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INSTITUTE FOR QUANTUM COMPUTING

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UNIVERSITY OF
WATERLOO

IQC Institute for
Quantum
Computing



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1. INTRODUCTION

1.1 Overview of IQC: The Future Re-imagined

IQC was officially created in 2002, sparked by the vision of Mike Lazaridis and then-University of Waterloo President David Johnston, to foster pioneering research into the next revolution in technology, quantum information. Harnessing the quantum laws of nature promises powerful new advances in fields spanning computing, communications and sensors — and IQC was created to lead this charge.

Throughout history, humans have learned to tame and control the forces of nature — fire, steam, electromagnetism — to improve their lives. IQC is now harnessing the *original* force of nature — the quantum fabric that underlies all things. The results of this research will transform the future in ways we have only begun to imagine.

Building on the University of Waterloo's longstanding strengths in engineering, math and computer science, IQC quickly attracted world-class researchers in computer science, providing the nucleus of excellence to entice experimentalists. Today, IQC is a highly successful partnership between the University of Waterloo, the private sector and both federal and provincial governments. David Johnston envisioned Waterloo becoming the world's "Quantum Valley," and IQC is turning this dream into a reality.

"Innate human curiosity has always been the driving force behind innovation."

Raymond Laflamme
Executive Director, Institute for Quantum Computing

In just 10 years, IQC has grown to become the world's largest research centre devoted to quantum information science and technology. It has created a unique training program for postdoctoral fellows and students unrivaled around the globe. It is intensifying communication and outreach programs to share the knowledge created and ignite widespread fascination in quantum science. Canada — and IQC — are becoming internationally recognized as leaders in the global quantum race.

A milestone in the coming year will be the move to an extraordinary new home, the Mike & Ophelia Lazaridis Quantum-Nano Centre. In what will be the biggest building at the University, scientists will study and manipulate the tiniest building blocks of nature. This 'think

tank with labs' will feature a state-of-the-art cleanroom, the most cutting-edge experimental infrastructure in the world and innovative spaces designed to foster collaboration and dialogue between researchers. It's a simple recipe: attract the best scientists in the field, give them the best possible research environment and a place to share ideas and test them, and breakthroughs will happen.

1.2 IQC's Guiding Principles

Vision

Harnessing quantum mechanics will lead to transformational technologies that will benefit society and become a new engine of economic development in the 21st century.

Mission

To develop and advance quantum information science and technology at the highest international level through the collaboration of computer scientists, engineers, mathematicians and physical scientists.

Strategic Objectives

1. To establish Waterloo as a world-class centre for research in quantum technologies and their applications

1. Conducting research in quantum information
2. Recruiting researchers
3. Collaborating with other researchers
4. Building, facilities and laboratory support

2. To become a magnet for highly qualified personnel in the field of quantum information

5. Attracting, educating and training highly qualified personnel

3. To establish IQC as the authoritative source of insight, analysis and commentary on quantum information

6. Disseminating knowledge
7. Communications and outreach strategy

8. Administrative support is connected to all three strategic objectives.

The strategic objectives, broken down into eight supporting tactics developed in partnership with Industry Canada, serve as a roadmap for all IQC's activities and is also the organizing framework for this report.

1.3 Executive Summary

This annual report is the second in a series of five reports that evaluate IQC's activities and outcomes as they relate to the \$50 million grant from Industry Canada. The performance period is May 1, 2010 to April 30, 2011 (the 2011 fiscal year) unless otherwise stated.

The purpose of the report is to demonstrate how Industry Canada's funding has enabled IQC to expand and make significant progress in achieving its three strategic objectives, which tightly align with the four long-term outcomes that support the IQC vision, developed with input from Industry Canada:

1. Increased knowledge in quantum information
2. New opportunities for students to learn and apply new knowledge
3. Canada becoming branded as a place to conduct research in quantum technologies
4. Canada becoming positioned to take advantage of the economic and social benefits of research

Canada's support of quantum research reinforces this country's scientific and technological leadership; that visionary investment is critically important as the quantum frontier is just beginning to be explored.

Within the report is an overview of scientific achievements, objectives set in fiscal 2011, a summary of the activities undertaken with the grant, the results achieved, objectives and expected results for fiscal 2012, specific activities and timelines, as well as a risk assessment and risk mitigation strategies. Additional explanatory information and supporting documentation is contained in the appendix.

In a nutshell, IQC has met or exceeded all its growth and development targets, and is well-positioned to meet next year's objectives — a positive return on investment. The proof is in the science: IQC continues to attract the highest calibre researchers in the world who made significant discoveries this year, are constantly adding to the body of knowledge in this field, and moving ever closer to realizing the limitless possibilities in taming the quantum universe.

A brief summary (below) of the year's many high points, as they relate to the three strategic objectives, is a snapshot of the tremendous potential being realized daily at IQC; more detail follows in the report and appendices:

1. To establish Waterloo as a world-class centre for research in quantum technologies and their applications:

IQC continued to build a team of theoretical and experimental researchers who are leaders in computer science, engineering, math, chemistry and physics. Prof. David Cory, three research assistant professors and 18 postdoctoral fellows joined IQC in 2011.

To support this world-class team, IQC has continued to invest in experimental infrastructure and is now reaping the benefits — developing quantum devices, implementing quantum protocols and building on the successful feasibility study for quantum communication using satellites. At the same time, good connections have been maintained with quantum computer scientists who are devising new protocols and applications for quantum processors that deepen our understanding of quantum information processing.

IQC researchers achieved significant results and breakthroughs — in photonics, quantum error correction and superconducting qubits, to name a few, which led to articles in such eminent journals as *Science*, *Nature*, *Nature Physics*, *Nature Photonics* and *Physical Review Letters*. Researchers produced a total of 160 articles this year.

The nature of the research at the institute necessitates and encourages strategic joint research projects with key scientists from a variety of fields in and outside of IQC. In 2010, researchers published papers with 166 researchers from 96 institutes located around the globe. The number of collaborative publications grew from 141 in 2009.

The new Mike & Ophelia Lazaridis Quantum-Nano Centre is a state-of-the-art facility unlike any other, which will offer ideal research conditions, promoting multi-disciplinary research that will be a tremendous draw for the world's top researchers. The construction completion date for the facility is July 2011. Commissioning is complex and will extend into the fall of 2011 with plans to begin migrating people and laboratories into the building in January 2012.

In 2012, the research focus will be to continue leading-edge investigation of theoretical approaches to quantum information processing in order to better understand the impact of quantum mechanics for information processing and to investigate new potential applications. Researchers at IQC will continue developing approaches to quantum information using photonic, nuclear and electron spins, quantum dots, superconducting technologies and proceed with studying the requirements needed to design an earth-to-satellite quantum cryptography systems.

2. To become a magnet for highly qualified personnel in the field of quantum information:

While IQC possesses a critical mass of leading researchers in quantum information science, it is imperative for the future of the institute to recruit, educate and train the next generation of leaders in the field.

In partnership with the faculties of Math, Science and Engineering at the University of Waterloo, IQC launched a multi-disciplinary quantum information graduate program last year. The institute fielded 117 applications for 20 available spaces in the collaborative program in quantum information; as well, 78 Waterloo students indicated an interest in quantum computing on applications to other graduate programs. Including all programs at IQC, there was an increase to 195 applications in 2011 from 104 in 2010.

To attract the best, IQC attended graduate fairs at the University of Waterloo, McGill University, the University of Alberta, the University of Western Ontario, the University of British Columbia, the Canadian Undergraduate Physics Conference, Beijing Normal University, Tsinghua University and Peking University, sharing information with and fielding questions from thousands of attendees.

In 2012, IQC plans to hire up to four faculty members, six to 10 postdoctoral fellows and 20 graduate students.

3. To establish IQC as the authoritative source of insight, analysis and commentary on quantum information:

IQC's third strategic objective is about disseminating quantum information through a number of means: researcher commentaries on key quantum developments and analyses published in leading journals or presented at conferences that add to the body of quantum knowledge is one such method. The IQC website will continue to be

enhanced so that it becomes a sought-after source of quantum information and IQC's people are positioned as leaders in this field.

It is also vital to inform many audiences — in addition to the scientific community — about the 'quantum revolution' and inspire the next generation of quantum scientists who will build on the seminal work being done today. Educating the first quantum-informed workforce will pave the way for productive partnerships with industry. Raising awareness about the role quantum science will play in our future, Canada's leadership, and the international excellence of IQC reinforce the importance of the major investment being made in quantum research and will secure the future of that investment.

To these ends, IQC has expanded its communication and outreach function to focus on knowledge dissemination, attracting students to IQC, raising awareness, and inspiring interest and support from all stakeholders.

The communications and outreach team launched a revamped website in September 2010 with enhanced interactivity, audience-specific features, expanded scientific information, and greater use of social media platforms. A new video library with over 30,000 total channel views explains quantum science in both easily accessible and more scientifically complex videos. Media coverage has nearly doubled over the past year.

IQC significantly increased the number of visitor and student tours, launched a new distinguished lectures series and participated in a variety of key community events such as TEDxWaterloo and Doors Open Waterloo.

The communications and outreach strategy for the next 12 to 18 months encompasses developing and implementing a plan of communications, outreach, events and other activities linked to IQC's 10th anniversary celebrations marking a decade of achievement and progress in quantum development; launching research and creative work that will identify key audiences, stakeholders and messages needed to help showcase the world-class science as broadly and effectively as possible; developing tools and processes for communications; and building relationships with key stakeholders and donors.

The report will take you into greater depth and detail about the science — and the people who are making it happen — at IQC. The future is bright.

1.4 Industry Canada Budget & Financial Statement (\$000s)

	2010 (Actual)	2011 (Actual)	2012 (Budget)	2013 (Budget)	2014 (Budget)	Total
Building	12,615	12,385				25,000
Equipment	938	1,062	1,000	1,000	1,000	5,000
People & Operations	2,947	3,533	4,000	4,500	5,000	20,000
Total	16,500	17,000	5,000	5,500	6,000	50,000

2. SCIENTIFIC HIGHLIGHTS

This section focusses on the fundamental engine that drives IQC — research. Included here are highlights from the past year including scientific results, the recruitment of new researchers (faculty, research assistant professors and postdoctoral fellows), new spin-off companies for quantum technologies, conferences and workshops hosted by IQC.

Researchers at IQC investigate how the laws of quantum mechanics can be harnessed to build new technologies. In particular, their research focusses on new approaches to three applications: computing, communicating and sensing. IQC fosters interdisciplinary collaboration between researchers with expertise in mathematics, physical sciences and engineering, combining theory and experiment.

Many discoveries begin with theoretical investigations and conclusions, which are then tested and proven in the laboratory. Proof-of-principle laboratory work then provides the knowledge and methodology needed to engineer new quantum technologies. We are already seeing this progression — from theory to lab to practical realization — in quantum sensors and actuators, which will offer unprecedented sensitivity and selectivity over their classical counterparts, and will form the building blocks of future quantum technologies including quantum computers.

The areas of research mentioned above can be further broken down into the following eight general themes:

1. Quantum Information Theory
2. Quantum Algorithms
3. Quantum Complexity
4. Quantum Cryptography
5. Quantum Error Correction and Fault-Tolerance
6. Optical Quantum Information Processing
7. Spin-based Quantum Information Processing
8. Nanoelectronics-based Quantum Information Processing

See Appendix C for a full review of each of these eight areas of research.

2.1 RESEARCH HIGHLIGHTS

The year started on a high note when a landmark paper co-authored by IQC faculty member John Watrous and doctoral student Sarvagya Upadhyay earned the prestigious Best Paper Award at the 2010 Symposium on Theory of Computing (STOC). The paper, entitled $QIP = PSPACE$, was chosen from a field of 279 submissions and 79 finalists as having made the most significant contribution to theoretical computer science over the past year. This paper, and its subsequent acknowledgements from the research community, exemplifies the world-class calibre of work happening at IQC.

Lab Experiments Breed Photon Triplets

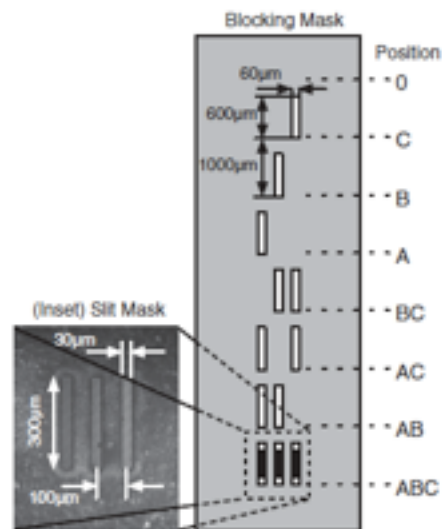
Throughout the year, many key results and breakthroughs clearly demonstrated that IQC is reaping the benefits of its investment in experimental infrastructure. For example, in the paper “Direct Generation of Photon Triplets Using Cascaded Photon-Pair Sources” published in *Nature* 446, 601-603 (2010), researchers in IQC’s quantum optics laboratories, in collaboration with scientists in Austria and Australia, achieved a longstanding milestone in



the field — the direct generation of photon triplets. In the past, the generation of pairs of photons (particles of light) revolutionized quantum optics and made possible emerging technologies such as quantum cryptography and quantum computing with photons. Typically, these photon pairs were created from strong lasers sent through a crystal — a process known as “parametric down-conversion.”

The creation of photon triplets had been sought for years, but never achieved until the IQC-led team first produced a pair of photons with an optical crystal, then split one of the pairs into two additional photons in a second crystal. “This is going to open a new frontier of quantum optics and allow a new class of experiments in quantum computing using photons,” said lead investigator Prof. Thomas Jennewein, an IQC faculty member and professor in the University of Waterloo’s Physics and Astronomy Department. Further research will aim at producing GHZ states, well known in quantum information theory, as they predict deterministic violation of classical behavior, in contradistinction with Bell pairs.

Researchers Test Fundamental Rule of Quantum Physics



Arrangement and dimensions of the slits used in the experiment. The blocking mask has open apertures depending on the measured slit combination. Inset is an image of the triple-slit mask

Following shortly after the photon triplets result was the publication in the journal *Science* of an IQC result that tested a fundamental tenet of quantum mechanics, Born's rule. "Ruling out Multi-Order Interference in Quantum Mechanics," *Science* 23, 418-421 (2010). The rule, which gives the probability that a measurement on a quantum system will yield a given result, is widely believed to always hold true, but had not been subjected to significant experimental scrutiny. It has been suggested that some theories of quantum gravity might violate Born's rule, leading to interesting results for quantum complexity theory. To test the rule, IQC postdoctoral fellow Urbasi Sinha created a "triple-slit experiment," a variation on the famous double-slit experiment (known as an elegant demonstration of quantum effects). Because Sinha and collaborators did not see any violations of quantum mechanical predictions, it helped affirm quantum mechanics as a pillar of modern physics and opened new avenues for exploration.

Team Advances Measurement-based Quantum Computing

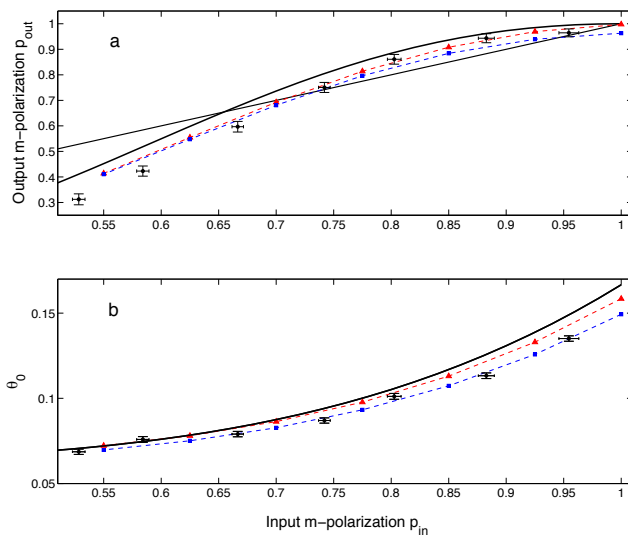
In another experiment conducted in IQC's quantum optics facilities, researchers made a significant step forward in measurement-based quantum computing. The experiment "capitalized on the fact that photonic states can simulate other quantum systems," summarized Jonathan Lavoie, a PhD student at IQC and co-author of the paper "Optical one-way quantum computing with a simulated valence-bond solid." *Nature Physics* 6, 850-845 (2010) published last October. The team experimentally achieved a result that had previously been theoretically considered as a resource for measurement-based (or "one-way") quantum computing. The researchers created and characterized, for the first time, a so-called AKLT (Affleck-Kennedy-Lieb-Tasaki) state, which can serve as a quantum processor. AKLT states are attractive for measurement-based quantum computing because they can be obtained simply by cooling the right solid-state system down to very low

temperatures. The IQC researchers devised the means to simulate the AKLT state by using properties of photons, the fundamental particles of light. The experiment demonstrates the viability of quantum computation using AKLT states, and will inform future work in condensed matter physics.

“Our experiment is bridging the gap between condensed matter physics and quantum information,” said Prof. Kevin Resch, an IQC faculty member and professor in the University of Waterloo’s Physics & Astronomy department. “That’s an important area to explore.”



Error-Correction Breakthrough



Experimental results after the completion of magic state distillation. Output m-polarization of the faulty magic state (a) and the probability θ_0 (b) of finding this state in the mixture of possible outcomes as a function of the input m-polarization of the initial faulty magic state. The experimental data are represented by the filled circles and the error bars are estimated from the uncertainty of the fitting parameters. The point above the straight line in a shows success in a distillation.

One hurdle on the road to building quantum computers is that they are very vulnerable to errors caused by unintended interactions with the environment. Indeed, errors are unavoidable in any device used for quantum information processing. In January 2011, IQC researchers published the paper “Experimental magic state distillation for fault-tolerant quantum computing,” *Nature Communications* 2, 169 (2011), explaining how they implemented a novel way to cope with errors inherent to quantum systems. A number of error-correcting and fault-tolerant methods have been developed in recent years to overcome quantum imperfections. In particular, some methods rely on the ability to prepare quantum bits (qubits)

in a special high-purity state: the so-called “magic state.” This is an area to which IQC faculty member Ben Reichardt has previously made valuable contributions in recent years.

In the recent experiment, researchers implemented, for the first time, magic-state distillation. This quantum algorithm involves applying quantum operations to five imperfect magic states and distilling one with high purity. The research team implemented the distillation protocol with a seven-qubit quantum processor. In order to successfully realize their experiment, they had to achieve a high degree of control over their qubits. The result is an important building block in the implementation of quantum information processing.

QIP2011 Conference, January 2011

In January Andrew Childs gave an invited presentation at the QIP2011 conference in Singapore. He reported on his work with elliptic curve isogenies. It is well known that quantum computers can break many of the most common public key cryptographic systems such as RSA (a result due to Shor) and elliptic curve cryptography (a result due to Zalka while he was a postdoctoral fellow at IQC). Cryptographers have since attempted to build new cryptosystems that are resilient to quantum attacks, an area of research called post-quantum cryptography. One of these systems is based on elliptic curve isogenies. Childs and his collaborators David Jao and Vladimir Soukharev found a quantum algorithm that was significantly faster than the best-known classical algorithm, which suggests these cryptosystems may be susceptible to quantum attacks. This is an important result that cast doubts on the belief of post-quantum cryptography.

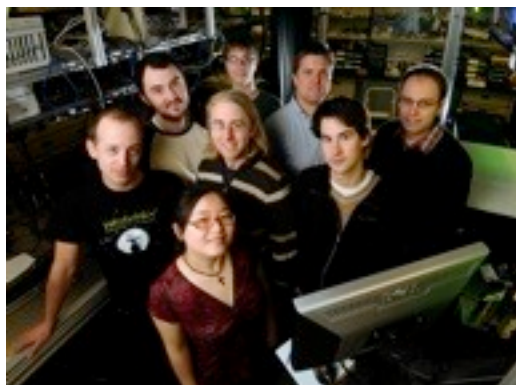
QIP is the premium international conference devoted to quantum algorithm and invited papers carry an important aura.

IQC was well represented at the 14th Workshop on Quantum Information Processing in Singapore. Contributions included:

- “Entanglement can increase asymptotic rates of zero-error classical communication over classical channels,” by Debbie Leung, Laura Mancinska, William Matthews, Maris Ozols and Adian Roy
- “Quantum interactive proofs with weak error bounds,” by Tsuyoshi Ito, John Watrous and collaborators
- “On the solution space of quantum 2-SAT problems,” by Jianxin Chen, Bei Zeng and collaborators

- “Quantum query and complexity of minor-closed graph properties,” by Andrew Childs and Robin Kothari
- “Finding is as easy as detecting for quantum walks,” by Maris Ozols and collaborators
- “Constructing elliptic curve isogenies in quantum subexponential time,” by Andrew Childs and collaborators

Entanglement a Game-Changer in Communication



In March 2011, researchers at IQC demonstrated that quantum entanglement — the powerful correlation between particles — can significantly enhance the accuracy of communication between parties. Building upon work led the previous year by IQC postdoctoral fellow Will Matthews, the team experimentally demonstrated the use of entanglement for communication over a “noisy” classical channel.

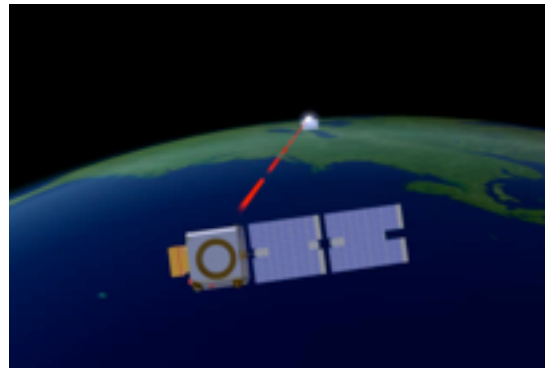
While entanglement cannot itself be used to communicate, the IQC optics researchers demonstrated that one can transmit information over a certain channel with higher success when using entanglement than with the means available in classical physics. The team published their results in the paper “Entanglement-Enhanced Classical Communication Over a Noisy Classical Channel,” *Physical Review Letters* 106, 110505 (2011). In a commentary article on physics.aps.org, writer Mark Wilde explains the experiment in terms of a game show, on which a pair of contestants named Alice and Bob play a game called “Guess That Button.” To win a date with Alice at a nice restaurant, Bob must guess which button Alice has randomly pushed on a board with four coloured buttons.

While the board offers hints as to which button Alice pushed, ultimately Bob is clueless as to exactly which button Alice has pushed — unless, that is, the rules of the game are changed from classical to quantum. The IQC researchers demonstrated a scenario in which Alice and Bob stand a much greater chance of winning the game by sharing entangled photons in advance. The game show analogy illustrates a “noisy classical communication channel,” over which communication between Alice and Bob is markedly improved by using entanglement. The experimental discovery, and the theoretical work that preceded it, were also highlighted in *Physics Today*.

"The fact that entanglement can be used in this way was only recently recognized," researcher Will Matthews said of the work. "It was great to be able to work with the optics researchers at IQC to demonstrate it experimentally so soon. I am currently working to understand theoretically just how useful entanglement can be in this context."

