED lights, MRIs and grocery store scanners [1]. The second quantum revolution, based on quantum information technologies, will have an even deeper societal and economic impact. This quantum future will require a STEM workforce and general population that are quantum-aware [2].

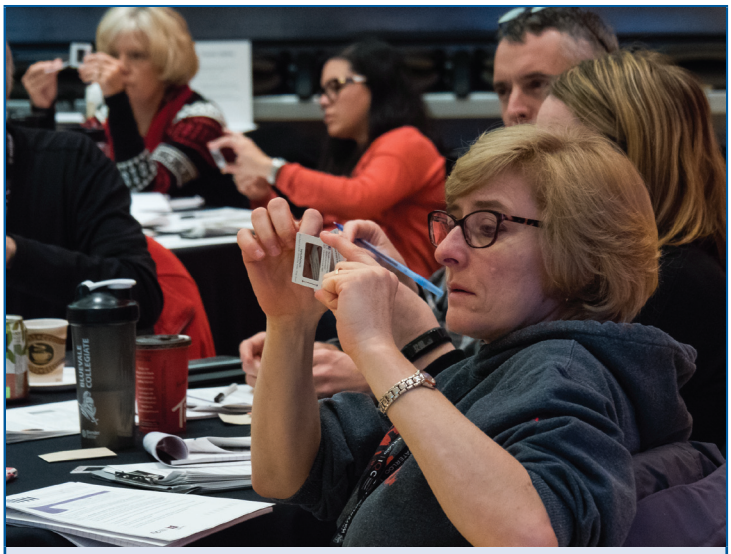

Fig. 1 Exploring wave-particle duality using light polarization.

This report discusses some of the specific scientific outreach efforts the Institute for Quantum Computing (IQC) at the University of Waterloo has developed to target high school teachers and students and the general public.

SCHRÖDINGER'S CLASS: TEACHING THE TEACHERS

The basic concepts of quantum mechanics are part of many high school physics curricula in Canada [3,4], but the allocated time to teach them is very limited. Anecdotal evidence suggests that a large portion of high school teachers lack the confidence in teaching the material. Quantum mechanics is a complex subject and a deep understanding is necessary in order to teach it effectively [5]. "By exposing teachers to more methods and more content, we give them the confidence to expand their classroom practice to reflect current understandings and current content." [6]

Schrödinger's Class (Fig. 1) is a three-day workshop for high school physics teachers designed to deepen the educators' understanding of quantum mechanics and give them hands-on resources to bring into their classroom. Some activities offer a new twist on curriculum material, while others discuss applications of quantum mechanics and quantum information and they could serve as extra-curricular activities in class or for science clubs. These include the use of quantum superposition to achieve unbreakable information security, or the use of quantum interference to perform a quantum computation.

The first two editions of Schrödinger's Class have attracted 50 participants and have been praised with an overall experience of 3.9/4.0 on average. Some educators left satisfied with their new level of understanding and others have already used some of the activities as part of their teaching material. The activities presented during Schrödinger's Class are currently being formatted into teacher resources and will be available online in

Summary

The Institute for Quantum Computing develops workshops for students and teachers and a travelling museum exhibition to raise awareness about quantum mechanics and quantum technologies.

Key words: Science Technology Engineering and Mathematics (STEM), scientific outreach, quantum mechanics, student enrichment programs, teacher training, public programming.

Martin Laforest <mlaforest@uwaterloo.ca>,

and

the Communication and Strategic Initiatives team

Institute for Quantum Computing, University of Waterloo, 200 University Ave. W., Waterloo, ON N2L 3G1

the near future. Schrödinger's Class is offered on the first weekend on December and will expand in size in the coming years.

QUANTUM CRYPTOGRAPHY SCHOOL FOR YOUNG STUDENTS

Since 2008, IQC has been offering the Quantum Cryptography School for Young Students (QCSYS), a grades 11-12 enrichment summer program for talented and curious students wishing to learn more about the beauty and importance of quantum mechanics. QCSYS has become a highly competitive and prestigious eight-day program that welcomes 45 exceptional students from all over the world every summer.