Quantum Key Distribution Via Satellite

Another project that has generated much interest at IQC and abroad is the effort to establish a secure global quantum communication network. Such a network would allow the testing some fundamental concepts in physics, and open the possibility of a worldwide system for quantum key distribution. A research team led by Thomas Jennewein, Norbert Lütkenhaus and Raymond Laflamme is developing the theory and technology necessary to establish such a global network in collaboration with industry/government partners COMDEV (global designer and manufacturer of space hardware), the Institut National d'Optique and the Canadian Space Agency, along with academic partners Perimeter Institute, the universities of Cambridge, Calgary, Toronto.



Schematic of QKD via Satellite

Such work on quantum key distribution and other facets of quantum optics has led toward IQC's first spin-off company: Universal Quantum Devices Incorporated (UQD). The company aims to provide instrumentation for use in sophisticated quantum optics laboratories around the world. UQD will provide optical instruments — some of which are made exclusively by UQD, having been originally created for use in optics laboratories at the Institute for Quantum Computing. UQD will also be the North American distributor of specialized quantum optics instruments produced overseas. The initial flagship instrument is the



IQCLogic Unit

IQCLogic Unit, designed and built in cooperation with DotFast Consulting. The unit combines a timing analyzer, a coincidence logic unit and counters for 16 input channels on one device — a useful instrument for an array of research in quantum optics. “It’s a high-level product for photon experiments that outperforms anything previously available,” said Thomas Jennewein, UQD co-founder and IQC faculty member.

IQC Papers Among Most Cited in Their Fields

Each year, the *New Journal of Physics* compiles a collection of papers that represent the very best scientific work published within its pages. In 2010, the journal named a paper by IQC researchers Seth Merkel and Frank Wilhelm as one of the ten-best papers in the field of quantum physics. The paper, “Generation and detection of NOON states in superconducting circuits,” was published in the September 2010 issue of the journal. The paper explores NOON states, which are highly nonclassical entangled quantum states with applications in super-resolution interferometry. Merkel and Wilhelm demonstrated how these states can be efficiently produced in circuit quantum electrodynamics using superconducting phase qubits and resonators. The article and others listed in “Best of 2010” were selected “for their presentation of outstanding new research, receipt of the highest praise from our international referees and the highest number of downloads last year.”

Sciencewatch.com conducted a review of the top 20 most cited papers in quantum computing over the past decade. Two publications by IQC faculty members made the top 10. In the top spot, “A scheme for efficient quantum computation with linear optics” by Raymond Laflamme and collaborators in *Nature* 409, 46-52 (2001) with 1160 total cites. Number 10 on the list was “Experimental one-way quantum computing” by Kevin Resch and collaborators in *Nature* 434, 169-176 (2005) with 284 total cites. For more information on these two publications see Appendix K.

2.2 NEW FACULTY & RESEARCH ASSISTANT PROFESSORS

Prof. David Cory joined IQC and the University of Waterloo as Canada Excellence Research Chair (CERC) in Quantum Information Processing in June 2010. Cory's state-of-the-art laboratory in the Research Advancement Centre II was outfitted with equipment for conducting experiments using nuclear spin, electron spin, superconducting qubits and quantum optics. Cory, who joins IQC from the Massachusetts Institute of Technology, leads experimental investigations into quantum sensors and actuators. Cory's research is expected to contribute to the world's first generation of practical quantum devices. These new technologies will have immediate and future applications in medicine, communications, biochemistry, physics and nanoscience.



Dmitry Pushin joined IQC as a research assistant professor in September 2010 from the Massachusetts Institute of Technology, where he worked as a postdoctoral associate with Prof. David Cory. Pushin is a specialist in the area of interface of neutron interferometry, condensed matter physics and quantum information. Pushin is working with the National Institute of Standards and Technology (NIST) to implement the "Power of one qubit" code that will make neutron interferometry measurements of magnetic cross-sections more robust. This has applications in material science, biology and nanotechnology.



Marco Piani became a research assistant professor in September 2010. He had been working at IQC in the area of quantum information theory before that, having joined the Institute in October 2007 as a postdoctoral fellow with Prof. Norbert Lütkenhaus and Prof. John Watrous. His interests lie mainly in the characterization, quantification, detection and exploitation of the non-classical features of correlations exhibited by distributed quantum systems.



Jay Gambetta started his research assistant professorship at IQC in October 2010 following a postdoctoral fellowship at the institute. He has contributed to leading-edge work with photons and superconducting qubits. The paper in the June 20 (2010) issue of *Nature Physics* explores quantum non-demolition (QND) measurement of photons. The research outlines techniques for detecting photons in microwave circuits with minimal

disturbance, which is an important step in the development of quantum communications. In the Sept. 29 (2010) issue of *Nature*, Gambetta and a team of former colleagues at Yale demonstrated three-qubit entanglement in a superconducting circuit.

To review IQC's full membership — including a list of all faculty, research assistant professors, postdoctoral fellows and students— see section 3.1.2 or Appendix E.

2.3 CONFERENCES & WORKSHOPS

IQC hosted six conferences in total in 2010. Aimed at fostering conversation and collaboration between leading-edge researchers from around the world, these events exemplify the interdisciplinary research mandate of IQC. Two of the six conferences at the institute in the past year stood out thanks to the exciting results and world class scientists that attended.

To review details about all six conferences see section 3.3.1.7.

The Workshop on Quantum Information Processing with Spins and Superconductors was organized by IQC researchers Jay Gambetta and Bill Coish. The event took place from May 17 to 19, 2010 and brought world leaders in superconducting quantum information to Waterloo. The workshop primarily focused on implementations for quantum computing that use either superconducting circuits or spins in semiconductors. In addition to implementations for the two separate systems, there were a number of talks focusing on hybrid platforms that attempt to use both the long coherence times of spin systems and the precision control of superconducting qubits. A number of key advances were explored, including, for instance, the first three-qubit register for superconducting qubits. There was roughly equal representation from the theory and experimental communities. Accordingly, the talks ran the gamut between reports on the current laboratory state of the art, explanations of observed errors and decoherence, and proposals for new devices and architectures.

The workshop titled *Theory and Realization of Practical Quantum Key Distribution* was held from June 14 to 17, 2010. It was organized by IQC researchers Norbert Lütkenhaus, Michele Mosca, Thomas Jennewein and Marco Piani. It focused on the most advanced present-day application of quantum information science, quantum key distribution (QKD), which has already seen real-world, commercial implementation. The workshop brought together leading experts from around the world who are investigating all aspects and subfields of QKD, spanning theory and experiment. The conference was highly successful in generating dialogue between theorists and experimentalists, sparking new ideas about quantum key distribution. Based on this success, organizers are holding the conference again in summer 2012.



To review all six of IQC's conferences and workshops this year see section 3.3.1.7

3. RESULTS

The following sections correspond to IQC's three strategic objectives.

As stated, IQC's three strategic objectives help to fulfill the institute's long-term goal of ensuring Canada plays a leading role in the development of new technologies. IQC fosters collaboration between computer scientists, engineers, mathematicians and physicists to ensure its ability to pursue a variety of experimental and theoretical approaches to quantum information research.

IQC produced a strategic research plan that integrates the institute's three main objectives, its mission, vision and the eight specific reporting measures developed in partnership with Industry Canada. The diagram is available in Appendix S.

The following sections show how IQC will continue to build a vibrant knowledge community of researchers to ensure Canada and Waterloo are positioned as global leaders in the quantum information revolution.

3.1 ESTABLISHING WATERLOO AS A WORLD-CLASS CENTRE FOR RESEARCH IN QUANTUM TECHNOLOGIES AND THEIR APPLICATIONS

IQC's first strategic objective, to establish Waterloo as a world-class centre for research in quantum technologies and their applications, is realized through four specific focus areas:

1. Conducting research in quantum information
2. Recruiting researchers
3. Collaborating with other researchers
4. Building, facilities and laboratory support

Within these areas, IQC made continuous and exciting progress in 2011.

Below you will find a review of the relevant objectives set by IQC in the 2010 Industry Canada report, and several metrics demonstrating how the institute achieved those objectives. Each focus area has facts and figures that demonstrate the institute's activities related to the first strategic objective of establishing Waterloo as a world-class centre for research in quantum technologies and their applications.

Objectives for 2012 can be found in section 4.

3.1.1 Conducting Research in Quantum Information

The institute's primary mandate is to conduct research in quantum information science at the highest international level. This goal has necessitated the ongoing recruitment of top faculty, postdoctoral fellows and students, the acquisition of cutting-edge equipment and resources, and the creation of a working environment that fosters scientific excellence. The continued expansion of the institute will allow researchers at IQC to explore new theoretical and experimental approaches to quantum information processing over the coming years.

2011 Objectives

- Leading-edge investigation of theoretical approaches to quantum information processing in order to better understand the impact of quantum mechanics for information processing and to investigate new potential applications
 - Information on publications can be found in section 3.1.1.2
 - Information on collaborative research projects can be found in section 3.1.3.1
- Develop approaches to quantum information using photonic, nuclear and electron spins, quantum dots, superconducting technologies and study the requirements needed to design earth-to-satellite quantum cryptography systems
 - An IQC research team led by Thomas Jennewein, Norbert Lütkenhaus and Raymond Laflamme is developing the theory and technology necessary to establish a secure global network encrypted by Quantum Key Distribution (QKD) via satellites in collaboration with the Canadian Space Agency. Relevant industry contacts have also been established, including COM DEV and INO

Below is a review of the grants awarded to IQC and its members in fiscal 2011, a look at the institute's publications dating back to 2002 and a summary of IQC's citations dating back to 2001.

These are three indicators that demonstrate IQC's research output. Additional important metrics, including collaborations and scientific visitors, follow in the coming sections.

3.1.1.1 New Grants

As per the University of Waterloo, Office of Research:

Including Industry Canada's installment of \$17 million in 2011, IQC received 80 new grants between May 1, 2010 and April 30, 2011 totaling \$25,297,158.

IQC's 2010 grants amounted to \$23,870,979 including Industry Canada's \$16.5 million contribution.

To review the summary of grants from IQC's 2011 fiscal year see Appendix H.

“IQC is a remarkable institution, admired by all its peers and competitors.”

Charles Clark,
Chief, Electron and Optical Physics Division
National Institute of Standards and Technology

3.1.1.2 Publications

IQC implemented an enhanced publication tracking system in 2011¹. The quality and number of publications show a strong research output that is comparable to other top institutions globally.

Below is a graph depicting publications at IQC for the 2010 calendar year.

Notable publications in the journals *Nature*, *Nature Photonics*, *Nature Physics*, *Physical Review Letters* and *Science* are important additions to the publications database.

Publication	Number
Nature	3
Nature Photonics	1
Nature Physics	5
Physical Review Letters	13
Science	1
STOC	2

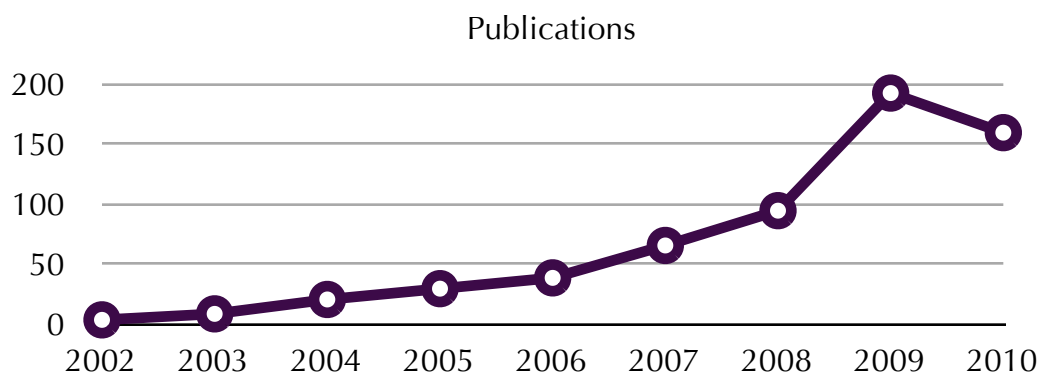
Publications were collected primarily from the curriculum vitas and annual faculty reports of each researcher that was a part of IQC since its establishment². A profile for each

¹ IQC implemented enhanced publications and citations tracking procedures which yield more complete results. As a result, we have re-stated 2010 numbers in this year's report to provide a more accurate comparison to 2010 activity.

² IQC researchers include Faculty, Research Assistant Professors, (certain) Associate members of IQC, Postdoctoral fellows, students and long term visitors.

researcher was created in a repository and it was populated with their respective IQC publications. The meta-data for each publication was then imported from various research databases and electronic archives including Web of Science, Scopus, IEEE Xplore, arXiv, and Cryptography ePrint Archive.

For a list of IQC's publications from the 2010 calendar year see Appendix I.



Year	2002	2003	2004	2005	2006	2007	2008	2009	2010
Publications	4	9	21	30	39	66	95	193	160

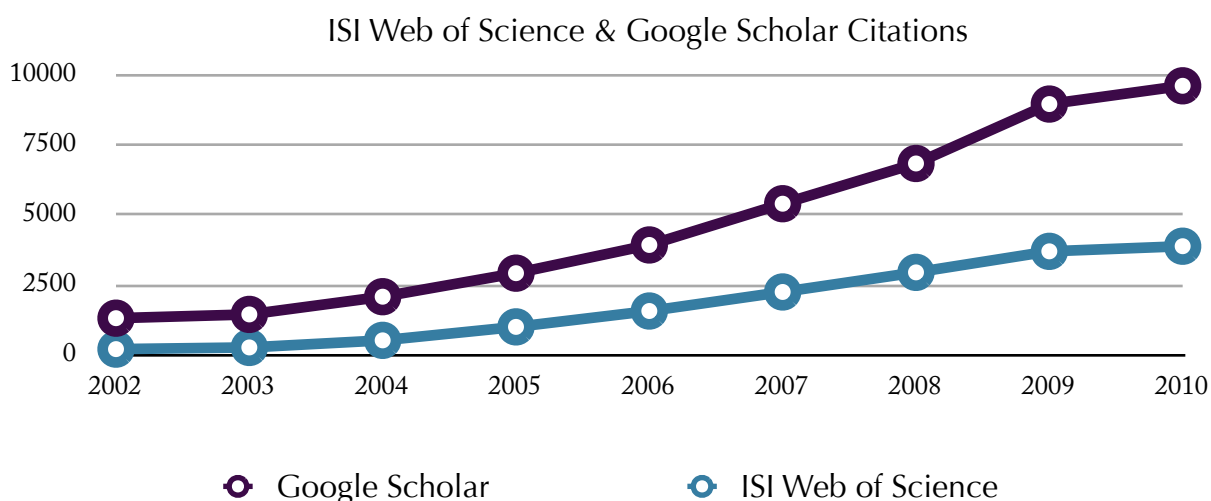
Visit IQC's "Quantum Library" at pubs.iqc.ca to explore the institute's electronic publications database launched in April 2011. The repository is able to store, share and search all of IQC's digital research material.

In a recent report on Quantum Capability by the Government of Canada, the University of Waterloo (Institute for Quantum Computing) was ranked fifth in the world for institutional affiliations in quantum computing literature.

3.1.1.3 Citations

The chart below illustrates the number of citations of publications with the designation “Institute for Quantum Computing” dating back to 2002. The graph shows a comparison of citations collected by both Google Scholar and the ISI Web of Science³.

Similarly, these trends should be interpreted alongside other metrics that show IQC advancing research in quantum technology including: publications, collaborative research projects, scientific visitors, presentations, and more.



	2002	2003	2004	2005	2006	2007	2008	2009	2010
ISI Web of Science	222	282	535	1016	1583	2263	2963	3714	3897
Google Scholar	1327	1461	2094	2934	3942	5415	6852	8947	9626

Since these figures were collected in March 2011, it is too early to determine all the citations that the 2010 publications received. A more accurate representation of these citations will be made able in our 2012 reporting.

³ The numbers collected from ISI Web of Science and Google Scholar were used to calculate the total citations that each researcher received for their IQC publications in a given year. These numbers were then used to calculate IQC's cumulative publication citations for every year, starting with 2001.

IQC collects additional bibliographic data. This is available upon request.

Top 10 Cited Papers Award

Sciencewatch.com conducted a review of the top 20 most cited papers in quantum computing over the past decade. Two publications by IQC faculty members made the top 10.

In the top spot, "A scheme for efficient quantum computation with linear optics" by Raymond Laflamme and collaborators in Nature 409, 46-52 (2001) with 1160 total cites.

In at number 10 on the list, "Experimental one-way quantum computing" by Kevin Resch and collaborators in Nature 434, 169-176 (2005) with 284 total cites.

For more information on these two specific publications see Appendix K.

The baseline time span for this database is 1999-December 31, 2009 (sixth bimonthly period 2009). The resulting database contained 12,386 (10 years) and 3,541 (2 years) papers. To construct the top 20 papers lists for the past decade and the past two years, the papers were further narrowed down by the title keywords "quantum comput*." This adjustment resulted in the top 20 papers being selected from a pool of 1,422 (10 years) and 243 (two years) papers.

For the full list of papers visit <http://sciencewatch.com/ana/st/quantum/papers10yr/>

"IQC will place Waterloo at the forefront of a new frontier of knowledge."

Governor General of Canada, David Johnston
Former President, University of Waterloo

3.1.2 Recruiting Researchers

The mission of IQC is to develop and harness quantum information science and technology at the highest international level through the collaboration of computer scientists, engineers, mathematicians and physicists. To this end, IQC must continue to build a team of theoretical and experimental researchers who are leaders in their respective disciplines. With such top researchers, IQC can achieve its strategic objectives of becoming a magnet for students and postdoctoral researchers, doing world-class science and becoming the authoritative source of insight, analysis and commentary on quantum information.

2011 Objectives

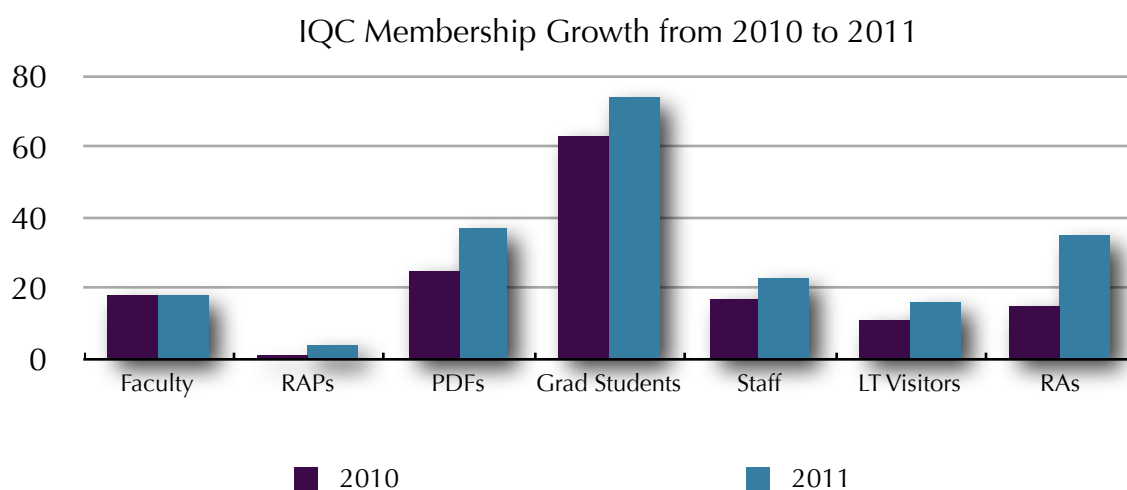
- Recruit up to three new faculty members
- Recruit between six to 10 new postdoctoral fellows
- Recruit 20 new graduate students
- Leverage conferences and other outreach forums as recruitment opportunities
 - IQC hosted six conferences and participated in seven graduate recruitment events. More information on recruitment events is available in section 3.3.1.3

Below is a review of the number of researchers at IQC during the 2011 fiscal year, a review of IQCs recruitment goals and actual recruitment totals. For details on Dr. David Cory, IQC newest faculty member and Canadian Excellence Research Chair in Quantum Computing, or the institute's new research assistant professors, see section 2.2.

3.1.2.1 Researchers at IQC

Over the next several years, IQC plans to expand to 30 faculty, 50 postdoctoral fellows and 125 graduate students.

The graph below shows the growth of IQC researchers from 2010 to 2011.



During the 2011 fiscal year, IQC was home to 18 faculty members, 4 research assistant professors, 37 postdoctoral fellows, 74 graduate students, 35 research assistants, 16 long-term visitors and 23 administrative support personnel.

3.1.2.2 Recruitment Goals

	Goal to Recruit	Researchers Recruited
Faculty	1 - 3	1 - Canadian Excellence Research Chair in Quantum Information Processing
Research Assistant Professors		3
Postdoctoral Fellows	6 - 10	18
Graduate Students	20	20

Postdoctoral fellows recruited during the 2011 fiscal year came to IQC from:

- Austrian Academy of Sciences, Austria
- Harvard University, USA
- Joseph Fourier University, France
- Kinki University, Japan
- Nicolaus Copernicus University, Poland
- Perimeter Institute
- Queen Mary, University of London, UK
- Rutgers, The State University of New Jersey, USA
- Tsinghua University, China
- University of California, Davis, USA
- University of Georgia, USA
- University of Toronto, Canada
- University of Vienna, Austria
- University of Waterloo, Canada

More information on student recruitment is available in section 3.2.1

3.1.3 Collaborating with Other Researchers

The field of quantum information processing spans many disciplines — physics, chemistry, computer science, mathematics and more. Breakthroughs in quantum information will come from collaborations between researchers in a variety of fields. IQC's strategy for success is to encourage interdisciplinary research between the various groups at IQC and national and international collaborators.

2011 Objectives

- IQC to be a catalyst to facilitate collaborations of quantum information scientists through networks such as QuantumWorks, Canadian Institute for Advanced Research (CIFAR) Quantum Information program and the Natural Sciences and Engineering Research Council of Canada (NSERC) Strategic Networks
- IQC researchers will attend international conferences on quantum information processing to build networks and connections
 - Information about domestic and international presentations by IQC faculty is available in section 3.1.1.9
- Increased number of publications co-authored by IQC researchers and external collaborators
 - Information about publications is available in section 3.1.1.2
- Organize three conferences that involve multi-disciplinary participants
 - IQC organized six conferences in fiscal 2011. More information on conferences is available in section 3.3.1.7
- Continue, enhance and increase visits to IQC by researchers from around the world
 - IQC hosted 138 visitors in fiscal 2011. More information on scientific and academic visitors is available in section 3.1.3.2

The following section recounts the collaborative research projects that IQC researchers participated in during the 2010 calendar year and research networks like those mentioned above. A review of scientific and academic visitors during the 2011 fiscal year and a list of IQC's memoranda of understanding also follow.

These are several indicators that demonstrate IQC's commitment to interdisciplinary research. Additional important metrics follow in the coming sections.

3.1.3.1 Collaborative Research Projects

Collaborative research projects involve IQC researchers networking with scientists around the world doing joint research and publishing their results together. IQC faculty members collaborated with 166 external researchers in the publication of 56 joint papers during the 2010 calendar year. As stated on the previous page, many publications resulted from collaborations between researchers internally at IQC.

56	Papers co-authored by IQC faculty and other non-IQC researchers
166	Number of non-IQC co-authors on publications
96	Institutes whose researchers have collaborated with IQC faculty

In 2009, IQC faculty members collaborated with 141 non-IQC co-authors yielding an increase of 25 new or renewed connections for the 2010 calendar year. In 2009, there were 41 joint publications whereas in 2010 there were 56. This shows IQC's international network expanding, laying the groundwork for exciting development in the future.

IQC researchers participated in collaborative research projects with institutes in 20 countries around the globe. The following illustration shows a map connecting IQC with the countries of collaborating institutes. Dark purple regions show areas with a higher number of collaborating institutions.



IQC researchers have collaborated with 166 collaborators in 96 institutes from 20 countries.

Research Networks

In order to help establish Waterloo as a world-class centre for research in quantum technologies and their applications, IQC intends to continue facilitating collaboration between quantum scientists through research networks.

QuantumWorks, Canada's research network in quantum information processing (based at the Institute for Quantum Computing) was established as an NSERC Innovation Platform in 2006. The network served as an umbrella organization, allowing for collaboration across diverse fields within quantum information in Canada. It also connected with stakeholders from the public and private sector, including the Communications Security Establishment Canada and ETSI. QuantumWorks will be concluding its mandate in the fall of 2011.

An application for a new research network has been submitted to NSERC to establish the NSERC Nano-Qubits Network (NNQ). Proposed Scientific Director of NNQ, David Cory, is the Canada Excellence Research Chair in quantum information processing and is based at IQC. Like QuantumWorks, NNQ has a Canada-wide focus, with collaborations among 18 researchers at Université de Sherbrooke, McGill University, University of Ottawa, University of British Columbia, University of Victoria, and University of Waterloo.

See Appendix J for a list of collaborating institutions.

“I had no idea that a place called Waterloo existed outside Europe before Perimeter and IQC were created, and now it is completely on the map. I would say that for quantum, it is *the* place in Canada.”

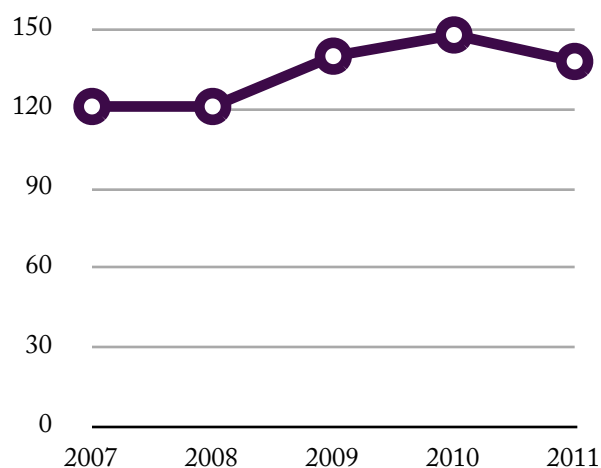
Tommaso Calarco
University of Ulm, Germany

3.1.3.2 Academic & Scientific Visitors

One hundred and thirty-eight academic or scientific researchers visited IQC during the 2011 fiscal year.

IQC hosted academics and scientific visitors from world-leading institutions in: Australia, Austria, Canada, China, France, Germany, India, Japan, Korea, Latvia, Netherlands, Norway, Singapore, Spain, Switzerland, Ukraine, United Kingdom and the United States.

Below is a chart showing the trend in IQC’s academic visitors over the past five years. For a full list of IQC’s academic and scientific visitors in 2011 see Appendix L.



Fiscal Year	# of Visitors
2011	138
2010	148
2009	140
2008	121
2007	121

For information on visits from government officials, industry or businesspeople and academic tour groups see section 3.3.1.6

“IQC is an amazing place, and I hope I will have a chance to visit again some day.”

Prof. Avinatan Hassidim, Massachusetts Institute of Technology

QuantumWorks also hosts visitors at the Institute for Quantum Computing. In fiscal 2011 the network invited 26 visitors. See Appendix L for the names of these additional 26.

3.1.3.3 Memoranda of Understanding

IQC has a total of six agreements to date. Generally, these constitute an agreement between parties that can help to facilitate collaborative research projects, joint research and the pursuit of common scientific interests.

National Research Council (NRC)— Memorandum of Understanding (May 2010)

National University of Singapore— Memorandum of Understanding (March, 2010)

International Business Machines (IBM) – Software License Agreement (January, 2010)

National Science Council of Taiwan— Statement of Understanding (December, 2009)

Indian Institute of Technology, Kanpur – Memorandum of Understanding (April, 2006)

National Institute of Informatics, Japan – Memorandum of Understanding (December, 2005)

3.1.4 Building, Facilities and Laboratory Support

Having the proper infrastructure to support world-class research is critical to the success of the institute. IQC is currently based in two buildings on the uWaterloo north campus in the Research Advancement Centre I & II (RAC I & RAC II). These two facilities have laboratories for research in optics, superconducting qubits, quantum dots, nuclear and electron magnetic resonance, single photon detectors and quantum sensors. Additionally, a successful interim cleanroom was constructed to service the needs of researchers until the fabrication facility in the Mike & Ophelia Lazaridis Quantum-Nano Centre is ready. The Industry Canada funding was essential to the completion of the RAC I cleanroom, an important step in enhancing IQC's international competitiveness.

Construction at the Mike & Ophelia Lazaridis Quantum-Nano Centre (QNC) is scheduled for completion in July 2011. The centre, located at the heart of the University Waterloo's main campus, will become IQC's new headquarters upon completion. The centre will be home to a 20,000 sq. ft. fabrication and metrology lab as well as the Waterloo Institute for Nanotechnology. IQC will continue to maintain laboratory space on the north campus at the University of Waterloo in RAC I and RAC II.

2011 Objectives

- Proceed with the construction of the Mike & Ophelia Lazaridis Quantum-Nano Centre and ensure that the building is constructed per specifications, on time and on budget
- Prepare equipment and other resources for expansion into to the QNC
- Continue the acquisition and maintenance of equipment for RAC I and RAC II laboratories

Below is a review of the changes in each of IQC's three research facilities over the past year.

3.1.4.1 Research Advancement Centre I

Industry Canada funding was spent on experimental laboratory equipment for use in RAC I.

RAC I Cleanroom:

Systems installed since last year's report include:

- E-beam evaporator needed for lift-off processes used by Baugh & Lupascu
- ICP RIE for etching of metals such as Al, Cr and Nb,
- Deep RIE for etching of silicon via Bosch or mixed gas processes
- Oxygen plasma etch system for removal of photoresist
- Atomic layer deposition system clustered with a plasma-enhanced chemical vapor deposition system (ALD/PECVD) for depositing a wide assortment of thin films, both conducting and insulating as well as transparent conducting oxides (TCO's)
- Electrical probe station



IQC's Information Technology team established the fabrication facility's website, which includes a scheduler for booking time on equipment, detailed training documents/procedures, process recipes routinely needed by researchers, and more.

Industry Canada funds have been used for the following items in RACI.

- Cooling unit for photon detectors which creates temperatures of -80C for system stability
 - The system is used for experiments in quantum cryptography (both in free-space and optical-fibre) as well as photon triplet experiments
 - These require detectors sensitive to telecom photons, which must be cooled between -50C to -80C
- Pockel's cell for photon triplets experiments
- Laser for photon triplets experiments
- Maintenance on the dilution refrigerator
- Preamplifier
- Custom photo mask for the fabrication of nanodevices, specifically in photolithography processes
- Magnetic shield for the cryostat
- Two low-noise amplifiers
- Microwave circulator

- 2-axis, 6-tesla vector magnet
- Cryogenic superconducting coaxial cable
- Sample storage box for microfabricated devices
- Low-noise DC-coupled amplifier to augment wideband DC-coupled signals
- Vector network analyzer
- Spectrum analyzer
- Lock-in amplifier for low noise electrical
- Soldering station for SMD components
- Cryogenic wafers for single photon detection
- Microscope
- Miscellaneous shared parts and components

3.1.4.2 Research Advancement Centre II

In the spring of 2010, construction on the Research Advancement Centre II (RAC II) was completed and by the end of summer the first floor was populated with the laboratory equipment of Prof. David Cory.

Although Industry Canada funds were focused on the laboratories in RAC I, the following list recounts the new equipment in RACII.

The laboratory is centered around spin-based approaches to quantum research, with emphasis on the development and engineering of sensitive and robust quantum sensors, actuators and transducers, with the long-term goal of engineering quantum devices.

RAC II laboratory is fully functioning with the following equipment:

- 7 nuclear magnetic spin resonance spectrometers
 - Made by Bruker BioSpin in the following strengths: 600MHz, 400 MHz, 300 MHz, 142 MHz and 100MHz
- One optically detected nuclear magnetic resonance setup



- One electrically detected nuclear magnetic resonance setup
- One dilution refrigerator
- One helium3 system
- One probe station
- One continuous wave x-band electron spin resonance spectrometer
- One pulsed x-band with endor-electron spin resonance spectrometer
- One q-band pulsed electron spin resonance system
- One s-band pulsed electron spin resonance system
- One v-band electron spin resonance system
- One atomic force microscopy system
- One nuclear quadrupole resonance spectrometer
- One micro-CT scanner

All equipment was transferred from Prof. David Cory's laboratory at the Massachusetts Institute of Technology except for the atomic force microscopy system, the probe station and one of the 300MHz spectrometers.

3.1.4.3 The Mike & Ophelia Lazaridis Quantum-Nano Centre

The Mike & Ophelia Lazaridis Quantum-Nano Centre is a state-of-the-art facility that will further cement IQC's reputation as a leading international research centre by offering ideal research conditions, promoting collaborative research between disciplines and serving as a magnet for the world's top researchers.

The centre will be home to a 20,000 sq. ft. fabrication and metrology lab, as well as the Waterloo Institute for Nanotechnology (WIN). The building will foster cross-disciplinary collaboration in its many common areas, lounges and meeting rooms. The centre will allow the institute to continue its aggressive growth, as the institute plans to expand to 30 faculty, 50 postdoctoral fellows and 125 graduate students over the coming years.

Designers of the facility were guided by three principles:

1. It must be functional, i.e. meet the highest scientific standards, including stringent vibration and temperature, humidity and low electromagnetic radiation standards
2. It must encourage interaction and collaboration between researchers and students
3. It should attract top scientists to Waterloo

The construction completion date for the facility is July 2011. Commissioning is complex and will extend into the fall of 2011 with plans to begin migrating people and laboratories

into the building in early 2012.

As of April 30, 2011, the Mike & Ophelia Lazaridis Quantum-Nano Centre was 85 per cent complete.

The project remains within the approved budget and is being constructed as per University of Waterloo specifications.

All funding provided by Industry Canada for the 2011 fiscal year with regards to the construction of the Mike & Ophelia Lazaridis Quantum-Nano Centre has been expended. The construction of the QNC created a total of 250 jobs related to the Industry Canada grant in 2010 and 2011⁴. There were 124 new jobs in 2011 and 126 new jobs in 2010.



Commissioning for the facility will be completed in early 2012.

⁴ If \$100,000 equals one job - with the April 2011 numbers projected

3.2 BECOMING A MAGNET FOR HIGHLY QUALIFIED PERSONNEL IN THE FIELD OF QUANTUM INFORMATION

IQC's second strategic objective, to become a magnet for highly qualified personnel in the field of quantum information, is realized primarily through attracting, educating and training students and researchers.

In the following section you will find a review of the relevant objectives set by IQC in the 2010 Industry Canada report, and several metrics demonstrating how the institute achieved those goals. Each focus area has facts and figures that demonstrate the institute's activities related to the second strategic objective of becoming a magnet for highly qualified personnel in the field of quantum information.

Objectives for 2012 can be found in section 4.

3.2.1 Attracting, Educating and Training Highly Qualified Personnel

The path toward the realization and commercialization of practical quantum information technologies will be forged by the current generation of students. Seeking out prospective students, recruiting them to IQC and providing them with the necessary resources and guidance is critical to the long-term mission and vision of IQC.

2011 Objectives

- Establish an open house event for graduate students to attract prospective applicants
 - IQC held tours for potential graduate students from the University of Waterloo, Wilfrid Laurier University, Laurentian University and the University of Guelph. Students from the Perimeter Scholars International (PSI) program were invited for a second year of study at IQC
 - Two students from the PSI program joined IQC for the fall and winter terms and three students have been offered positions to join in fall 2011
- Enhance prominence and content of graduate studies program on the IQC website
 - The graduate studies section on iqc.uwaterloo.ca/welcome/graduate is now home to detailed program and course information. For information on IQC's website see section 3.3.2.3
- Attend at least four graduate fairs and host an information session for uWaterloo students
 - IQC attended seven graduate recruitment events. For information on graduate fairs see section 3.3.1.2
- Field at least 120 applications to the uWaterloo/IQC graduate studies program
 - There were 195 applications. For more information on program applications see section 3.2.1.2

Below is a review of the metrics related to attracting, educating and training highly qualified personnel including: application numbers for researcher positions at the institute, international and domestic researchers at IQC, information about the quantum information graduate program, courses taught over the past year, and information on current and former graduate students.

3.2.1.1 Domestic and International

Below is a chart showing the citizenship of IQC's faculty, research assistant professors, postdoctoral fellows and graduate students.

	Canadian/ Dual Citizens	Applying for Permanent Residency	International
Faculty	11	1	6
Research Assistant Professors	1	0	3
Postdoctoral Fellows	11	0	26
Graduate Students	32	0	42

"IQC seems to be a spectacularly successful effort, collecting top people in quantum computing and getting them to work together. It's very laudable."

Andrew Cleland, University of California, Santa Barbara

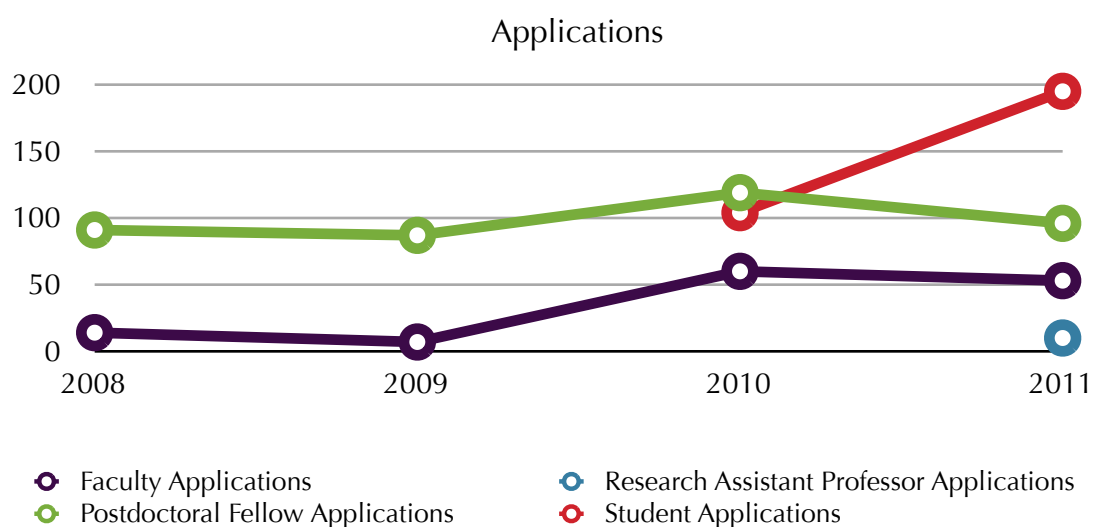
3.2.1.2 Faculty, Postdoctoral Fellow & Student Applications

IQC continued to receive high-quality applicants from top institutions around the world. In fiscal 2011, the institute received a total of 53 applications to faculty positions within the last fiscal year. There were a total of 10 applications to the new research assistant professor position in fiscal 2011. There were a total of 96 applications to postdoctoral fellowship positions within the last fiscal year.

117 applications to the graduate studies for the collaborative program in quantum information. This is the second year for the collaborative graduate program. Seventy-eight

additional students indicated on their application to uWaterloo⁵ that they had an interest in quantum computing or quantum information.

This gives a total of 195 students applying or indicating interest in quantum information. IQC achieved its goal of fielding a 20 per cent increase in applications (compared to 104 applications last year).



	2008	2009	2010	2011
Faculty	14	7	60	53
Research Assistant Professors				10
Postdoctoral Fellows	91	87	119	96
Students			104	195

⁵ Students who applied to the departments of: Applied Math, Combinatorics & Optimization, Electrical & Computer Engineering, Physics & Astronomy, Chemistry or the David R. Cheriton School of Computer Science and indicated an interest in quantum computing or quantum information.

3.2.1.3 Graduate Program in Quantum Information: Update

The Ontario Council for Graduate Studies approved the collaborative quantum information graduate program in January of 2010. The University of Waterloo and IQC are working together to offer students a new interdisciplinary approach to graduate studies in quantum information leading to a MMath, MSc, MASc or PhD degrees.

The program is offered in collaboration with the Faculties of Mathematics, Science and Engineering and the Departments of Applied Mathematics, Combinatorics and Optimization, Chemistry, Physics and Astronomy, Electrical and Computer Engineering and the David R. Cheriton School of Computer Science.

The collaborative program in quantum information helps to achieve a long-term objective of the Industry Canada grant— providing new opportunities for students to learn and apply new knowledge.

The graduate program exposes students to a wide range of advanced research projects and courses on the foundations, applications and implementations of quantum information processing. One particularly special feature of the new graduate program is its scope and breadth, encompassing both experimental and theoretical aspects of quantum information. Students will be required to take two key courses: Quantum Information Processing, and Implementation of Quantum Information Processing, and students have the opportunity to take a wide range of other specialized courses in quantum information, ranging from Theory of Quantum Information to Quantum Algorithms to Nanoelectronics Implementations of Quantum Information Processing.

During the 2011 fiscal year, 20 new students joined IQC with start dates in the spring, fall or winter terms.

Five supervisors were approved to join the collaborative program: David Cory (IQC), Christopher Fuchs (Perimeter Institute), Shohini Ghose (Wilfrid Laurier University), Rob Spekkens (Perimeter Institute) and Bei Zeng (University of Guelph).

To promote the collaborative graduate program, IQC attended seven graduate fairs including: the University of Waterloo, McGill University, the University of Alberta, the University of Western Ontario, the University of British Columbia, and the Canadian Undergraduate Physics Conference. In addition, the University of Waterloo's Graduate Studies Office promotes the program at international graduate fairs.

3.2.1.4 New Courses

The quantum information graduate program is introducing the following course starting in spring 2011:

QIC 891 Selected Advanced Topics in Quantum Information

Credit weight: 0.25

Course co-ordinator: Michele Mosca

3.2.1.5 Graduate Courses

The following courses were offered at IQC during the spring, fall and winter semesters in 2010 and 2011.

QIC 710 Quantum Information Processing

Instructor: Ben Reichardt

This course covers: quantum information, quantum algorithms, quantum complexity theory, entropy and noiseless coding, error-correcting codes and fault tolerance, nonlocality and cryptography.

QIC 750 Implementations of Quantum Information Processing

Instructor: Frank Wilhelm

An introduction to physical implementations of quantum computers with an emphasis on common and connecting themes.

QIC 769 Sir Anthony Leggett Lecture Series

Instructor: Sir Anthony Leggett

This course covers: open quantum systems, fermi-liquid theory, band theory, topological insulators, integral quantum hall effect, fractional quantum hall effect, basics of superconductivity and more.

CO 781 Theory of Quantum Communication

Instructor: Debbie Leung

This courses covers core results and a select subset of additional topics on the theory of quantum communication.

QIC 823 Quantum Algorithms

Instructor: Andrew Childs

An investigation of algorithms that allow quantum computers to solve problems

faster than classical computers.

QIC 845 Open Quantum Systems

Instructor: Joseph Emerson

Explores the theory of open quantum systems, which consists of a set of mathematical techniques and phenomenological models for describing generalized quantum dynamics and quantum measurements, and methods of quantum control.

QIC 885 Quantum Electronics and Photonics

Instructor: Hamed Majedi

For engineers who are interested to learn applied quantum mechanics to study quantum behaviours of electrons, photons and their interaction.

QIC 890 Spin-based Implementations

Instructor: Jonathan Baugh

An in-depth introduction to quantum information processing implementations based on nuclear and electron spin.

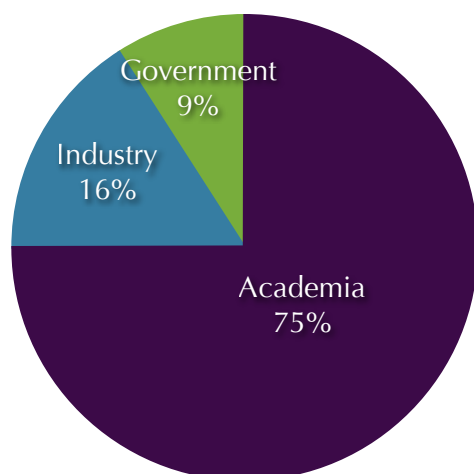
QIC 890 Applied Quantum Cryptography

Instructor: Norbert Lütkenhaus

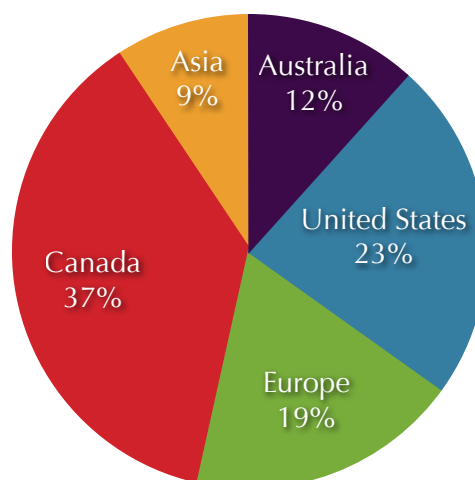
The goals of this course are to understand the context of QKD, the principles that allow us to realize QKD, the principles of formal security proofs and their elements, quantum optical implementations of QKD and open problems of QKD research.

3.2.1.6 IQC Student Alumni

Student Alumni: Field of Employment



Student Alumni: Where They Are Now



3.2.1.7 IQC Students from Top Undergraduate Schools Internationally

The Times Higher Education World University Rankings judge educational institutions based on peer-review, academic polls, teacher-to-student ratios, internationalization rate and number of research citations.

This year 41 of IQC's 74 graduate students studied at one or more of these top-ranked graduate or undergraduate institutions before coming to IQC. Last year 40 of IQC's graduate students studied at one or more of the top-ranked institutions.

Students came from one or more of the following institutions:

- California Institute of Technology
- McGill University
- National University of Singapore
- Peking University
- Tsinghua University
- University of Oxford
- University of Queensland
- University of Toronto
- University of Waterloo

For more information on the Times Higher Education World University Rankings and to see the full list see Appendix M.

“Prior to my visit I was unsure about going to Waterloo for graduate school but after this visit I am strongly considering it. Thanks.”