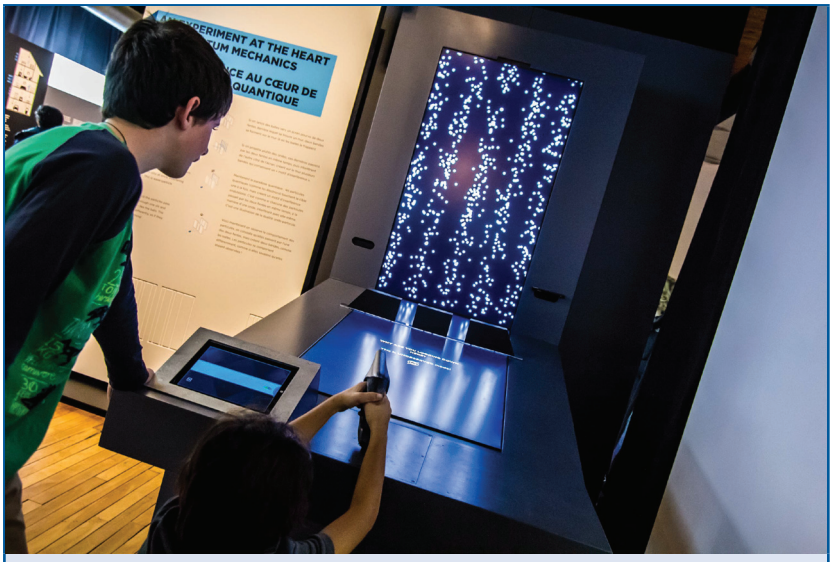

Fig. 2 Visitors experiencing a full classical and quantum simulation of the double-slit experiment.

Quantum cryptography is the most market-ready quantum information technology and we use it as the narrative to teach mathematics, quantum mechanics and their technological applications. The program is a blend of traditional lectures, hands-on experiments, peer-instruction and group work. Students explore various concepts of quantum mechanics, both through a phenomenological approach and then quantitatively using basic linear algebra and complex numbers. The students are then exposed to the classical and quantum cryptography and learn how quantum optics turns these ideas into real hardware devices. By the end, they have the opportunity to design and build their own version of a quantum cryptography system.

Parallel to the academic program, the school includes various social activities in the evenings, a trip to Niagara Falls and two mentoring sessions where students have the opportunity to meet and discuss with IQC's researchers. Past students have left very satisfied with their experience, giving QCSYS an average rating of 4.8/5.

In addition to QCSYS, IQC continuously develops quantum-related activities. By visiting and hosting high school groups and partnering with other outreach organizations, IQC delivers face-to-face programing to upward of 1200 students annually.

QUANTUM: THE EXHIBITION – CELEBRATING CANADIAN QUANTUM INNOVATION

Through IQC's public talks and annual open houses, thousands of science enthusiasts from the Waterloo Region have been exposed to quantum information science and technology and the ways it will shape the technological landscape of tomorrow. Acknowledging that Canada as a nation plays a leading role in this technological revolution, we wanted to bring awareness about the second quantum revolution to as many Canadians as possible. A travelling museum exhibition was deemed the perfect vehicle for that.

QUANTUM: The Exhibition is the first-ever travelling exhibition about quantum information science and technology. It stands at 4000 square feet and is designed to engage a variety of audiences. By using a well-balanced mixture of written content, interactive activities and multimedia displays, neophytes are exposed to the wonder of the quantum world, while people with previous knowledge still learn something. There are also enough levers to pull, buttons to push and screens to touch to engage young children.

To expose the audience to the beauty and power of quantum mechanics and quantum technology, the exhibition is broken into three sections. The first section is all about quantum mechanics, where the visitor is exposed to the fundamental concepts, like wave-particle duality, quantum superposition, interference, and uncertainty (Fig. 2). The second, smaller, section is about information technology, a necessary detour needed to fully appreciate the third section about quantum information technology. In this final section, the visitor learns and experiences quantum computing, quantum cryptography and quantum sensors.

The exhibition opened in Kitchener in October 2016 and travelled across Canada in 2017, with stops in Vancouver, Saskatoon, Calgary, Halifax and Ottawa. QUANTUM: The Exhibition has already reached upward of 150 000 Canadians and has been widely praised for its simplicity, originality and design. Starting 2018, the exhibition will travel the world.

CONCLUSIONS

The overarching goal of IQC's outreach efforts is to raise awareness about the beauty, but also the importance, of quantum mechanics and how it will play a significant role in tomorrow's technological landscape.

ACKNOWLEDGEMENTS

We would like to thank the Government of Canada, the Province of Ontario and Mike and Ophelia Lazaridis for financially supporting IQC's scientific outreach initiatives.

REFERENCES

1. National Research Council (Ed), *Adapting to a Changing World—Challenges and Opportunities in Undergraduate Physics Education,* National Academy Press, 2013.
2. National Science and Technology Council, *Advancing quantum information science: national challenges and opportunities,* 2016.
3. Ontario Ministry of Education, *The Ontario Curriculum Grade 11 and 12: Science*, 2008; Available from http://www.edu.gov.on.ca/
4. British Columbia Ministry of Education, *Area of Learning: SCIENCE – Physics*, 2016; Available from https://curriculum.gov.bc.ca/
5. M.A. Asikainen, and P.E. Hirvonen, "A study of pre- and inservice physics teachers' understanding of photoelectric phenomenon as part of the development of a research-based quantum physics course", *American Journal of Physics,* **77**, 658 (2009).
6. L. Pankratz, Physics 30 Assessment Manager, Alberta Education, Private communication, 2017.