Potential Graduate Student

3.2.1.8 Students with a High Grade Point Average

IQC had 74 students registered during the 2011 fiscal year. Sixty-two per cent of graduate students have a GPA score of 90 per cent or higher.

Seventy-five per cent of students have a GPA score of 85 per cent or higher.

These high scores show that IQC is recruiting some of the top students in the world.

3.2.1.9 Transatlantic Exchange Partnership

The Collaborative Student Training in Quantum Information Processing project is part of the European Union-Canada Programme for Cooperation in Higher Education, Training and Youth. The project is meant to give graduate students in Canada and the European Union exposure to study quantum information processing abroad.

Each year, the 36 students involved in the program participate in an internship with a faculty supervisor and course work in the relevant topics at the host institution. Students study QIP, its sub-disciplines and allied subjects including: algorithms and complexity, error-correction, cryptography, communication, information theory, experimental implementations of QIP devices, communication and practical cryptography.

Students involved in the EU-Exchange program during the 2011 fiscal year:

- Agnes Ferenczi (IQC)
- Sevag Gharibian (IQC)
- Thomas Gunthner (Universität Innsbruck)

- Bettina Heim (Friedrich-Alexander-University of Erlangen-Nuremberg)
- Stacey Jeffery (IQC)
- Nathan Killoran (IQC)
- Christian Konrad (Universute Paris-Sud)
- Ansis Rosmanis (IQC)
- Jamie Sikora (IQC)
- Sarvagya Upadhyay (IQC)
- Ricardo Wickert (Friedrich-Alexander-University of Erlangen-Nuremberg)

3.2.1.10 Student Scholarships & Fellowships

At IQC, 20 of 32 eligible Canada students hold NSERC scholarships.

External

David R. Cheriton Graduate Scholarship

Sevag Gharibian
 Sarvagya Upadhyay
 Abel Molina Prieto
 Robin Kothari

NSERC Alexander Graham Bell Canada Graduate Scholarship— Masters

Daniel Criger
 Pierre-Luc Dallaire-Demers
 Robin Kothari
 Evan Meyer-Scott
 Stacey Jeffery
 Kent Fisher
 Luke Govia
 Tomas Jochym-O'Connor
 Nickolay Gigov

NSERC Alexander Graham Bell Canada Graduate Scholarship— Doctoral

Easwar Magesan
 Jonathan Lavoie
 Sevag Gharibian
 Farzad Qassem

NSERC Postgraduate Scholarship— Master's Extension

Deny Hamel

NSERC Postgraduate Scholarship— Doctoral

Chris Erven

Chris Ferrie

Jamie Sikora

Jamie Smith

Felix Motzoi

NSERC Vanier Canada Graduate Scholarship

Deny Hamel

Gina Passante

Ontario Graduate Scholarship

Cozmin Ududec

Thomas McConkey

Hamid Mohebbi

Nathan Killoran

Evan Meyer-Scott

Fatin Haque

Ontario Graduate Scholarship in Science & Technology

Peter Groszkowski

Thomas McConkey

Chunqing Deng

David Pitkanen

President's Graduate Scholarship

Cozmin Ududec

Deny Hamel

Daniel Criger

Pierre-Luc Dallaire-Demers

Robin Kothari

Thomas McConkey

Chris Erven

Hamid Mohebbi

Stacey Jeffery

Nathan Killoran
Jamie Sikora
Chris Ferrie
Easwar Magesan
Jamie Smith
Evan Meyer-Scott
Kent Fisher
Luke Govia
Fatin Haque
Tomas Jochym-O'Connor
Jonathan Lavoie
Sevag Gharibian
Felix Motzoi
Farzad Qassemi
Nickolay Gigov

Internal Awards

There are three internal scholarships available to IQC students: the Mike and Ophelia Lazaridis Fellowship, the IQC Achievement Award and the IQC David Johnston Award for Scientific Outreach.

There were nine recipients of the IQC Achievement Award (formerly the Bell Family Research Fund Award) in 2011: Felix Motzoi, Farzad Qassemi, Sarvagya Upadhyay, Evan Meyer-Scott, Kent Fisher, Luke Govia, Tomas Jochym-O'Connor, Nickolay Gigov and Christopher Wood.

Yingkai Ouyang, Iman Marvian, Amin Eftekharian, Sarvagya Upadhyay, Abel Molina Prieto and Ansis Rosmanis received the Mike and Ophelia Lazaridis Fellowship.

2011 is the first year for the IQC David Johnston Award for Scientific Outreach. The award was created to celebrate David Johnston's pivotal contributions to IQC, his passion for leadership and his enthusiasm for continuous learning, innovation and achievement. David Johnston was president at the University of Waterloo from 1999 to 2010. The three winners were: Chris Erven, Gina Passante and Jean-Luc Orgiazzi.

A full list of award winners is available in Appendix N.

3.2.1.11 Faculty Awards

Richard Cleve

Fellow of the Royal Society of Canada (November 2010)

David Cory

Canadian Excellence Research Chair (May 2010)

Joseph Emerson

"40 Under 40" award from *The Waterloo Region Record* (February 2011)

Raymond Laflamme

Doctor Honoris Causa, The University of Sherbrooke, (September 2011)

Adrian Lupascu

Sloan Research Fellowship from the Alfred P. Sloan Foundation (February 2011)

Hamed Majedi

Faculty of Engineering Distinguished Performance Award, University of Waterloo
(February 2011)

Michele Mosca

Canada's Top 40 Under 40, Globe and Mail (April 2011)

Kevin Resch

Outstanding Performance Award, University of Waterloo (January 2011)

John Watrous

Outstanding Performance Award, University of Waterloo (January 2011)

Frank Wilhelm

Outstanding Performance Award, University of Waterloo (January 2011)

3.2.1.12 Postdoctoral Fellow Awards

Anne Broadbent

- NSERC Postdoctoral Fellowship (2008)
- NSERC Doctoral Prize (January 2009)
- John Charles Polanyi Prize (November 2010)
- CIFAR Junior Fellow (August 2011)

Brendon Higgins

- Banting Postdoctoral Fellowship (April 2011)

Robert Prevedel

- MRI Award (October 2009)
- Erwin-Schrödinger-Fellowship (November 2009)

Aidan Roy

- University of Waterloo Fields Scholarship (August 2010)

Krister Shalm

- CIFAR Fellowship (October 2010)

3.3 ESTABLISHING IQC AS THE AUTHORITATIVE SOURCE OF INSIGHT, ANALYSIS AND COMMENTARY ON QUANTUM INFORMATION

IQC's third strategic objective is interpreted in several ways. Developing an international reputation as the authoritative source of information and commentary about quantum science is occurring naturally. The quality of the science speaks for itself, is showcased in numerous journals around the world, and is reinforced through media coverage, IQC publications, and more. Additionally, researchers provide analyses and commentaries on scientific developments outside IQC; disseminating these through the IQC website and other vehicles positions IQC researchers as thought leaders in the field. Beyond the global scientific network, it is also vital to 'get the word out' to other audiences including future students and researchers, industry and government partners, and the general public.

Educating broader audiences about quantum research and its fundamental importance will inspire the next generation of quantum scientists who will build on the foundational work being done today. Educating the first quantum-informed workforce will pave the way for productive partnerships with industry. Raising awareness about the role quantum will play in our future, Canada's leadership, and the international excellence of IQC reinforces the importance of the major investment being made in quantum research and will secure the future of that investment.

In the following section you will find a review of the relevant objectives set by IQC in the 2010 Industry Canada report, and several metrics demonstrating how the institute achieved those goals. Each focus area has facts and figures that demonstrate the institute's activities related to the third strategic objective of establishing IQC as the authoritative source of insight, analysis and commentary on quantum information.

3.3.1 Disseminating Knowledge

Meetings, workshops, conferences and outreach activities are organized annually to complement the research that is happening at IQC. These events range from general interest lectures to highly specialized conferences. IQC launched a new website that will help with outreach and knowledge dissemination in the future.

2011 Objectives

- Host five conferences at IQC with three distinct target audiences including researchers, undergraduate students and high school students
 - IQC hosted six conferences. For more information on conferences and workshops see section 3.3.1.7
- Complete website redesign project and launch new web presence
 - The institute's new website was launched in September 2010. For information on IQC's website see section 3.3.2.3
- Compile a database of the publications by IQC researchers on RefBase
 - "The Quantum Library"— IQC's publications database— was launched in April 2011. For more information on publications and IQC's database see section 3.1.1.2
- Increase external media coverage
 - IQC was featured in local, national and international media 86 times— including prominent stories in the Globe and Mail, New York Times, Telegraph (India) and Scientific American. For information on media coverage see section 3.3.2.5

Below you will find information on IQC's commentary and analysis objective, outreach events, recruitment and international events, tours of the institute's various facilities and presentations by IQC faculty members.

3.3.1.1 Commentary and Analysis

Below is a list of papers, presentations and videos that give an overview or provide comments about the status of the quantum information processing field.

General Scientific Commentary

Articles

1. Harnessing the Quantum World: 2008 CAP Congress Herzberg Lecture
 - Raymond Laflamme and Jeremy Chamilliard
 - La Physique au Canada, Vol. 65, No. 1 (2009)

Videos

1. Introduction to Quantum Technologies: Quantum Computers, Quantum Teleporters & Quantum Cryptography: Perimeter Institute Lecture
 - Michele Mosca
 - May 2006
2. TEDxWaterloo “Sparked by Curiosity” Public Lecture
 - Raymond Laflamme
 - February 2010
3. Harnessing the Quantum World: Perimeter Institute Public Lecture
 - Raymond Laflamme
 - June 2008
4. From Weird to Wired: Perimeter Institute Public Lecture
 - Joseph Emerson
 - March 2010
5. What Great Philanthropy Can Do: Interview
 - Interview with Raymond Laflamme and former University of Waterloo president, David Johnston

For a list of IQC’s full video library see section 3.3.2.4

Quantum Information and Communication

Articles

1. Introduction to Quantum Information Processing R. Laflamme and collaborators
2. Introduction to Quantum Complexity Theory, by R. Cleve
3. Non-locality and Communication Complexity, by R. Cleve and collaborators

Lectures

1. USEQIP 2010: Introduction to Quantum Information Processing, by M. Mosca

Quantum Algorithms and Complexity

Articles

1. Quantum Algorithms, by J. Smith and M. Mosca
2. Quantum Algorithms for Algebraic Problems, by A. M. Childs and W. van Dam
3. Quantum Computational Complexity, by J. Watrous,

Lectures

1. IOI 2010: Algorithms for Quantum Computers, by A. Childs
2. USEQIP 2010: Quantum Algorithms, by M. Laforest and M. Mosca

Quantum CryptographyArticles

1. The case for quantum key distribution, by D. Stebila, M. Mosca and N. Lükenhaus
2. Quantum cryptography, by N. Lükenhaus and collaborators

Lectures

1. USEQIP 2010: Quantum key distribution: Linking theory and experiment, by N. Lükenhaus)
2. USEQIP 2010: Quantum communication with polarized entangled photons, by T. Jennewein

Videos

1. Animation of IQC's quantum cryptography link
2. Chris Erven explains IQC's quantum cryptography link, by C. Erven
3. Ontario Center of Excellence Discovery 2010 video contest (Third prize), by C. Erven and R. Horn

Quantum Error Correction and Fault-ToleranceArticles

1. Introduction to Quantum Error Correction, by R. Laflamme and collaborators

Lectures

1. USEQIP 2010: Quantum Error Correction, by R. Laflamme

Videos

1. Experimental Quantum Error Correction, by R. Laflamme

Spin-based Quantum Information ProcessingArticles

1. How to build a better iPod: Spintronics hold the key, by W. A. Coish
Quantum physics and voltmeters, by F. K. Wilhelm
2. 2-Qubit Quantum Information Processing by Zeeman-Perturbed Nuclear Quadrupole Resonance, by P. Xian and T. Borneman
Introduction to NMR quantum information processing, by R. Laflamme, D. G. Cory, C. Negrevergne and collaborators
3. Quantum information processing using nuclear and electron magnetic resonance: review and prospects, by J. Baugh, J. Chamilliard, C. M. Chandrashekar, D. G. Cory, M.

Ditty, A. Hubbard, R. Laflamme*, M. Laforest, D. Maslov, O. Moussa, C. Negrevergne, M. Silva, S. Simmons, and C. A. Ryan and collaborators

4. Nuclear spin in nanostructures, by W. A. Coish and J. Baugh
5. Quantum computing with spins in solid, by W. A. Coish and D. Loss
6. Spins interactions, relaxation and decoherence in quantum dots, W. A. Coish and collaborators

Lectures

1. Introduction to NMR and NMR QIP, by J. Baugh

Nanoelectronics-based Quantum Information Processing

Articles

1. Quantum computing with superconductors I: Architectures, by F. K. Wilhelm and collaborators
2. Superconducting qubits II: Decoherence, by F. K. Wilhelm and collaborators

Lectures

1. USEQIP 2010: Introduction to superconducting qubit, by A. Lupascu
2. USEQIP 2010: Infra red single photon detectors, by H. Majedi

Optical Quantum Information Processing

Articles

1. Linear optics quantum computation: an overview, by C. R. Myers and R. Laflamme

Lectures

1. USEQIP 2010: Bell's inequalities and quantum optics, by K. Resch
2. USEQIP 2010: Mach-Zehnder interferometer, by K. Resch
3. USEQIP2010: State tomography of one and two-qubit systems, by K. Resch
4. USEQIP 2010: Optical implementations of quantum information, by K. Resch

“The drive that moves researchers here is to develop this beautiful vision of bringing quantum into our daily lives.”

Tommaso Calarco
University of Ulm, Germany

3.3.1.2 Outreach Activities

In addition to hosting six conferences, IQC has coordinated or participated in nine key outreach activities in the last year. IQC attended seven graduate fairs in Canada and four international recruiting events. IQC hired a Manager of Scientific Outreach in May 2010.

Innovation Insights

- Executive Director Raymond Laflamme
- Presentation about IQC and quantum information for a business-technology audience
- Accelerator Centre, Waterloo, 150 participants
- June 3, 2010

Canadian Undergraduate Mathematics Conference

- Deputy Directory Michele Mosca
- Keynote speaker for undergraduate students
- University of Waterloo, 245 participants
- July 8, 2010

International Olympics of Informatics

- Faculty member Andrew Childs
- Presenter about quantum algorithms
- University of Waterloo, approximately 250 participants
- August 15, 2010

IQC Open House/Doors Open Waterloo

- Tours of IQC's labs and theory rooms, a hands-on Discovery Zone for children, public lecture by Prof. David Cory, a science show for kids, animation and video displays, a screening of the *Quantum Tamers* and more
- RAC I & II, 800+ participants
- September 18, 2010

Ladies Night Out

- Postdoctoral fellow Anne Broadbent
- Public talk for the Federated Women's Institutes of Ontario
- Listowell, Ontario, approximately 120 participants

Royal Canadian Institute Public Lecture

- Faculty member Joseph Emerson

- Public lecture titled “The Quantum World: Weird to Wired”
- Royal Canadian Institute, approximately 200 participants
- February 6, 2011

TEDxWaterloo

- IQC sponsored the 2011 TEDxWaterloo event, also staging a quantum exhibit that demonstrated some quantum experiments to hundreds of attendees
- March 3, 2011, approximately 1,000 participants

Quantum Frontiers Distinguished Lecture Series

- The inaugural lecture was presented by Dr. Don Eigler, an eminent physicist at IBM’s Almaden Research Centre in California
- Approximately 200 people attended
- April 1, 2011

3.3.1.3 Graduate Fairs & Special Seminars

IQC’s recruiters attended a total of seven graduate fairs. At selected universities they offered a special seminar for interested students to learn more about IQC and quantum information.

- University of Waterloo Graduate Fair
 - September 21, 2010
- University of British Columbia Graduate Fair
 - September 29, 2010
 - Special seminar, September 30, 2010, 45 participants
- University of Alberta Graduate Fair
 - October 20, 2010
- Canadian Undergraduate Physics Conference Graduate Fair
 - October 25, 2010, Dalhousie University
- University of Western Ontario Graduate Fair
 - October 28, 2010
 - Special seminar, November 11, 2010, 50 participants

- McGill University Graduate Fair
 - November 3, 2010
 - Special seminar, McGill University, November 3, 2010, 45 participants
 - Special seminar, Laval University, November 4, 2010, 60 participants
- Atlantic Undergraduate Physics & Astronomy Conference
 - February 5, 2011

3.3.1.4 International Events

- Beijing Normal University Student Seminar, China
 - Special seminar about the University of Waterloo, IQC and the collaborative quantum information program
 - November 24, 2010, 60 participants
- Roundtable, Canadian Embassy, China
 - Participated with the University of Waterloo and representatives from 16 other Canadian universities, more than 30 Chinese universities and representatives from the Canadian embassies in Japan and Korea
 - November 25, 2010, approximately 100 participants
- Graduate Fair, Beijing, China
 - November 27, 2010
 - Participated with the University of Waterloo in the large international graduate fair
- Tsinghua and Peking University Student Seminar, China
 - Special seminar about the University of Waterloo, IQC and the collaborative quantum information program
 - November 29, 2010, 15 participants
- American Association for Advancing Science: Annual Meeting, Washington, USA
 - Attended the event to network with science journalists and hear world-renowned speakers discuss important progress on pressing science, technology, and policy issues, and share insights into future directions
 - February 17 - 21, 2011

3.3.1.5 Tours of the Mike & Ophelia Lazaridis Quantum-Nano Centre

The construction site of the Mike & Ophelia Lazaridis Quantum-Nano Centre is not yet open to the public.

For more on the construction progress and for information about the facility itself see section 3.1.4.3

3.3.1.6 Tours of the Research Advancement Centre I & II

IQC offers tours of RAC I and RAC II at varying levels of technical complexity. Researchers at the institute help guide tours for high school students, government officials, industry or businesspeople and members of the community. Below find a breakdown and highlights from each of the categories of tour participants.

For more information on academic or scientific visitors see section 3.1.3.2

“Your organization has helped to establish Waterloo as a global leader in the quantum information revolution and it is truly incredible to have the largest institution of this kind right here in our own backyard.”

Laura A. Gainey
Regional President, Ontario South West, Royal Bank of Canada
Tour Participant

Government Tours

IQC hosted 8 government tour groups in the 2011 fiscal year.

Highlights include: David C. Onley (Ontario Lieutenant Governor), Glen Murray (Minister of Research and Innovation), Jim Flaherty (Minister of Finance), Peter Braid (MP, Kitchener-Waterloo), Stephen Woodworth (MP, Kitchener Centre), Masuo Aizawa (Council for Science and Technology Policy Cabinet Office, Japan).

For a full list of government tours see Appendix P.

“We were very impressed and interested to learn of the work of IQC...we appreciate the time you took to describe the work underway at your institute...I know we will all be hearing much more about Canada’s advances in thinking about quantum physics and the

development of Waterloo as the new Quantum Valley!”

Sara Hradecky
Assistant Deputy Minister, Afghanistan Task Force
Privy Council Office, Ottawa

Business/Industry Tours

IQC hosted 9 tours for industry or businesspeople in the 2011 fiscal year.

Highlights include: Royal Bank of Canada (Ontario-based executives), Research in Motion, Moloney Electric Inc., Lockheed Martin Aeronautics Company, Michael Goodkin (Capital Investor).

For a full list of business/industry tours see Appendix P.

Academic Tours

Academic tours are perhaps the most popular tour that comes to IQC. These tours, typically for high school classes or undergraduate students, can be for anywhere from five to 30 or 40 students at once. This year, IQC hosted 27 academic tours.

Highlights include: Gerald Sussman and the University of Waterloo Computer Science Club, University of Waterloo Physics Alumni, Senior science students from Uxbridge Secondary School, Perimeter Scholars International, Wilfrid Laurier Physics and Computer Science students.

For a full list of academic tours see Appendix P.

“On behalf of the first-year physics and photonics students, I must say that we were thoroughly impressed and tremendously enjoyed the visit. Many of the tour participants commented on the excellent guided tour. Special thanks to Martin [Laforest] for his unique way of explaining the beauty of IQC and the impressive laboratories with state-of-the-art equipment and cutting-edge research.”

Prof. Hasan Shodiev
Lab Coordinator, Departments of Physics and Computer Science
Wilfrid Laurier University

3.3.1.7 Workshops Summer Schools & Conferences

In the past year, IQC hosted six conferences. The institute hosts conferences to help attract the next generation of quantum scientists, to spread the word about quantum science to more audiences, create opportunities for researchers to share research with their peers, and allow people to learn more about IQC and the cutting-edge science being done here.

1. Cross-Border Workshop on Laser Science

May 3 - May 5, 2010

78 participants

The workshop is intended to foster interaction between students and leading experts in laser science in an informal setting. Graduate and undergraduate students are encouraged to participate in the workshop to be exposed to laser-related research outside their usual field.

2. Quantum Information Processing with Spin and Superconductors

May 17 - May 19, 2010

62 participants

Recent progress in quantum information processing with solid-state systems has seen the demonstration of high-fidelity operations, long coherence times, measurement of entanglement, and the first solid-state algorithm. To continue at this rate of progress will require a significant degree of cross-fertilization between communities working on superconducting systems and electron spins. It is the goal of this workshop is to bring leaders in the two fields together to discuss recent progress, unanswered questions, and future directions for building a solid-state quantum-information processor.

“It was very successful. All the speakers delivered talks that inspired discussion.”

Jay Gambetta
Conference Organizer

3. Undergraduate School on Experimental Quantum Information Science

May 24 - June 4, 2010

13 participants

The program is designed to introduce students to the field of quantum information processing. Students are encouraged to apply for a summer internship within IQC following the summer school. USEQIP gives students a

firsthand look at what IQC has to offer with the hopes of recruiting them as graduate students later in their educational career.

“One of those shining opportunities where you will get to do quantum computation...the experimental procedures we went through here were very exciting which is what really sets it apart from anything else.”

Justin Dove, Adelphi University
USEQIP Participant

“I’ve been able to see what the applications of physics can be in this area and how real people are working on it. The hands-on work really helps you understand.”

Barbara Cervantes, University of Victoria
USEQIP Participant

4. Theory and Realization of Practical Quantum Key Distribution

June 14 - June 17, 2010

69 participants

A workshop focussed on the most advanced present-day application of quantum information science, quantum key distribution (QKD), which has already seen real-world, commercial implementation. The workshop brought together leading experts from around the world who are investigating all aspects and subfields of QKD, spanning theory and experiment. The conference was highly successful in generating dialogue between theorists and experimentalists, sparking new ideas about quantum key distribution. Based on this success, organizers are holding the conference again in summer 2012.

5. Quantum Cryptography School for Young Students

July 26 - July 30, 2010

38 participants

Students often choose their program of study in university based on the avenues to which they are exposed in high school. The goal of this conference is to increase awareness of quantum computing and cryptography among talented students about to enter university. By conveying the excitement and the challenges in the field, we hope to eventually draw this talent into our graduate program.

“The lectures covering quantum key distribution approaches and protocols was the most interesting, as it acted to unite all of the topics previously covered in both a fun and interesting manner.”

Christopher Nunn, R. H. Kings Academy Scarborough
QCSYS Participant

“I really enjoyed learning so many new things, being around brilliant and interesting people. The lessons on linear algebra and classical cryptography were the most interesting.”

Fletcher Tomalty, MIND High School, Montreal
QCSYS Participant

6. Nano Structured & Entangled Photon Sources for Quantum Information Processing

April 28 - 29, 2011

25 participants

This is the third and last annual meeting for the NSERC-funded grant proposal on nano-structured single and entangled photon sources for quantum information processing. The team of 10 Canadian professors and researchers from NRC along with their postdoctoral fellows and students got together to exchange their recent ideas and share their achievements in a lively presentations and discussions through talks and posters.

3.3.1.8 Sponsored Conferences & Events

IQC sponsored the following conferences and events this year. The institute sponsors events in support of its outreach objectives, to build ties with scientific and other communities and partner with the University of Waterloo as co-sponsors.

1. 14th Workshop on Quantum Information Processing
2. Conceptual Foundations and Foils for Quantum Information Processing
3. QCRYPT 2011: First Annual Conference on Quantum Cryptography
4. Superconductivity Canadian Association of Physicsts Lecture Tour
5. TEDxWaterloo 2011
6. Communitech's Tech Leadership Conference 2011

3.3.1.9 Presentations

IQC faculty and research assistant professors presented their research at a total of 80 events during the 2011 fiscal year. Thirty presentations occurred within Canada while 50 took place at various international institutes, events and conferences.

For a full list of the presentations see Appendix O.

3.3.2 Communications and Outreach Strategy

IQC's communications and outreach goals are guided by IQC's three strategic objectives, most directly to establish IQC as the authoritative source of information, analysis and commentary on quantum information. The Communications and Outreach strategy for the next 12 to 18 months encompasses developing and implementing a plan of communications, outreach, events and other activities linked to IQC's 10th anniversary celebrations marking a decade of achievement and progress in quantum development; launching research and creative work that will identify key audiences, stakeholders and messages needed to help showcase the world-class science as broadly as possible; developing tools and processes for communications; building relationships with key stakeholders and donors.

2011 Objectives

- Establishment of a full, five-member Communications and Outreach team
- Lay IQC branding groundwork, including market research, focus groups, interviews/surveys with stakeholders
- Complete the website redesign to increase IQC's web presence, interactivity and outreach scope
- Develop key messages and themes for IQC communications
- Targeted outreach to highlight IQC's scientific strengths and attract researchers to the institute
- Planning for IQC's 10th anniversary and the expansion into the new Mike & Ophelia Lazaridis Quantum-Nano Centre

The following section includes an update on the key communications messages, an update on the communications, branding and website projects, social media statistics, and a brief overview of the plans for IQC's 10th anniversary.

3.3.2.1 Key Messages

IQC communications materials are focused on four key messages:

1. IQC is laying the foundations for the quantum revolution
2. IQC is contributing to Canada's international technology leadership
3. IQC is developing a quantum-enabled workforce of the future
4. IQC is attracting and nurturing the scientific excellence that will turn breakthroughs into benefits for society.

3.3.2.2 Communications & Branding Plans

IQC's communications and outreach strategy is guided by IQC's three strategic objectives, most directly the third objective: "To establish IQC as the authoritative source of insight, analysis and commentary on quantum information." The team works to share the IQC story with a variety of stakeholders and audiences. IQC's five-member communications

and outreach team has been in place since June 2010.

This year, IQC has three focused strategic initiatives: to create a robust and compelling plan for 10th anniversary celebrations, implement a targeted outreach strategy and continue with the creative branding work that began in October 2010. IQC also handles the website, publications, video projects, media relations and internal communications and support.

Last year, IQC launched a new website, published IQC's first-ever Annual Report, revamped the semesterly newsletter, held a very successful open house and hosted many high-profile visitors including Stephen Hawking, Ontario Lieutenant Governor David C. Onley and Canadian Finance Minister James M. Flaherty.

IQC entered its 2009/2010 Annual Report into the LACP Vision Awards Competition — an international competition representing a broad range of industries and organizational sizes. More than 4,400 entries representing upwards of 25 countries were received. Materials were judged in peer-level competitions. IQC received the highest honour available in the category of education — a platinum award — and a score of 28th in the competition overall. IQC's annual report also received the top ranking overall for any entry from Canada.

“Overall, we find this work outstanding, earning a total score of 96 out of a maximum 100 points awarded in this competition...The level of creativity exhibited in the report judged for the Institute for Quantum Computing, University of Waterloo is outstanding, which is supported by excellent clarity in communicating this year's key messages. It should also be noted that accessibility to key information sought by readers is outstanding.”

Christine Kennedy, LACP Managing Director
2009/2010 Vision Awards Competition

“It's safe to say that this report offers some of the highest production values found in any report this year. We were impressed from beginning to end...and that takes a lot! Outstanding!”

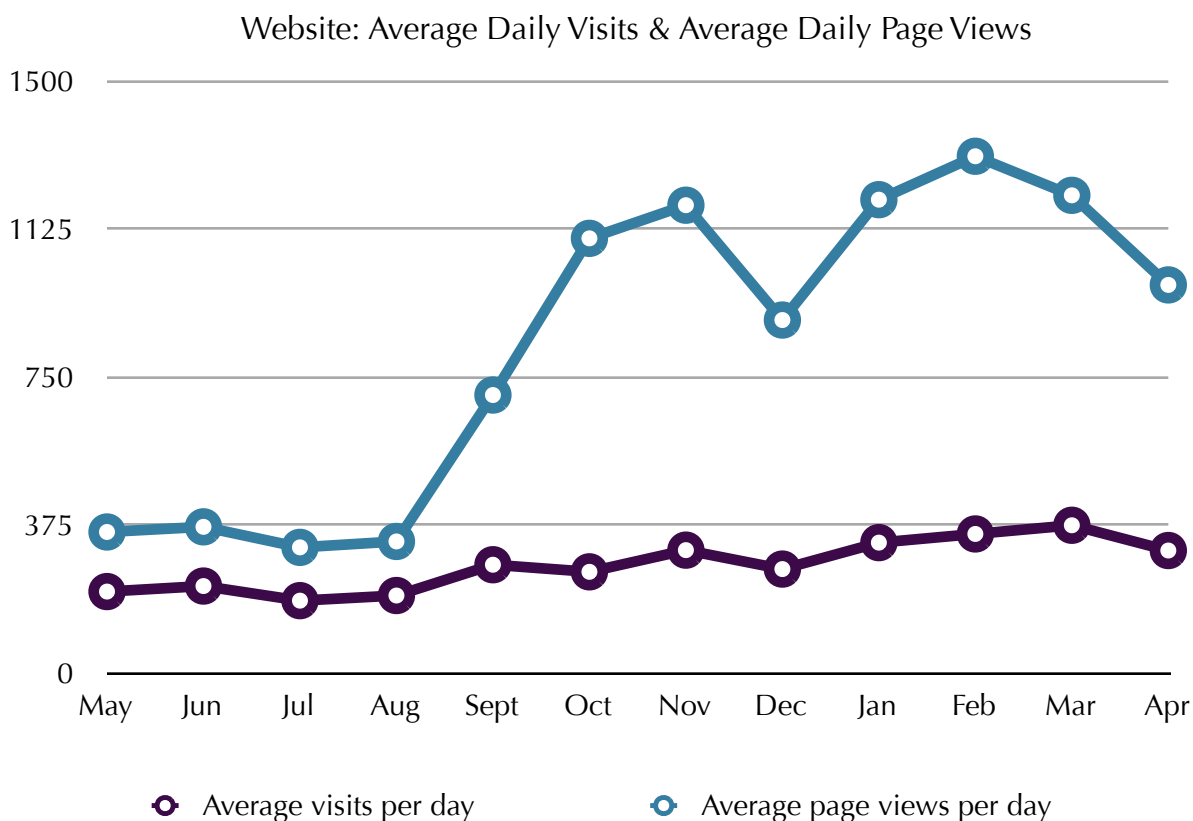
Judges Comments for the LACP Vision Awards Competition

3.3.2.3 Website

IQC launched a new website in September 2010 on a new platform and with a revamped look and content. The website has enhanced interactivity, audience-specific features, expanded scientific information, and greater use of social media platforms. The site was created with input from IQC faculty, postdoctoral fellows, students, staff and web design experts. It serves as a news source, recruiting tool, learning resource and a gateway to IQC social media.

In the next year and beyond, the IQC communications and outreach team will continue to strengthen IQC's web presence to convey quantum information broadly and attract people to IQC.

Below is a graph showing the average daily visits and the average daily page views for iqc.uwaterloo.ca. The launch of the new website is reflected in the increased page views in September. A dip in the page views during the winter holidays is also visible in the graph below.



Below is a map from Google Analytics showing data from the launch of the new website to the end of April 2011. The map shows where visitors to IQC's website are located. Seventy countries/territories are shown to have at least one visitor coming to the site. Canada, the United States, China and India have the highest number of visitors (in that order.)



3.3.2.4 Social Media

A brief survey of students and postdoctoral fellows found that IQC's target audiences are looking for information about the institute online in a variety of places. IQC uses social media to attract who are using these tools.

The Quantum Factory Blog

quantumfactory.wordpress.com

Launched February 2011, the Quantum Factory is a fun and informative blog spearheaded by IQC's communications and outreach team. The blog is home to a variety of diverse posts including video interviews, news articles, travelogues and a photo gallery of the new Mike & Ophelia Lazaridis Quantum-Nano Centre construction site. The blog launched in February 2011. As of April 30, 2011, the blog had 2,601 all-time views, 172 views on the busiest day.

Facebook

IQC's Facebook group page can be found at facebook.com/QuantumIQC. There were 457 Facebook fans on April 30, 2011. This is a large increase from 197 in fiscal 2010.

Twitter

IQC's Twitter page can be found @QuantumIQC. There were 649 Twitter followers in 2011. This is an increase from 195 in fiscal 2010.

Flickr Stream

IQC's Flickr stream can be found at flickr.com/quantumiqc. As of April 30, 2011 there were 11,048 views of photos and videos on the stream.

YouTube Channel

IQC's YouTube channel can be found at youtube.com/QuantumIQC. In 2011, there were 30,977 total upload views, 2,999 total channel views and 116 subscribers, up from only six in 2010.

IQC has uploaded the following 28 videos onto the YouTube channel:

1. The Music of Quantum Science - Tommaso Calarco
2. Quantum Frontiers Lecture: Don Eigler of IBM
3. The Benefits of Quantum Research - Tommaso Calarco
4. Understanding Quantum Computing: Tommaso Calarco
5. Quantum: Harnessing the Fundamental Forces of Nature
6. Quantum Gets Big: Andrew Cleland on the Breakthrough of the Year
7. Quantum Computing 101
8. Teleportation: Fact v.s Fiction
9. Quantum Cryptography: The Future of Information Security
10. Quantum Cryptography Pioneer: Gilles Brassard
11. Quantum Computing Breakthrough: QIP=PSPACE
12. Casimir Effects: Peter Milonni's lecture at the Institute for Quantum Computing
13. Stephen Hawking at the Institute for Quantum Computing: The Boomerang of Time
14. The USEQIP Experience
15. Harnessing Quantum Mechanics: David Cory
16. Speaking the Language of Quantum Mechanics: David Cory
17. Seth Lloyd on Canada's Quantum Leadership
18. The Quantum Mechanics of Time Travel
19. Seth Lloyd on the Universe as a Quantum Computer

20. Seth Lloyd on the Simple Beauty of Quantum Mechanics
21. Seth Lloyd on the Importance of Quantum Research
22. Seth Lloyd on Quantum Weirdness
23. Nuclear Magnetic Resonance @ IQC
24. Mike & Ophelia Lazaridis Quantum-Nano Centre - Virtual tour
25. Introduction to the Institute for Quantum Computing
26. Born to Rule - Dr. Urbasi Sinha Explains the Triple-Slit Experiment
27. Quantum Key Distribution Animation
28. Quantum Key Distribution

3.3.2.5 News Items and Media Coverage

In the 2011 fiscal year, IQC was featured in 90 articles in third-party publications including several reputable science blogs. This is an increase from 33 articles in 2010. International coverage in The Telegraph (India), India Abroad, Scientific American and ComputerWorld are highlights on the list. For the full list of third party publications is available in Appendix R.

The University of Waterloo published 24 articles about IQC this year. This number is steady from 17 articles in the 2010 fiscal year. For the full list of news articles from the University of Waterloo see Appendix R.

IQC published 43 articles or press releases last year. This is an increase from last year when there were 36 articles or press releases. For a full list, see Appendix Q.

3.4 ADMINISTRATIVE SUPPORT

This activity encompasses all of the previous objectives. The fundamental function of IQC's administrative team is to provide researchers and students with professional support needed to pursue leading-edge research in quantum information. Information technology is integral to IQC's success and its support ranges from enabling administrative functions to supporting scientific research and online outreach. IQC's information technology strategy encompasses infrastructure, information/transaction management and stakeholder support. Technical laboratory support is critical to the ongoing continuity of experimental research. For the administrative team to effectively support and sustain the many academic, research and outreach activities at IQC, it is necessary to develop and maintain best practices.

2011 Objectives & Results

- Documenting and standardizing processes, jobs and back-ups in a rapidly expanding institute
 - Terms of reference have been developed for each of IQC's committees including researcher recruitment, the graduate program, scholarly visitor and colloquium committees — the terms of reference highlight the mandate, roles and responsibilities, process and reporting for each committee
 - Practices and procedures related to internal controls for financial transactions have been documented
 - Job descriptions have been rewritten, job procedures written and cross-training has taken place for administrative roles. The institute prepared its first budget and is now reporting actuals relative to this benchmark
- Establishing a grant life cycle process for standardizing and tracking sources of funding
 - The admin team was trained to help researchers with grants including: finding the grant opportunity, applying for the grant, reporting and managing budget
 - Documentation includes clearly defined roles and responsibilities between faculty and staff, background information for use when preparing grants and standard templates for reporting
- Developing desktop and other software/hardware tools and techniques
 - The institute moved its desktop and BlackBerry email service to the central campus "Connect" services
 - An antivirus protocol for the fabrication facility in RAC1 was implemented
 - To improve the effectiveness of technology support within the Operations Team, a common desktop platform was implemented
 - Instant messaging, common file sharing and centralized backup were all implemented
- Developing tools and processes for a new website
 - The technology support for the institute's new website includes new internally developed software to aid in the recruitment of faculty and post doctorate fellows. Also, new software was developed to record and communicate visiting scholars

“I’m very excited (to visit IQC) because this is one of the most successful examples of centres in quantum technologies worldwide. I’m very interested to learn how it’s structured, how it works and what are the keys to its success.”

Tommaso Calarco
University of Ulm, Germany

4. 2012 OBJECTIVES

The following objectives are for the 2011-2012 fiscal year.

To establish Waterloo as a world-class centre for research in quantum technologies and their applications:

4.1 Conducting Research in Quantum Information

The research at IQC will produce new knowledge that will lead to publications and presentations at conferences. This knowledge will include a better understanding of quantum information processors and laboratory demonstrations of their control, and the development of technologies based on these processors. Ultimately it will lead to new technologies and applications.

Objectives

- Continue leading-edge investigation of theoretical approaches to quantum information processing in order to better understand the impact of quantum mechanics for information processing and to investigate new potential applications
- Continue developing approaches to quantum information using photonic, nuclear and electron spins, quantum dots, superconducting technologies and proceed with studying the requirements needed to design earth-to-satellite quantum cryptography systems

4.2 Recruiting Researchers

Assembling a critical mass of theoretical and experimental researchers, exploring a broad range of approaches to quantum information processing, will establish IQC at the forefront of the field. The ongoing recruitment of top-tier faculty to IQC will further enhance the institute's fundamental objective of pursuing quantum information research at the highest international level. This, in turn, will fuel the institute's objectives of being a magnet for top students and being the authoritative source for information and analysis on the field. Fulfilling all these objectives will put IQC, and therefore Canada, at the forefront of the international pursuit of quantum information technologies.

Objectives

- Recruit up to four new faculty members
- Recruit up to two new research assistant professors
- Recruit up to seven new postdoctoral fellows
- Leverage IQC's 10th anniversary celebrations, conferences and other outreach forums as recruitment opportunities

4.3 Collaborating with Other Researchers

Strategic collaborations with key researchers from across disciplines will enhance IQC's international reputation, draw highly qualified personnel to IQC, and increase the

probability of experimental and theoretical breakthroughs. By fostering such collaboration, IQC will continue to build its reputation as a world-class centre for research and development of quantum information technologies.

Objectives

- Be a catalyst for collaborations of quantum information scientists through networks such as the NSERC Nano-Qubits Network (NNQ), the Canadian Institute for Advanced Research (CIFAR) Quantum Information program and the Natural Sciences and Engineering Research Council of Canada (NSERC) Strategic Networks
- Promote collaborations through participation in national and international conferences
- Produce internationally recognized, high-calibre publications co-authored by IQC researchers
- Organize at least three conferences that involve multi-disciplinary participants
- Continue, enhance and increase visits to IQC by international scientists and academics from around the world

4.4 Building, Facilities and Laboratory Support

This activity will result in the Mike & Ophelia Lazaridis Quantum-Nano Centre building being completed and operational on schedule. Additionally, the RAC I & II laboratories will be operational and fully functional.

Objectives

- Ensure the Mike & Ophelia Lazaridis Quantum-Nano Centre is completed per specifications, on time and on budget
- Complete commissioning phase and move into the Mike & Ophelia Lazaridis Quantum-Nano Centre beginning in early 2012

To become a magnet for highly qualified personnel in the field of quantum information

4.5 Attracting, Educating and Training Highly Qualified Personnel

Student targeted outreach will lead to an increased number of applications to the graduate studies program, providing a larger pool of prospective applicants from which IQC can recruit the best. Training students in quantum information research is vital since they will be the decision makers in 10 to 15 years when quantum information devices become more widespread. IQC prides itself in ensuring that students have the right knowledge to make wise decisions in the future.

Objectives

- Attend at least four graduate fairs to connect with prospective students
- Field at least 240 applications to the uWaterloo/IQC graduate studies program

- Expand connections made with undergraduate programs at Ontario and Canadian universities
- Take part in at least two international outreach or recruitment events

To establish IQC as the authoritative source of insight, analysis and commentary on quantum information

4.6 Disseminating Knowledge

The increase in outreach and knowledge dissemination will help to achieve the strategic objective of establishing IQC as the authoritative source of information, analysis and commentary on quantum information. It will also help to promote IQC and Canada as a world-class centre of research in quantum technologies and their applications.

Objectives

- Develop and implement a year-long plan of communications, outreach events and other activities linked to IQC's 10th anniversary celebrations
- Increase interest in camps, workshops, conferences and programs through targeted marketing and increase the scale of the events with technology
- Reflect IQC's outreach priorities and programs on the web
- Host at least three conferences with distinct target audiences
- Increase external media coverage, especially international media coverage

4.7 Communications and Outreach Strategy

The year-long plan for events and activities linked to the 10th anniversary as an institute will ramp up IQC's profile and support its three strategic objectives. Branding work should help to showcase the world-leading science as broadly as possible. Continued work with the website should allow for world-class presentation of key scientific information that will build and reinforce IQC's identity as the authoritative source of insight, analysis and commentary on quantum information around the world. The branding project will be founded on the strategic aspirations of IQC with the recognition that IQC is part of a global community who share many of the same goals.

Objectives

- Develop a year-long plan of communications, outreach, events and other activities linked to IQC's 10th anniversary
- Hold an Open House in mid-2012 in partnership with the University of Waterloo main campus to celebrate IQC's move into the Mike & Ophelia Lazaridis Quantum-Nano Centre
- Continue and develop the research and creative work that will result in key messages per stakeholder group, consistent and compelling brand identity for IQC to help convey world-class science as broadly as possible

- Continue with website development to showcase IQC's scientific achievements and intensify the outreach activities

4.8 Administrative Support

A seamless transition to the QNC and the related commissioning of equipment will minimize research disruptions. An information management repository will provide an effective resource to access research and business information of the institute including governance, practices and procedures, and providing ready access to management information and performance metrics. Software support for the operations of the fabrication facility will streamline workflows and aid in providing for higher quality assurance on equipment. A stakeholder development plan will be prepared with a view to ensuring the institute's main stakeholders are kept informed of our mission, strategic objectives and our accomplishments.

Objectives

- Plan for the expansion into the Mike & Ophelia Lazaridis Quantum Nano Centre, including the commissioning of the labs (scheduled for early 2012), facilities and equipment
- Implement in the fall semester an information management repository that provides intuitive retrieval and administration of the institute's business, including practices and procedures, financial reports, metrics, governance framework (e.g. committee terms of reference), and other information that facilitates the successful operation of the institute
- Implement software for the fabrication facility (clean room) during the winter semester to provide for equipment scheduling (including assurance that users are trained), billing to end-users and maintenance planning
- Establish a funding mechanism for the ongoing operating costs (utilities and maintenance) for the QNC prior to the winter semester
- Develop a stakeholder relations plan

5. RISK ASSESSMENT & MITIGATION STRATEGIES

		LIKELIHOOD		
		Low	Med	High
IMPACT	High	6	8	9
	Med	3	5	7
	Low	1	2	4

Risk Factor	Impact Score	Likelihood Score	Risk Rating	Explanation of Score	Mitigation Measures
1) IQC may not be able to attract high quality researchers	High	Medium	8	The market for world-class researchers is highly competitive, and IQC is still building brand awareness. However, researchers are the cornerstone on which institutional reputation is built	<ul style="list-style-type: none"> •Pursue recruits from a wide breadth of areas of research •Offer competitive job offers/package. •Adequately promote the world class researchers and the cutting-edge facilities/equipment at IQC

Risk Factor	Impact Score	Likelihood Score	Risk Rating	Explanation of Score	Mitigation Measures
2) Key staff may defect from IQC	High	Medium	8	IQC's research and recruitment efforts are largely the responsibility of a few key individuals. These individuals would be difficult to replace	<ul style="list-style-type: none"> •Diversify the nature of staff members' work •Provide a challenging work environment •Ensure adequate technical and administrative support •Ensure world-class facilities and equipment •Provide a stimulating environment •Provide attractive benefits and employee/spousal programs.
3) Transformational technologies may render current research less relevant	High	Low	6	If IQC research is rendered less relevant, HQP and data seekers will go elsewhere	<ul style="list-style-type: none"> •Ensure a wide breadth of research to investigate (this would differentiate IQC from its competitors) •Continue applications for research funds to support leading edge equipment
4) Graduate program may not be approved or may suffer delays	Medium	Low	3	Delays may hinder IQC's recruitment efforts	<ul style="list-style-type: none"> •Ensure high-quality graduate program application
5) IQC may not be able to recruit enough HQPs	High	Low	6	Many international HQP come from potentially politically unstable countries (top three are Iran, China, India)	<ul style="list-style-type: none"> •Promote IQC sufficiently •Ensure excellent research •Diversify markets/ countries from which students are recruited

Risk Factor	Impact Score	Likelihood Score	Risk Rating	Explanation of Score	Mitigation Measures
6) Lack of financial information (regarding endowment) impedes long-term planning	High	Low	6	Sustainability/ source of funds (other than IC) is largely unknown	<ul style="list-style-type: none"> • Prepare a 10-year financial plan for ongoing operations
7) Operating constraints limit IQC's efforts to brand itself	High	Low	6	Operating constraints include limited resources (including staff), degree of flexibility	<ul style="list-style-type: none"> • Recruit the right people/talent/skills • Develop and deliver a branding project plan • Foster close working relationships with appropriate units within the university
8) Construction costs may exceed budget	Low	Medium	2	The IC grant amount is fixed. University has committed to compensate for shortfall.	N/A
9) Construction schedule may be delayed	Medium	Low	3	Outcomes would be delayed, but not changed	N/A

6. APPENDIX

- A. Industry Canada Grant Agreement
- B. Industry Canada Page Reference Guide
- C. IQC's Eight Areas of Research
- D. 2011 Objectives
- E. Members List
- F. Governance List
- G. Financial Supporters
- H. 2011 Grants
- I. Publications Review
- J. Collaborating Institutions
- K. Citation Award
- L. Visitors
- M. Financial Times Rankings
- N. Awards
- O. Presentations
- P. Tours
- Q. Press Releases
- R. Media Coverage
- S. Strategic Research Model

A. Industry Canada Grant Agreement

This report focuses on two main evaluation issues (consistent with the new Treasury Board Policy on Evaluation effective April 1, 2009): relevance and performance. Within these two categories, the evaluation will consider:

- Appropriateness and effectiveness of the design and delivery of the research conducted by IQC
- Results achieved to date:
 - Outputs and immediate outcomes
 - Intermediate outcomes, such as the establishment of a world-class facility for QI (quantum information) research and training

According to the Grant Agreement, the University of Waterloo's Board of Governors must approve IQC's annual report to Industry Canada.

IQC's annual report will include:

1. A statement of the institute's objectives for that year and a statement on the extent to which the institute met those objectives
2. A list of activities undertaken with the grant
3. A statement of the institute's objectives for the next year and the foreseeable future
4. A description of the proposed activities for the next year to be undertaken within the context of this agreement, and a description of how the institute intends to implement them
5. A proposed schedule for the implementation of the activities for the next year
6. The anticipated results of those activities
7. Results achieved in the past year in accordance with a performance measurement strategy developed by Industry Canada
8. Risk assessment and mitigation strategies and ongoing performance monitoring strategies

The five-year grant from Industry Canada will enable the establishment of a new world-class research facility, which will support the government's science and technology strategy aimed at building a strong Canadian economy via knowledge and innovation. In the long-term, Industry Canada expects four key outcomes as a result of this grant:

1. Increased knowledge in quantum information
2. New opportunities for students to learn and apply new knowledge
3. Canada branded as a place to conduct research in quantum technologies
4. Canada positioned to take advantage of economic and social benefits of research

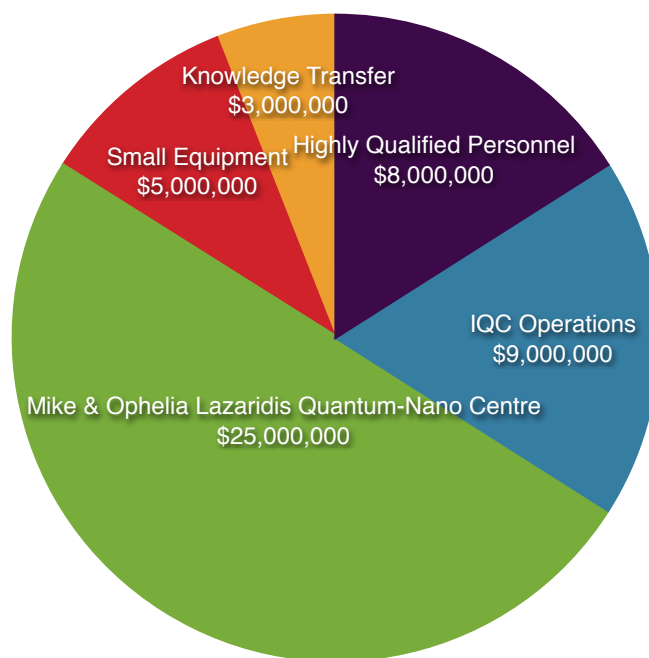
This chart illustrates the distribution of Industry Canada funds over five years:

Fiscal Year	Funding Amount (\$ in Millions)
2010	\$16.5
2011	\$17.0
2012	\$5.0
2013	\$5.5
2014	\$6.0
Total	\$50.0

With the aim of supporting IQC in its pursuit of these expected results, Industry Canada has allotted \$25 million over two years to the construction of the new Mike & Ophelia Lazaridis Quantum-Nano Centre, \$5 million over five years for the purchase of small equipment and \$20 million over five years to the following four activities:

1. Recruiting and retaining highly qualified personnel
2. Transferring knowledge
3. Supporting administrative and technical staff members
4. Purchasing materials and supplies (other than small equipment)

Industry Canada Funding Alottment

**B. Industry Canada Reporting Requirements: Page Guide**

Section	Metric	Page #
Objectives	2011 Objectives	93
	2012 Objectives	76
Results		
Activity 1: Building facility and equipment	Per cent of construction that is complete	40
	Per cent of equipment is in place/labs finished	36
	Degree to which construction is on budget	40
	Degree to which construction is on schedule	40
	Number of jobs created (construction)	40

Section	Metric	Page #
Activity 2: Collaborating with Other Researchers	Number of requests to visit the facility	34
	Number of new grants	23
	Number of collaborations (between two or more researchers)	32
	Type of collaborations	32
	Number of collaborators	32
	Number of citations	26
	Number of peer reviewed publications	24
	Number of spinoffs, disclosures, patents, etc.	17
	MOUs with other universities or organizations	35
	Number of faculty awards	52
	\$ investment by government and industry	108
Activity 3: Recruiting Researchers/Conducting Research in QI	Number of citations	26
	Number of peer reviewed publications	24
	Number of spinoffs, disclosures, patents, etc.	17
Activity 4: Attracting, Educating and Training HQPs	Number and type of new courses and labs	45
	Documented establishment of graduate program	44
	Type of practical opportunities for graduates	47
	Number of scholarships/fellowships/awards received by IQC HQP	49
	Per cent of graduates working in the QI field in Canada	47
	Number of books/chapters authored by IQC researchers	24
	Per cent of IQC HQPs from top undergraduate/graduate schools (as ranked by the FT)	4

Section	Metric	Page #
	Per cent of IQC HQPs with high GPAs	48
	Number of domestic/international HQPs at IQC/ jobs created	42
Activity 5: Disseminating Knowledge	Number of workshops held	64
	Number of visitors to IQC	34
	Number of presentations at conferences made by IQC HQP	67
	Number of applications to IQC (faculty and postdocs)	43
	Number of visits to the IQC website	70
	Type of content on the IQC website	70
	Number and type of outreach activities (including number of participants)	59
	Number of press releases by/articles written on IQC	73
	Number and type of researchers at IQC	29
Activity 6: Communications and Outreach Strategy	Documented communications/branding plan, roadmap	68
	Number and type of outreach activities (including number of participants)	59
Risks	Situational assessment	80
	Mitigation strategies	80
	Ongoing performance monitoring strategies	80

C. IQC's 8 Main Areas of Research

The research at IQC is aimed at harnessing the quantum world and transforming the scientific and industrial landscape. At the deepest level of the atomic world, the laws of physics are

governed by quantum mechanics, which imposes fundamental physical limits to controlling systems. Quantum information science and technology provide the framework to understand and utilize quantum properties of nature. The approach at IQC aims to take advantage of a critical mass of researchers in mathematics, physical science and engineering. We are focussing on three main applications: computing, communication and sensing. Computing is the manipulation and storage of information, communication relates to the transmission and sensing is related to the detection of signal or stimuli that could allow us to navigate the nanoscopic world. Quantum mechanics allows these applications to be more efficient and more precise than what can be done using classical devices using a similar amount of resources.

The development of quantum sensors, quantum communications and quantum information systems will harness quantum phenomena and use them for a technological advantage. The development of practical quantum sensors and actuators will find its first applications in the realm of nanotechnology as tools for navigating and controlling the nanoscopic world. As we harness the quantum world, quantum computers will become reality.

IQC's research breadth spans from the foundations of quantum information science to the development of quantum technologies; some experiments focus on the nano-scale, while others world on the planetary scale via satellite. Below are some of the areas of specialization explored by IQC's theoretical and experimental scientists.

Quantum Information Theory

Computers have steadily become smaller and more powerful over the past half-century, thanks to the miniaturization of transistors. But as ever-shrinking technology crosses the threshold into the atomic realm, the laws of quantum physics suddenly take hold. While this poses serious hurdles for classical computing, it opens incredible new possibilities in the realm of quantum computing.

Classical computers use binary "bits" of ones and zeros. Quantum computers will encode such bits in physical systems where we can also harness the quantum mechanical properties and obtain a more powerful system of quantum bits, or qubits. Thanks to the amazing rules of quantum mechanics, qubits can be in a "superposition" of zero and one simultaneously. Another quantum property called "entanglement," which Einstein and others debated decades ago, has since been harnessed in laboratories, and allows us to achieve tasks such as quantum teleportation and squeezing two bits of classical information into a single qubit. Quantum teleportation allows a qubit of information to be transmitted over a distance (indeed, teleported) by sending only two bits of classical information, and has important applications in

quantum communication and building robust quantum computers.

IQC faculty members are exploring the fundamental properties of quantum information. Ashwin Nayak has led pioneering work in quantum coding with random access codes. Debbie Leung's work has contributed to the refutation of the "additivity conjecture" for quantum channel capacities. Norbert Lütkenhaus, Richard Cleve and John Watrous have made significant discoveries in the theory of communication using qubits.

Quantum Algorithms

The field of quantum computing was kick-started in the 1980s when it was discovered that certain computational problems can be tackled more efficiently with quantum algorithms than with their classical counterparts. The most prominent such breakthrough came when MIT researcher Peter Shor (then at AT&T) unveiled an algorithm that could efficiently factor very large numbers — a feat believed to be impossible for classical computers. Since then, an increasing number of difficult computing tasks, such as "needle-in-haystack" search problems, have been shown to be sped up with quantum algorithms. Andrew Childs, Richard Cleve, Michele Mosca, Ashwin Nayak and John Watrous are contributing to this field.

Quantum Complexity

Whereas algorithms focus on what a quantum computer can achieve, the study of complexity examines how well they can (or cannot) achieve these tasks and by counting the resources needed. Quantum complexity examines the concept of difficulty — the "hardness" of certain problems to solve. In 2009, John Watrous and collaborators achieved a major breakthrough when they resolved a decade-old complexity problem by proving the equivalence of two collections of computational problems called QIP and PSPACE. Contributions that have shaped the field have also been made by IQC faculty including Andrew Childs, Richard Cleve, Michele Mosca, Ashwin Nayak and Ben Reichardt.

Quantum Cryptography

Every time you perform an online transaction, such as a purchase or bank transfer, you entrust your personal data to a secure encryption system. Such encryption is based on mathematical problems too difficult for present-day computers to crack, which is why your information is

relatively safe. But future computers — quantum computers in particular — will be able to decrypt many such coded messages. We need new cryptographic tools that are secure in a quantum world. Fortunately, the rules of quantum mechanics enable codes that cannot be broken with any amount of computing power.

The rules of quantum mechanics dictate that a quantum system cannot be observed without being disrupted. This means that “key” material exchanged via quantum communication will bear the indelible fingerprint of any attempted eavesdropping. Eavesdropped keys can be abandoned, and only truly private keys are kept to be used in unbreakable encryption protocols. IQC is home to Alice, a photon receiver in a Quantum Key Distribution system. Alice’s counterpart, Bob, is housed in an office at Waterloo’s Perimeter Institute for Theoretical Physics. Alice and Bob receive entangled (highly correlated) photons emitted from a crystal excited by a laser. By measuring the unique polarization of the photons, Alice and Bob receive random (but identical) “keys,” which can be used to encode messages. IQC researcher Norbert Lütkenhaus is a leading international authority on the security of practical quantum key distribution systems. Thomas Jennewein is a world leader in quantum communication and quantum cryptography in free space. IQC researchers including Richard Cleve, Raymond Laflamme, Norbert Lütkenhaus, Debbie Leung, Michele Mosca and Ashwin Nayak have worked on this and other facets of quantum cryptography, such as quantum fingerprints, quantum money and quantum private channels.

Quantum Error Correction & Fault Tolerance

One of the biggest hurdles faced by quantum computing researchers is called decoherence — the tendency of quantum systems to be disturbed. This vulnerability to noise leads to errors, which can be overcome by Quantum Error Correction. Because error correction techniques are themselves susceptible to noise, it is crucial to develop fault-tolerant correction.

IQC Director Raymond Laflamme is one of the pioneers of quantum error correction and the theory of fault-tolerant quantum computing. In collaboration with new IQC faculty member David Cory, Laflamme conducted the first experimental testing of quantum error correction in liquid-state nuclear magnetic resonance. IQC faculty members Joseph Emerson, Ben Reichardt, Frank Wilhelm and Debbie Leung have all made significant contributions to the field, including: noise characterization, decoherence theory, control theory and approximate quantum error correction.

Spin-Based Quantum Information Processing

A well-known technology that has long been used in biomedical imaging also serves as a natural test-bed for quantum computing. Nuclear Magnetic Resonance (NMR) manipulates the quantum states of nuclear “spins” in molecules. Because the nuclei behave like tiny magnets, they can be controlled and manipulated using magnetic fields and radiofrequency pulses — and thus serve as qubits. So far, NMR has been the most successful system in implementing quantum algorithms.

A team of researchers led by IQC faculty Raymond Laflamme and David Cory hold the current record for the most well-characterized qubits harnessed in a single experiment (12). Other IQC faculty including Jonathan Baugh, Joseph Emerson, Debbie Leung, and Michele Mosca have also made numerous critical contributions to the development of spin-based quantum computing.

Future research will require a platform that can be scaled up to harness an increasing number of qubits. Trapping and controlling single electron spins in nanoscale devices (such as point defects, quantum wires or semiconductor quantum dots) is at the heart of research done by IQC researchers Jonathan Baugh and David Cory. Creating a viable system with many qubits is key to realizing the full power of quantum information processing.

Spin-based systems can be used not only as quantum computer prototype but also as sensors. IQC faculty member David Cory’s research in this area has included the improvement of neutron interferometry (NI), in collaboration with the National Institute of Standards and Technology (NIST) in Maryland. The development of interferometers inspired by quantum error correction techniques has already resulted in greatly enhanced robustness and permitted the design of special purpose NI for new applications to magnetic and soft matter. Quantum actuators currently under development in Cory’s lab include electron spin control of nuclear spins, electron spin control of transport, optical control of electron and nuclear spins, and electron spin control of superconducting circuits. Ultimately, this research aims to integrate quantum sensors and actuators into more complex systems and achieve higher levels of functionality. These complex systems could be used, for example, to detect single spins or even serve as building blocks for the development of practical quantum information processors.

Nanoelectronics-Based Quantum Information Processing

Because they are based on standard semiconductor technology, nanoscale systems such as quantum dots and superconducting circuits make good candidates for practical quantum computers. Once a few such systems are shown to work above a given threshold, the key will be to make them work together in scalable technology. Significant progress has been made in reducing errors, implementing algorithms and observing entanglement using these systems.

IQC is home to two new labs in these fields: the Quantum Spintronics laboratory and the Superconducting Quantum Devices laboratory. IQC theorists and experimentalists including Frank Wilhelm, Jonathan Baugh, Adrian Lupascu and Hamed Majedi are leading these investigations. Their work will be essential as quantum information technology moves closer toward practical realization and commercialization.

Optical Quantum Information Processing

In quantum optics, photons (particles of light) are used to carry quantum information. Each photon has a polarization — for instance, vertical or horizontal, which can be ascribed with the classic bit states of zero and one, respectively. But polarization can also be in a quantum superposition of these states — essentially zero and one at the same time. Since the means of manipulating the polarization of photons are well understood and easily achievable, optics makes an ideal test-bed for investigating quantum information processing. Some of the first realizations of novel quantum effects, such as teleportation and quantum key distribution, were achieved through optics research.

The seminal proposal by Emanuel Knill, Raymond Laflamme and Gerard Milburn (the KLM proposal) allows universal and scalable optical quantum computing using only single photons, linear optics and measurement. IQC faculty member Norbert Lütkenhaus has conducted leading research into such areas as entanglement verification and quantum logic operation. The team led by Kevin Resch focuses on the generation and applications of quantum entanglement, fundamental tests of quantum mechanics and novel approaches to optical imaging. Thomas Jennewein's optical research team investigates quantum communication through free space via satellite.

D. 2011 — Original Objectives

1. Conducting Research in Quantum Information

Background

The institute's primary mandate is to conduct research in quantum information science

at the highest international level. This goal has necessitated the ongoing recruitment of top faculty and students, the acquisition of cutting-edge equipment and resources, and the creation of a working environment that fosters scientific excellence. The continued expansion of the institute will allow researchers at IQC to explore new theoretical and experimental approaches to quantum information processing over the next year.

Activities & Timeline

- Leading-edge investigation of theoretical approaches to quantum information processing in order to:
 - Better understand the impact of quantum mechanics for information processing
 - Investigate new potential applications
 - Develop approaches to quantum information using photonic, nuclear and electron spins, quantum dots, superconducting technologies and study the requirements needed to design earth to satellite quantum cryptography systems

Expected Results

The research at IQC will produce new knowledge that will lead to publications and presentations at conferences. This knowledge will include a better understanding of quantum information processors and laboratory demonstrations of their control, and the development of technologies based on these processors. Ultimately it will lead to new technologies and applications.

2. Recruiting Researchers

Background

The mission of IQC is to develop and harness quantum information science and technology at the highest international level through the collaboration of computer scientists, engineers, mathematicians and physicists. To this end, IQC must continue to build a team of theoretical and experimental researchers who are leaders in their respective disciplines. With such top researchers, IQC can achieve its other strategic objectives: becoming a magnet for students and postdoctoral researchers, and becoming the authoritative source of information, analysis and commentary about quantum information.

Activities & Timeline

- Recruit up to three new faculty members
- Recruit between six to 10 new postdoctoral fellows
- Recruit 20 new graduate students
- Leverage conferences and other outreach forums as recruitment opportunities

Expected Results

The ongoing recruitment of top-tier faculty to IQC will further enhance the institute's fundamental objective of pursuing quantum information research at the highest international level. Assembling a critical mass of theoretical and experimental researchers, exploring a broad range of approaches to quantum information processing, will establish IQC at the forefront of the field. This, in turn, will fuel the institute's objectives of being a magnet for top students and being the authoritative source for information and analysis on the field. Fulfilling all these objectives will put IQC, and therefore Canada, at the forefront of the international pursuit of quantum information technologies.

3. Collaborating with Other Researchers

Background

The field of quantum information processing spans many disciplines — physics, chemistry, computer science, mathematics and others — and we expect that many breakthroughs will come from collaborations between researchers from a variety of fields. At IQC we are pursuing opportunities (joint grants, research projects, memoranda of understanding) to forge strong collaborative relationships with top scientists and researchers around the world.

Activities & Timeline

- IQC to be a catalyst to facilitate collaborations of quantum information scientists through networks such as QuantumWorks, Canadian Institute for Advanced Research (CIFAR) Quantum Information program and the Natural Sciences and Engineering Research Council of Canada (NSERC) Strategic Networks
- Researchers will attend international conferences on quantum information processing to build networks and connections
- Increased number of publications co-authored by IQC researchers and external collaborators
- Organize three conferences that involve multi-disciplinary participants
- Continue, enhance and increase visits to IQC by researchers from around the world

Expected Results

Strategic collaborations with key researchers from across disciplines will enhance IQC's international reputation, draw highly qualified personnel to IQC, and lead to experimental and theoretical breakthroughs (for example, the QIP=PSPACE

breakthrough achieved by IQC's John Watrous and outside collaborators). By fostering such collaboration, IQC will become an world-class centre for research and development of quantum information technologies.

4. Building, Facilities and Laboratory Support

Background

IQC's mission is to develop and advance quantum information science and technology through collaboration of computer scientists, engineers, mathematicians and physical scientists. There are currently two construction projects underway that will help IQC achieve this goal. The Research Advancement Centre II (RAC II) will host some of the IQC's future projects and the Mike & Ophelia Lazaridis Quantum-Nano Centre (QNC) will become IQC's new headquarters. The QNC is located at the heart of the University of Waterloo's main campus. The centre will be home to a 20,000 sq. ft. fabrication and metrology lab as well as the Waterloo Institute for Nanotechnology.

Activities

- Proceed with the construction of the Mike & Ophelia Lazaridis Quantum-Nano Centre and ensure that the building is constructed per specifications, on time and on budget
- Establish a new 10,000 sq. ft. laboratory in the Research Advancement Centre II (RAC II) building with research focused on quantum sensors and actuators
- Prepare equipment and other resources for expansion into to the QNC
- Continue acquisition and maintenance of equipment for RAC I laboratories

Timeline

- RAC II will be completed June 2010
- QNC construction
- The floor slabs on floors two to five were completed
- The main structure of building was completed in March 2010
- Currently, the exterior building envelope is approximately 20 per cent complete
- The building will be watertight by August 2010
- The majority of the mechanical and electrical work will be completed by April 2011
- The building construction will be complete in July 2011

Expected Results

This activity will result in buildings and equipment that are installed and operational.

5. Attract, Educate and Train Highly Qualified Personnel

Background

While IQC possesses a critical mass of leading researchers in quantum information science, it is imperative for the future of the institute to recruit, educate and train the next generation of leaders in the field. The path toward the realization and commercialization of practical quantum information technologies will be forged by the next waves of student researchers. Seeking out those prospective students, recruiting them to IQC and providing them with the necessary resources and guidance is therefore critical to the long-term mission and vision of IQC.

Activities & Timeline

- Roll-out the graduate program
- Establish an open house event for graduate students to attract prospective applicants
- Enhance prominence and content of graduate studies program on the IQC website (including background information, course materials, etc.)
- Attend at least four graduate fairs to connect with prospective students
- Field at least 120 applications to the UW/IQC graduate studies program (a 20 per cent increase over applications in 2009/2010)
- Host an information session for University of Waterloo students

Expected Results

The establishment of a Graduate Program will be an important tool for IQC to be a magnet for students. The Graduate Student Open House will aid in the recruitment of top-tier students who may be weighing various options. Enhancing the content, accessibility and interactivity of the Graduate Studies section of the IQC website will aid in attracting the best students from around the world. These means of student targeted outreach will lead to an increased number of applications to the graduate studies program, providing a larger pool of prospective applicants from which IQC can recruit the best.

6. Disseminating Knowledge

Background

Meetings, workshops, conferences and outreach activities are organized annually to complement the research that is happening at IQC. These events range from general interest lectures to highly specialized conferences. IQC is currently working on a

website redesign project that will influence the outreach strategy and the dissemination of knowledge in the future.

Activities & Timeline

- Host five conferences at IQC with 3 distinct target audiences including researchers, undergraduate students and high school students
- Complete website redesign project and launch new web presence
- Compile a database of the publications by IQC researchers on RefBase2
- Increase external media coverage

Expected Results

The increase in outreach and knowledge dissemination will help to achieve the strategic objective of establishing IQC as the authoritative source of information, analysis and commentary on quantum information. It will also help to promote IQC as a world-class centre of research in quantum technologies and their applications.

7. Communications and Outreach Strategy

Background

IQC's communications and outreach goals are guided by IQC's three strategic objectives, most directly to establish IQC as the authoritative source of information, analysis and commentary on quantum information. The Communications and Outreach Strategy encompasses: identifying key audiences, stakeholders and messages, developing tools and processes for communications, building relationships with outreach partners, and identifying the institute's unique culture to build the IQC brand.

Activities & Timeline

- Assemble the full communications and outreach team by August 2010
- Lay IQC branding groundwork, including market research, focus groups, interviews/surveys with stakeholders – beginning summer 2010
- Complete website redesign to increase IQC's web presence, interactivity and outreach scope
- Develop key messages and themes for IQC communications
- Targeted outreach to highlight IQC's scientific strengths and attract researchers to the institute
- Planning for IQC's 10th anniversary and the expansion into the new Quantum-Nano Centre

Expected Results

The establishment of a full, five-member Communications and Outreach team will allow for the creation and execution of a long-term strategy that fulfills IQC's objective of becoming the authoritative source of analysis and insight on quantum information. The addition of an Associate Director of Communications & Outreach will allow the team to operate more strategically and autonomously. This in turn will lead to the development of communications strategies, outreach activities and a clear IQC brand that fully conveys IQC's stature as the authoritative source of information, analysis and commentary on quantum information.

8. Administrative Support

Background

The fundamental function of IQC's administrative team is to provide researchers and students with the professional support needed to pursue leading-edge research in quantum information. To this end, it is necessary for the administrative team to have clearly delineated roles and responsibilities that fully support the scientific goals of the Institute. To support and sustain the many academic, research and outreach activities at IQC, it is necessary to develop and maintain best practices for financial standards, processes and documentation. Information technology is integral to IQC's success and its support ranges from enabling administrative functions to supporting scientific research and online outreach. IQC's information technology strategy encompasses infrastructure, information/transaction management and stakeholder support.

Activities & Timeline

- Documenting and standardizing processes, jobs and back-ups in a rapidly expanding institute
- Planning for expansion into RAC II and the QNC
- Establishing a grant life cycle process for standardizing and tracking sources of funding
- Developing desktop and other software/hardware tools and techniques
- Developing tools and processes for a new website

Expected Results

The creation of standardized processes will create efficiency and repeatability for IQC's administration in the long-term. The clear establishment of roles and responsibilities will allow administrative personnel to better support the scientific activities at IQC. Establishing an efficient, standardized process for monitoring grant details (grant names, amounts, investigators, agencies) will allow greater efficiency in attaining and tracking

funding sources. Refining and streamlining information technology processes for IQC researchers and staff will enable the highest quality work. Providing IQC personnel with the resources necessary for their roles and help reduce support demands and improve efficiency, allowing longer-term planning of IT strategies.

E. Members

IQC's official headcount includes all members that conducted research at the institute during the fiscal year and may not reflect the current headcount as of April 30, 2011.

Faculty, research assistant professors and postdoctoral fellows are counted if they conducted research at IQC during the 2011 fiscal year (and until their formal resignation is received). Students are counted in the official headcount if they were registered for at least one term at the University of Waterloo during the 2011 fiscal year. Staff are counted as of April 30, 2011.

Faculty

- | | |
|--|----------------------------|
| 1. Jonathan Baugh | 5. Jianxin Chen |
| 2. Andrew Childs | 6. William Coish |
| 3. Richard Cleve | 7. Motohisa Fukuda |
| 4. David Cory | 8. Oleg Gittsovich |
| 5. Joseph Emerson | 9. Patryk Gumann |
| 6. Thomas Jennewien | 10. Gus Gutoski |
| 7. Raymond Laflamme | 11. Brendon Higgins |
| 8. Debbie Leung | 12. Rolf Horn |
| 9. Adrian Lupascu | 13. Hannes Huebel |
| 10. Norbert Lütkenhaus | 14. Lawrence Iannou |
| 11. Hamed Majedi | 15. Tsuyoshi Ito |
| 12. Michele Mosca | 16. Rainer Kaltenbaek |
| 13. Ashwin Nayak | 17. Piotr Kolenderski |
| 14. Ben Reichardt | 18. Xiongfeng Ma |
| 15. Kevin Resch | 19. William Matthews |
| 16. John Watrous | 20. Seth Merkel |
| 17. Gregor Weihs (resignation July 2010) | 21. Rajat Mittal |
| 18. Frank Wilhelm | 22. Osama Moussa |
| | 23. Florian Ong |
| | 24. Robert Prevedel |
| | 25. Emily Pritchett |
| | 26. Colm Ryan |
| | 27. Robabeh Rahimi Darabad |
| | 28. David Rideout |
| | 29. Aidan Roy |
| | 30. Krister Shalm |
| | 31. Urbasi Sinha |
| | 32. Yipu Song |
| | 33. Jon Tyson |
| | 34. Nathan Weibe |
| | 35. Zhizhong Yan |
| | 36. Bei Zeng |
| | 37. Jingfu Zhang |

Research Assistant Professors

1. Jay Gambetta
2. Dmitri Maslov
3. Marco Piani
4. Dmitry Pushin

Postdoctoral Fellows

1. Gorjan Alagic
2. Mohammad Ansari
3. Dominic Berry
4. Anne Broadbent

Graduate Students

1. Jeyran Amirloo
2. Razeih Annabestani
3. Jean-Philippe Bourgoïn
4. Jeremy Chamilliard
5. Alessandro Cosentino
6. Daniel Criger
7. Pierre-Luc Dallaire-Demers
8. Chunqing Deng
9. Amin Eftekharian
10. Chris Erven
11. Agnes Ferenczi
12. Chris Ferrie
13. Kent Fisher
14. Jen Fung
15. MirMotjaba Gharibi
16. Sevag Gharibian
17. Behnood Ghohroodi Ghamsari
18. Nickolay Gigov
19. Luke Govia
20. Christopher Granade
21. Peter Groszkowski
22. Nupur Gupta
23. Deny Hamel
24. Fatin Haque
25. Tyler Holden
26. Catherine Holloway
27. Amir Jafari Salim
28. Stacey Jeffery
29. Tomas Jochym-O'Connor
30. Artem Kaznatcheev
31. Mohsen Keshavarz
32. Botan Khani
33. Milad Khoshnagar Shahrestani
34. Nathan Killoran
35. Robin Kothari
36. Jonathan Lavoie
37. Nicholas LeCompte
38. Xian Ma
39. Easwar Magesan
40. Laura Mancinska
41. Iman Marvian
42. Thomas McConkey

43. Matthew McKague
44. Evan Meyer-Scott
45. Sergei Mikheev
46. Hamid Mohebbi
47. Abel Molina Prieto
48. Felix Motzoi
49. Varun Narasimhachar
50. Mohamad Niknam
51. Jean-Luc Orgiazzi
52. Yingkai Ouyang
53. Maris Ozols
54. Adam Paetznick
55. Kyungdeock Park
56. Gina Passante
57. Om Patange
58. David Pitkanen
59. Farzad Qassemi
60. Wenling Qiao
61. Ansis Rosmanis
62. Yuval Sanders
63. Kurt Schreiter
64. Cheng Shen
65. Jamie Sikora
66. Jamie Smith
67. Jason Soo Hoo
68. Gelo Noel Tabia
69. Cozmin Ududec
70. Sarvagya Upadhyay
71. Christopher Wood
72. Rui Xian
73. Mengyun Zhai
74. Yingjie Zhang

Research Assistants

1. Tessa Alexanian
2. Haig Atikian
3. Mark Cachia
4. Steven Casagrande
5. Grant Cleary
6. Eric Crever
7. Rongjie Du
8. Julian Glaessel
9. Bassam Helou
10. Ian Hincks

11. Brad Huiskamp
12. Sakshi Jain
13. Erika Janitz
14. Andrew Kowalczyzyn
15. Daniel Kumar
16. Yang Lu
17. Thomas Lutz
18. Allison MacDonald
19. Shazib Mahmood
20. Ian McMullan
21. Marius Oltean
22. Deanna Pineau
23. David Pomaranski
24. Daniel Puzzuoli
25. Sujeet Shukla
26. Fil Simovic
27. Natalie Sisombath
28. DJ Strouse
29. Veli Tezgel
30. Denis-Alexandre Trottier
31. Victor Veitch
32. Matthew Volpini
33. Caleb Wherry
34. Xiaodi Wu
35. Tong Zhao

Long-Term Visitors & Exchange Students

1. Troy Borneman, Massachusetts Institute of Technology
2. Moritz Ernst, Institut fuer Theoretische Physik, Universitaet zu Koeln
3. Maria Fernanda, Universidad de los Andes
4. Guanru Feng, Tsinghua University
5. Bettina Heim, Friedrich-Alexander-University of Erlangen-Nuremberg
6. Won-Young Hwang, Chonnam National University
7. Yusuke Kondo, University of Tokyo
8. Christian Konrad, Université Paris-Sud
9. Kevin Krsulich, Massachusetts Institute of Technology
10. Tony Leggett, University of Illinois at Urbana-Champaign
11. Youning Li, Tsinghua University
12. Sarah Sheldon, Massachusetts Institute of Technology
13. Seiichiro Tani, NTT Communication Science Laboratories
14. Virginia Villanueva, The National University of Mexico
15. Ricardo Wickert, Friedrich-Alexander-University of Erlangen-Nuremberg
16. Yafei Yu, South China Normal University

Administrative Staff

1. Jeremy Chamilliard
2. Matthew Cooper
3. Andrew Dale
4. Lisa David
5. Monica Dey
6. Michael Ditty
7. Brian Goddard
8. Jasmine Graham
9. Katharin Harkins
10. Colin Hunter
11. Lorna Kropf
12. Martin Laforest
13. Vito Logiudice
14. Steve MacDonald
15. Mary Lyn Payerl
16. Laszlo Petho
17. Wendy Reibel
18. Rodello Salandanan
19. Kimberly Simmermaker
20. Marta Szepietowski
21. Ivar Taminiau
22. Carly Turnbull
23. Steve Weiss

F. Governance

Other governing bodies that contribute to shaping the strategic direction of IQC include the institute's Board of Directors, the Executive Committee and the Scientific Advisory Committee.

IQC Board of Directors

IQC's Board of Directors is made up of internationally recognized leaders from academia, business and government. The Board provides strategic advice on all aspects of management including finances, planning, commercialization and outreach.

Douglas Barber, Distinguished Professor-in-Residence, McMaster University
 Tom Brzustowski, RBC Professor, Telfer School of Management, Chair, IQC Board of Directors
 Paul Corkum, University of Ottawa and National Research Council
 George Dixon, Vice-president, University Research, University of Waterloo
 Cosimo Fiorenza, Vice-president and General Counsel, Infinite Potential Group
 David Fransen, Consul General, Canadian Consulate General in Los Angeles
 Peter Hackett, Executive Professor, School of Business at the University of Alberta & Fellow, National Institute for Nanotechnology
 Raymond Laflamme, Executive Director, Institute for Quantum Computing
 Mike Lazaridis, President and Co-Chief Executive Officer, Research in Motion
 Steve MacDonald, Chief Operating Officer, Institute for Quantum Computing
 Michele Mosca, Deputy Director, Institute for Quantum Computing
 Peter Nicholson, Retired President, Council of Canadian Academies
 William R. Pulleyblank, Professor of Operations Research, United States Military Academy, West Point

Executive Committee

IQC's Executive Committee is chaired by the Dean of Science at the University of Waterloo and is made up of the Deans of Mathematics, Science and Engineering, the Vice-president of Research and IQC's senior management team.

Ian Goulden, Dean, Faculty of Mathematics, University of Waterloo
 George Dixon, Vice-president, Chair, University Research, University of Waterloo
 Raymond Laflamme, Executive Director, Institute for Quantum Computing
 Steve MacDonald, Chief Operating Officer, Institute for Quantum Computing

Terry McMahon, Dean, Faculty of Science, University of Waterloo
 Michele Mosca, Deputy Director, Institute for Quantum Computing
 Adel S. Sedra, Dean, Faculty of Engineering, University of Waterloo

Scientific Advisory Committee

IQC's Scientific Advisory Committee is made up of leading international scientists. The committee meets twice annually to assess IQC's progress toward fulfilling its mission and achieving its strategic goals. The committee advises the Executive Director on areas of strength and weakness in the institute's scientific endeavour to ensure the success of IQC.

Prof. Harry Buhrman, Centrum voor Wiskunde en Informatica
 Prof. Anthony J. Leggett, University of Illinois at Urbana-Champaign
 Prof. Gerard Milburn, University of Queensland
 Prof. Christopher Monroe, University of Maryland
 Prof. Umesh Vazirani, University of California, Berkeley
 Prof. Anton Zeilinger, University of Vienna
 Prof. Wojciech Hubert Zurek, Laboratory Fellow, Los Alamos National Laboratory
 and Santa Fe Institute

IQC's faculty members are appointed in six departments:

1. Combinatorics and Optimization
2. Computer Science
3. Applied Math
4. Physics & Astronomy
5. Chemistry
6. Electrical and Computer Engineering

These departments span three faculties:

1. Faculty of Mathematics
2. Faculty of Science
3. Faculty of Engineering

G. Financial Supporters

Industry Canada

Industry Canada granted \$50 million to IQC to be allocated over a five-year period. In the 2010/2011 year (2011 fiscal year), \$17 million was awarded with the following allotment: \$12.5 million for the construction of the Mike & Ophelia Lazaridis Quantum-Nano Centre, \$1.0 million for equipment purchasing, \$1.1 million toward highly qualified personnel, \$0.6 toward knowledge transfer and \$1.6 million for operations.

Mike and Ophelia Lazaridis

Mike and Ophelia Lazaridis have donated a total of \$105 million to IQC since inception.

The Government of Ontario

The Government of Ontario has granted \$50 million to the University of Waterloo to help strengthen Ontario's leading-edge research capacity. The Ontario Ministry of Research and Innovation granted IQC nearly \$18 million. (Includes the Ontario Innovation Trust and the Ontario Research Development Challenge Fund.)

The University of Waterloo

The University of Waterloo has committed to supporting the salaries of 33 IQC faculty.

Canadian Foundation for Innovation

CFI has contributed over \$14 million to IQC since inception.

Natural Sciences and Engineering Research Council of Canada

NSERC has committed over \$11 million to developing quantum information science and technology since the inception of IQC in 2002.

Canada Research Chairs

The Canada Research Chairs Secretariat Program supports IQC through faculty positions at the University of Waterloo that are jointly appointed by IQC and one of the departments in the Faculties of Science, Engineering or Mathematics. Current Research Chairs at IQC are: Raymond Laflamme, Michele Mosca and Debbie Leung.

Canada Excellence Research Chairs

The Canada Excellence Research Chairs program supports IQC with funding of \$10 million over seven years to support faculty member David Cory.

Many other agencies provide grants to IQC and its researchers including IARPA, DARPA, CESEC, MITACS and more.

H. Fiscal 2011 Grant Installments

Sponsor	# of Awards	Total
CERC (Canada Excellence Research Chairs)	1	1,600,000
CFI (Canada Foundation for Innovation)	8	1,477,100
Communications Security Establishment Canada	1	22,120
CRC (Canada Research Chair)	3	400,000
Human Resources Development Canada	1	21,004
MITACS (Mathematics of Information Technology and Complex Systems)	7	97,500
MRI (Ministry of Research and Innovation)	9	2,549,599
NSERC (Natural Sciences and Engineering Research Council of Canada)	18	715,386
Private Sector	14	391,923
IARPA	2	257,446
DARPA	1	50,380
US - Government and Public Sector	1	210,000
Industry Canada	1	17,000,000
QuantumWorks	13	504,700
Total	80	25,297,158

I. 2010 Publications

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- Broadbent, A., & Tapp, A. (2010). CAN QUANTUM MECHANICS HELP DISTRIBUTED COMPUTING? *INTERNATIONAL JOURNAL OF QUANTUM INFORMATION*, *8*(1-2), 259–269.
- Broadbent, A., Fitzsimons, J., & Kashefi, E. (2010). Measurement-Based and Universal Blind Quantum Computation. In *FORMAL METHODS FOR QUANTITATIVE ASPECTS OF PROGRAMMING LANGUAGES* (Vol. 6154, pp. 43–86).
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- Buhrman, H., Cleve, R., Massar, S., & de Wolf, R. (2010). Nonlocality and communication complexity. *REVIEWS OF MODERN PHYSICS*, 82(1), 665–698.
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J. Collaborating Institutions

IQC researchers collaborate with researchers from the following institutes on collaborative publications, in research networks and in other collaborative research projects.

Austrian Academy of Sciences, Vienna, Austria

BBN Technologies, Cambridge, Massachusetts, United States

Brown University, Providence, Rhode Island, United States

California Institute of Technology, Pasadena, California, United States

Canadian Space Agency, Saint-Hubert, Quebec, Canada

Center for Computational Intractability, Princeton, New Jersey, United states

Center for Quantum Photonics, Bristol University, Bristol, United Kingdom

Centrum Wiskunde & Informatica, Science Park, Amsterdam, Netherlands

Ciudad Universitaria, Coyoacan Tucumán Province, Argentina

Columbia University, New York City, New York, United States

COM DEV, Cambridge Ontario, Canada

Dartmouth University, Hanover, New Hampshire, United States

Delft University of Technology, Delft, Netherlands

Gdańsk University of Technology, Gdansk-Wrzeszcz, Poland

Google Inc., Mountain View, California, United States

Green Innovation Research Laboratories, NEC Worldwide, Tokyo Japan

Griffith University, Southport, Queensland, Australia

IBM, Markham, Ontario, Canada

Institut de Ciències Fòniques, Barcelona, Spain
Institució Catalana de Recerca i Estudis Avançats, Barcelona, Spain
Institute for Quantum Optics and Quantum Information, Austrian Academy of Sciences, Austria
Institut für Theoretische Physik Johann Wolfgang Goethe-Universität, Frankfurt, Germany
Institute for Advanced Studies in Basic Sciences, Zanjan, Iran
Isfahan University of Technology, Khomeynishar, Iran
Janelia Farm Research Campus, Howard Hughes Medical Institute, Loudoun County, Virginia, United States
Japan Science and Technology Agency, Saitama, Japan
Karlsruhe Institute of Technology, Karlsruhe, Germany
Kinki University, Higashiosaka City, Osaka, Japan
Laboratoire d'Information Quantique, Belgium, Europe
Laboratoire de Nanotechnologie et d'Instrumentation Optique, Troyes Cedex, France
Laboratoire Kastler Brossel, Paris, France
Laboratoire Pierre Aigrain, Paris, France
Leiden University, Leiden, Netherlands
Lockheed Martin, Amsterdam, Netherlands
Los Alamos National Laboratory, Los Alamos, New Mexico, United States
Ludwig-Maximilians-Universität, Fürstfeldbruck, Germany
Massachusetts Institute of Technology, Cambridge, Mass, United States
Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str., Germany
McGill University, Montreal, Quebec, Canada
McMaster University, Hamilton, Ontario, Canada
Michigan State University, East Lansing, Michigan United States
National Institute of Standards and Technology, Gaithersburg, Maryland, United States
National Quantum Information Center of Gdansk, Sopot, Poland
National Research Council of Canada, Ottawa, Ontario, Canada
National University of Singapore, Singapore
NEC Corporation, Singapore
Nippon Telegraph Telephone Corporation, Tokyo Japan
Osaka City University, Osaka Prefecture, Japan
Osterreichische Akademie der Wissenschaften, Vienna
Perimeter Institute for Theoretical Physics, Waterloo, Ontario, Canada
Poornaprajna Institute of Scientific Research, Karnataka, India
Queensland University of Technology, Brisbane, Australia
Raman Research Institute, Karnataka, India
Rutgers University, Rutgers, New Jersey, United States

Schlumberger Doll Research Lab, Ridgefield, Connecticut, United States
Stanford University, Palo Alto, California, United States
Syracuse University, Syracuse, New York, United States
The Chinese University of Hong Kong, Hong Kong
The Institute of Physical and Chemical Research (RIKEN), Japan
The University of Queensland, St Lucia, Australia
The University of Sydney, Sydney Australia
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Universitat Autònoma de Barcelona, Cerdanyola del Vallès, Spain
Universität des Saarlandes, Saarbrücken, Germany
Universität Stuttgart, Stuttgart, Germany
Université de Sherbrooke, Sherbrooke, Quebec, Canada
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University of Central Florida, Orlando, Florida, United States
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University of Georgia, Athens, Georgia, United States
University of Guelph, Guelph, Ontario, Canada
University of Innsbruck, Innrain, Austria
University of Latvia, Riga, Latvia
University of Leeds, Leeds, United Kingdom
University of Maryland, College Park, Maryland, United States
University of Michigan, Ann Arbor, Michigan, United States
University of Ottawa, Ottawa, Ontario, Canada
University of Toronto, Toronto, Ontario, Canada
University of Vienna, Wien, Vienna
University of Vigo, Spain
University of Wisconsin, Madison, Wisconsin, United States
University of Victoria, Victoria, British Columbia, Canada

K. Top 20 Cited Papers in 10 Years: Quantum Computers (March 2010)

The baseline time span for this database is 1999-December 31, 2009 (sixth bimonthly period 2009). The resulting database contained 12,386 (10 years) and 3,541 (2 years) papers. To construct the top 20 papers lists for the past decade and the past two years, the papers were further narrowed down by the title keywords "quantum comput*." This adjustment resulted in the top 20 papers being selected from a pool of 1,422 (10 years) and 243 (two years) papers.

For the full list of papers visit <http://sciencewatch.com/ana/st/quantum/papers10yr/>

Article 1:

Special Topic Interview with: Gerard Milburn

Total Cites: 1160

Article Title: A scheme for efficient quantum computation with linear optics

Authors: Knill, E, Laflamme, R, Milburn, GJ

Journal: NATURE

Volume: 409

Page: 46-52

Year: 2001

Addresses:

- Los Alamos National Lab, Los Alamos, NM, USA
- University of Queensland, Centre for Quantum Computer Technologies, St Lucia, Australia
- University of California, Los Alamos National Lab, MS B265, Los Alamos, NM, USA

Article 10:

Total Cites: 284

Article Title: Experimental one-way quantum computing

Authors: Walther, P, Resch, KJ, Rudolph, T, Schenck, E, Weinfurter, H, Vedral, V, Aspelmeyer, M, Zeilinger, A

Journal: NATURE

Volume: 434

Page: 169-176

Year: 2005

Addresses:

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- Univ Munich, Dept Phys, Munich, Germany
- Max Planck Society, Garching, Germany
- Erwin Schrodinger Inst Math Phys, Vienna, Austria
- Univ Leeds, Sch Phys & Astron, Leeds, England
- Austrian Acad Sci, IQOQI, Vienna, Austria
- Ecole Normale Super, Paris, France
- Univ Vienna, Inst Expt Phys, Boltzmanngasse 5, Vienna, Austria

L. Scientific Visitors

- | | |
|---|--|
| 1. Mohamed Abutaleb, Massachusetts Institute of Technology | of Quantum Optics in Garching, Germany |
| 2. Antonio Acin, Institut de Ciències Fotòniques | 17. Guido Burkard, University of Konstanz |
| 3. Andris Ambainis, University of Latvia | 18. Jianming Cai, Institut für Theoretische Physik - Universität Innsbruck |
| 4. Henri Angelino, National Institute of Informatics, Tokyo | 19. Tommaso Calarco, University of Innsbruck |
| 5. Joonwoo Bae, Korea Institute for Advanced Study (KIAS) | 20. Krishna Chetry, University of Cincinnati |
| 6. Mustafa Bal, Dartmouth College | 21. Chen-Fu Chiang, University of Central Florida |
| 7. Olaf Benningshof, Universiteit Leiden | 22. Giulio Chiribella, Perimeter Institute |
| 8. Jacob Biamonte, University of Oxford | 23. Eric Chitambar, University of Toronto |
| 9. Jonathan Blackman, University of British Columbia | 24. Andrew Cleland, University of California, Santa Barbara |
| 10. Hendrik Bluhm, Harvard University | 25. Christophe Couteau, Université de Technologie de Troyes |
| 11. Fabien Boitier, L'École Polytechnique | 26. Marcos Curty, University of Vigo |
| 12. Aggie Branczyk, University of Queensland | 27. Carlos Perez Delgado, University of Sheffield |
| 13. Fernando Brandao, Imperial College, London | 28. Ivan Deutsch, University of New Mexico |
| 14. Andrew Briggs, University of Oxford | 29. John Donohue, University of Windsor |
| 15. Winton Brown, Dartmouth College | 30. Frédéric Sébastien Dupuis, Eldgenössische Technische Hochschule Zürich |
| 16. Oliver Buerschaper, Max Planck Institute | |

31. Don Eigler, IBM
London
32. Alessandro Fedrizzi, University of Queensland
33. Stephen Fenner, University of South Carolina
34. Joe Fitzsimons, University of Oxford
35. Sergey Frolov, Delft University of Technology
36. Silvano Garnerone, University of Southern California
37. Mike Geller, University of Georgia
38. Shohini Ghose, Wilfred Laurier University
39. J  r  mie Gobeil, Universit   du Qu  bec    Trois-Rivi  res
40. Robert Hadfield, Heriot-Watt University
41. Avinatan Hassidim, Massachusetts Institute of Technology
42. Patrick Hayden, McGill University
43. Brendon Higgins, Griffith University
44. Richard Hughes, Los Alamos National Laboratory
45. Atac Imamoglu, Eidgen  ssische Technische Hochschule Z  rich
46. Rahul Jain, Centre for Quantum Technologies & National University of Singapore
47. Zhengfeng Ji, Perimeter Institute
48. Nathaniel Johnston, University of Guelph
49. Rainer Kaltenbaek, University of Vienna
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51. Vadym Kliuchnikov, University of Ukraine
52. Sacha Kocsis, Griffiths University
53. Robert K  nig, Institute for Quantum Information at Caltech
54. Matthew Leifer, University College London
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57. Mirko Lobino, University of Bristol
58. Brian Lowans, QinetiQ Ventures
59. Shunlong Luo, Chinese Academy of Sciences
60. Alex Lvovsky, University of Calgary
61. Lars Lydersen, Norwegian University of Science and Technology (NTNU)
62. Xiongfeng Ma, No Affiliation
63. Frederic Magniez, Laboratoire de Recherche en Informatique
64. Vadim Makarov, Norwegian University of Science and Technology (NTNU)
65. Rachael Mansbach, Swarthmore College
66. Alexandra Mech, University of Vienna
67. Zhenghua Mie, McMaster University
68. Gerard Milburn, Queensland University
69. Peter Milonni, Los Alamos National Laboratory
70. Vesna Mitrovic, Brown University
71. Christopher Monroe, University of Maryland
72. Cristopher Moore, University of New Mexico
73. Shahpoor Moradi, Ravi University
74. Mustafa Muhammad, University of Cincinnati
75. Ion Nechita, University of Ottawa
76. Beth Nordholt, Los Alamos National Laboratory
77. Kumar Patra, University of York, UK
78. Michael Peskin, Stanford University
79. Laszlo Petho, University of California, Berkeley

80. Tilman Pfau, Universität Stuttgart
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92. Mary Beth Ruskai, Tufts University
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106. John Sipe, University of Toronto
107. Paul Skrzypczyk, University of Bristol
108. Graeme Smith, IBM TJ Watson Research Centre
109. John Smolin, IBM TJ Watson Research Centre
110. Rolando Somma, Los Alamos National Laboratory
111. Ajay Sood, IISc, Bangalore and President of the Indian Academy of Sciences
112. Douglas Stebila, University of Queensland
113. DJ Strouse, University of Southern California
114. Martin Suchara, Princeton University
115. G. Sundararajan, Director of ARCI Hyderabad
116. Kristan Temme, University of Vienna
117. John Teufel, National Institute of Standards and Technology
118. Mike Thewalt, Simon Fraser University
119. Falk Unger, University of California, Berkeley
120. Anton Van der Ven, University of Michigan
121. Umesh Vazirani, University of California, Berkeley
122. Lorenzo Campos Venuti, Institute for Scientific Interchange
123. Thomas Vidick, University of California, Berkeley
124. Arlette de Waard, Milli Kelvin Technologiwa/Leiden Cryogenics, The Netherlands
125. Zak Webb, University of Washington

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| <p>126. Christian Weedbrook, University of Queensland</p> <p>127. Chieh Wei, University of British Columbia</p> <p>128. Tzu Chieh Wei, University of British Columbia</p> <p>129. Gregor Weihs, University of Innsbruck</p> <p>130. Nathan Wiebe, University of Calgary</p> <p>131. Mark Wilde, McGill University</p> <p>132. Andreas Winter, University of Bristol</p> <p>133. Ronald de Wolf, Centrum Wiskunde & Informatica</p> <p>134. James Wootton, University of Leeds</p> <p>135. Faxian Xiu, University of California</p> <p>136. Albion Yang, Simon Fraser University</p> <p>137. Man Hong Yung, Harvard University</p> <p>138. Wojciech Zurek, Los Alamos National Laboratory and Santa Fe Institute</p> | <p>9. Ming Yu, COM DEV</p> <p>10. Alexandre Blais, Université de Sherbrooke</p> <p>11. Rogerio De Sousa, University of Victoria</p> <p>12. Dominique Drouin, Université de Sherbrooke</p> <p>13. Guillaume Gervais, McGill University</p> <p>14. Pawel Hawrylak, University of Ottawa/ National Research Council (NRC)</p> <p>15. Michel Pioro-Ladriere, Université de Sherbrooke</p> <p>16. David Poulin, Université de Sherbrooke</p> <p>17. Bertrand Reulet, Université de Sherbrooke</p> <p>18. Andrew Sachrajda, Université de Sherbrooke/ National Research Council (NRC)</p> <p>19. Robin Williams, University of Ottawa/ National Research Council (NRC)</p> <p>20. Carolyn Young, McGill University</p> <p>21. Roger Delisle, NSERC</p> <p>22. Marek Korkusinski, National Research Council (NRC)</p> <p>23. Christina Wood, NSERC</p> <p>24. Raymond Beausoleil, HP USA</p> <p>25. Bruce Gaulin, McMaster University</p> <p>26. Franco Nori, RIKEN (Japan), University of Michigan</p> |
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QuantumWorks Visitors

1. Mark Elliot, Lockheed Martin
2. Martin Hurlimann, Schlumberger
3. Mark Ketchen, IBM
4. Tom Ohki, BBN
5. Chad Rigetti, IBM
6. Tony Stajcer, COM DEV
7. Matthias Steffan, IBM
8. Greg Tallant, Lockheed Martin

M. The Times Higher Education World University Reputation Rankings 2010-2011

<http://www.timeshighereducation.co.uk/world-university-rankings/2010-2011/reputation-rankings.html>

- | | |
|---|--|
| <ol style="list-style-type: none"> 1. Harvard University | <ol style="list-style-type: none"> 2. Massachusetts Institute of Technology |
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3. University of Cambridge
4. University of California Berkeley
5. Stanford University
6. University of Oxford
7. Princeton University
8. University of Tokyo
9. Yale University
10. California Institute of Technology
11. Imperial College London
12. University of California Los Angeles
13. University of Michigan
14. Johns Hopkins University
15. University of Chicago
16. Cornell University
17. University of Toronto
18. Kyoto University
19. University College London
20. University of Massachusetts
21. University of Illinois - Urbana
22. University of Pennsylvania
23. Columbia University
24. Swiss Federal Institute of Technology Zurich
25. University of Wisconsin
26. University of Washington
27. National University of Singapore
28. Carnegie Mellon University
29. McGill University
30. University of California San Diego
31. University of Texas at Austin
32. University of British Columbia
33. Lomonosov Moscow State University
34. University of California San Francisco
35. Tsinghua University
36. Duke University
37. London School of Economics and Political Science
38. University of California Davis
39. Georgia Institute of Technology
40. Northwestern University
41. University of North Carolina, Chapel Hill
42. University of Hong Kong
43. University of Minnesota
44. Peking University
45. University of Melbourne
46. University of Edinburgh
47. Purdue University
48. University of Munich
49. Delft University of Technology
50. Osaka University
51. Australian National University
52. Karolinska Institute
53. New York University
54. Ohio State University
55. Seoul National University
56. Tohoku University
57. Tokyo Institute of Technology
58. University of California Santa Barbara
59. University of Pittsburgh
60. University of Sydney
61. Boston University
62. École Polytechnique
63. King's College London
64. Pennsylvania State University
65. Technical University of Munich
66. University of Florida
67. University of Manchester
68. University of Maryland College Park
69. University of Zurich
70. Uppsala University
71. École Polytechnique Federale of Lausanne
72. Humboldt University of Berlin
73. Lund University
74. Michigan State University
75. Rutgers the State University of New Jersey
76. University of Arizona
77. University of Colorado
78. University of Southern California
79. Utrecht University
80. Washington University Saint Louis
81. Catholic University of Leuven
82. Indian University
83. Leiden University
84. National Taiwan University
85. Ruprecht Karl University of Heidelberg
86. Texas A&M University
87. University of Amsterdam
88. University of Bristol
89. University of Leeds
90. University of Queensland Australia

91. Hong Kong University of Science and Technology
92. Indian Institute of Science
93. Korea Advanced Institute of Science and Technology
94. London School of Hygiene & Tropical Medicine
95. Nanyang Technological University
96. University of Helsinki
97. University of Paris Pantheon Sorbonne
98. University of Sheffield
99. University of Vienna
100. University of Waterloo

N. Student Awards

Internal Awards

IQC Achievement Award

Felix Motzoi
Farzad Qassemi
Sarvagya Upadhyay
Evan Meyer-Scott

IQC Entrance Award

Kent Fisher
Luke Govia
Tomas Jochym-O'Connor
Nickolay Gigov
Christopher Wood

Mike and Ophelia Lazaridis Fellowship

Sarvagya Upadhyay
Abel Molina Prieto

The IQC David Johnston Award for Scientific Outreach

Chris Erven
Gina Passante
Jean-Luc Orgiazzi

External

David R. Cheriton Graduate Scholarship

Sevag Gharibian
Sarvagya Upadhyay
Abel Molina Prieto
Robin Kothari

NSERC Alexander Graham Bell Canada Graduate Scholarship - Masters

Daniel Criger

Pierre-Luc Dallaire-Demers
Robin Kothari
Evan Meyer-Scott
Stacey Jeffery
Kent Fisher
Luke Govia
Tomas Jochym-O'Connor
Nickolay Gigov

NSERC Alexander Graham Bell Canada Graduate Scholarship - Doctoral

Easwar Magesan
Jonathan Lavoie
Sevag Gharibian
Farzad Qassemi

NSERC Postgraduate Scholarship - Master's Extension

Deny Hamel

NSERC Postgraduate Scholarship - Doctoral

Chris Erven
Chris Ferrie
Jamie Sikora
Jamie Smith
Felix Motzoi

NSERC Vanier Canada Graduate Scholarship

Deny Hamel
Gina Passante

Ontario Graduate Scholarship

Cozmin Ududec
Thomas McConkey
Hamid Mohebbi
Nathan Killoran
Evan Meyer-Scott
Fatin Haque

Ontario Graduate Scholarship in Science & Technology

Peter Groszkowski
 Thomas McConkey
 Chunqing Deng
 David Pitkaneni'II

President's Graduate Scholarship

Cozmin Ududec
 Deny Hamel
 Daniel Criger
 Pierre-Luc Dallaire-Demers
 Robin Kothari
 Thomas McConkey
 Chris Erven
 Hamid Mohebbi
 Stacey Jeffery
 Nathan Killoran
 Jamie Sikora
 Chris Ferrie
 Easwar Magesan
 Jamie Smith
 Evan Meyer-Scott
 Kent Fisher
 Luke Govia
 Fatin Haque
 Tomas Jochym-O'Connor
 Jonathan Lavoie
 Sevag Gharibian
 Felix Motzoi
 Farzad Qassemi
 Nickolay Gigov

O. Presentations

Jonathan Baugh	3/7/11	High Fidelity Quantum Control in Solid-State Magnetic Resonance	Princeton University
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Jonathan Baugh	3/30/11	Simulation of statistical mechanics on an NMR quantum information processor	American Chemical Society
Andrew Childs	2/4/11	Quantum query complexity of minor-closed graph properties	University of Waterloo
Andrew Childs	12/3/10	Constructing elliptic curve isogenies in quantum subexponential time	University of California Berkeley
Andrew Childs	12/7/10	Constructing elliptic curve isogenies in quantum subexponential time	California Technical Institute
Andrew Childs	1/13/11	Constructing elliptic curve isogenies in quantum subexponential time	Center for Quantum Technologies
Andrew Childs	3/14/11	Quantum query complexity of minor-closed graph properties	Massachusetts Institute of Technology
Andrew Childs	7/17/10	Quantum algorithms	University of British Columbia
Andrew Childs	8/16/10	Algorithms for quantum computers	University of Waterloo
Andrew Childs	10/29/10	Constructing elliptic curve isogenies in quantum subexponential time	University of Maryland
Andrew Childs	12/13/10	Constructing elliptic curve isogenies in quantum subexponential time	Princeton
Richard Cleve	1/5/11	Introduction to Quantum Computing	Kyoto University
Richard Cleve	2/16/11	Efficient Discrete-Time Simulations of Continuous-Time Quantum Query Algorithms	University of Tokyo
Richard Cleve	4/14/11	Efficient Discrete-Time Simulations of Continuous-Time Quantum Query Algorithms	Centrum Wiskund & Informatica (CWI)
Richard Cleve	6/30/10	Quantum nonlocality and communication complexity	Advanced School in Quantum Information Processing and Quantum Cryptography
David Cory	10/4/10	Quantum Computing	McMaster University
Joseph Emerson	10/12/10	Randomization and Partial Tomography	University of Toronto

Joseph Emerson	4/19/11	Objective models for quantum theory and their constraints	Universite de Luminy
Joseph Emerson	4/26/11	Randomization and Partial Tomography for Quantum Information Systems	Universite Paul Sabatier
Joseph Emerson	11/19/10	Robust Randomized Benchmarking	CIFAR- Canadian Institute for Advanced Research
Agnes Ferenczi	8/29/10	Connection between optimal eavesdropping and optimal cloning	The University of Tokyo
Agnes Ferenczi	8/30/10	Security proof of the phase-encoded BB84 protocol	The University of Tokyo
Thomas Jennewein	6/1/10	Direct Ceneration of Photon Triplets	QuantumWorks
Thomas Jennewein	7/6/10	Satellite based quantum optics experiments	University of Toronto
Thomas Jennewein	10/1/10	Satellite based quantum optics experiments	University of Waterloo
Thomas Jennewein	3/16/11	Final Review Meeting of the Feasibility Study	Canadian Space Agency
Thomas Jennewein	11/25/10	Photon Triplets and Tripple slit experiments, a new frontier in quantum optics	University of Waterloo
Raymond Laflamme	6/3/10	Quantum Computing	University of Waterloo
Raymond Laflamme	8/23/10	Quantum Computing	Ciudad Universitaria
Raymond Laflamme	10/27/10	Benchmarking Quantum Information Processing Devices	Optical Society of America
Raymond Laflamme	03/07/11	Quantum Information in Canada, NSERC's 107th Council meeting	Ottawa
Debbie Leung	4/4/11	Authentication of Quantum messages -- how well can we do it	Perimeter Institute for Theoretical Physics
Debbie Leung	11/9/10	What's hot and not, and what's cool about quantum information	James Frank Institute, University of Chicago

Debbie Leung	10/16/10	Improving zero-error classical communication capacity with entanglement	Nordic Institute for Theoretical Physics
Debbie Leung	10/21/10	Entanglement can increase rates of zero-error classical communication over classical channels	Mittag-Leffler Institute
Adrian Lupascu	3/4/11	Quantum Electrical Circuits	University of Ottawa
Adrian Lupascu	3/7/11	Quantum Electrical Circuits	Carleton University
Adrian Lupascu	3/9/11	Quantum Electrical Circuits	Trent University
Adrian Lupascu	12/2/10	Introduction to superconducting qubits	Dayalbagh Educational Institute
Adrian Lupascu	3/14/11	Quantum Electrical Circuits	University of Prince Edward Island
Adrian Lupascu	3/15/11	Quantum Electrical Circuits	Mount Alison University
Adrian Lupascu	3/16/11	Quantum Electrical Circuits	Université de Moncton
Adrian Lupascu	3/17/11	Quantum Electrical Circuits	University of New Brunswick at Fredericton
Adrian Lupascu	3/31/11	Quantum Electrical Circuits	University of Western Ontario
Adrian Lupascu	10/26/10	Quantum superconducting circuits	University of Guelph
Norbert Lütkenhaus	3/1/11	Quantum Optics & Quantum Information: A toolbox	Max Planck Institute (MPL)
Norbert Lütkenhaus	3/25/11	Light Sources for Quantum Cryptography	ETH Zürich - Eidgenössische Technische Hochschule Zürich (ETH - Swiss Federal Institute of Technology, Zurich)

Norbert Lütkenhaus	3/29/11	Testing Quantum Devices for Quantum Communication	ETH Zürich - Eidgenössische Technische Hochschule Zürich (ETH - Swiss Federal Institute of Technology, Zurich)
Norbert Lütkenhaus	07/19-23/10	Testing and Benchmarking of Optical Quantum Communications Devices	The University of Queensland
Norbert Lütkenhaus	10/18-20/10	Security analysis of practical QKD systems	National Institute of Informatics
Michele Mosca	6/1/10	On the case of QKD	University of New Brunswick
Michele Mosca	8/1/10	Trends in QIP	Centre for Quantum Technologies, National University of Singapore
Michele Mosca	01/--/11	Quantum Cryptography	Wilfred Laurier University
Ashwin Nayak	4/4/11	Improved bounds for the randomized decision tree complexity of recursive majority	IAS
Ashwin Nayak	4/6/11	Recognizing well-parenthesized expressions in the streaming model	Rutgers
Ashwin Nayak	4/11/11	The Quantum Substate Theorem	PI Institute
Ashwin Nayak	1/28/11	The index function and the streaming complexity of Dyck languages	Centre for Quantum Technologies, National University of Singapore
Marco Piani	11/8/10	Non-classicality of correlations: quantum entanglement and beyond	CUNY Graduate Center
Marco Piani	11/8/10	Usefulness of entanglement in channel discrimination with and without restricted measurement	IBM Thomas J. Watson Research Center
Marco Piani	7/17/10	Entanglement theory where you do not expect it: Multipartite "violation" of Gleason's theorem and stochastic simulation of channels in quantum optics	Max Planck Institute for Mathematics in the Sciences

Marco Piani	7/20/10	Usefulness of entanglement in channel discrimination with and without restricted measurements	Leibniz Universität
Marco Piani	7/23/10	Quantumness Activation and Quantification	ICFO Barcelona
Ben Reichardt	1/9/11	Quantum query complexity	Center for Quantum Technologies
Ben Reichardt	1/23/11	Faster quantum algorithm for evaluating game trees	Society for Industrial and Applied Mathematics
Ben Reichardt	1/23/11	Reflections for quantum query algorithms	Society for Industrial and Applied Mathematics
Ben Reichardt	2/25/11	The query complexity of generating quantum states	University of California, Berkeley
Ben Reichardt	8/28/10	A semi-definite program for quantum query complexity	Princeton
Kevin Resch	7/3/09	Chirped-Pulse Interferometry: from Quantum Insights to Classical Technologies	Optics and Quantum Electronics Seminar, Department of Electrical Engineering and Computer Science, Massachusetts Institute of Technology
Kevin Resch	11/9/10	Quantum-inspired classical interferometry	Department of Physics, University of Michigan
Kevin Resch	11/22/10	Quantum-inspired classical interferometry	Department of Physics & Atmospheric Science, Dalhousie University
Frank Wilhelm	1/7/11	Optimal control of imperfect qubits	University of Victoria
Frank Wilhelm	1/12/11	NSERC Nano-qubits initiative	IMEC, National Research Council
Frank Wilhelm	7/10/11	Junction noise in superconducting qubits	Ludwig-Maximilians-Universität Munich
Frank Wilhelm	7/10/11	News from circuit QED: NOON states and photon counting	Munich University of Technology

Frank Wilhelm	7/10/11	Optimal control of superconducting qubits	University Ulm
Frank Wilhelm	10/10/11	Artificial atoms from superconducting qubits	Department of Physics and Physical Oceanography, Memorial University of Newfoundland
Frank Wilhelm	1/13/11	NSERC Nano-qubits initiative	IBM Bromont
Frank Wilhelm	1/20/11	Theory of junction noise in superconducting qubits	IARPA- Intelligence Advanced Research Projects Activity
Frank Wilhelm	3/23/11	Multi-resonator circuit QED II: Generation and detection of NOON states	American Physical Society
Frank Wilhelm	8/23/10	Noise in Josephson Qubits -- Roughness, Traps, and Quasiparticles	UC Santa Barbara, Kavli Institute for Theoretical Physics

P. Tour Groups

Academic Tour Groups

Group	Date	Participants
Gerald Sussman UW CS Club Tour Group	5/14/10	5
Centre Wellington District High School Tour Group	5/27/10	40
Stephen Hawking	6/23/11	1
ISSYP Students	7/14/10	40
Leo Kadanoff, James Franck Institute in Chicago	7/19/10	2
EinsteinPlus Teachers	7/29/10	40
UW Physics Alumni Tour	9/25/10	75
Senior Science Students at Uxbridge Secondary School	10/14/10	20
Raytheon BBN Technologies Group	10/25/10	4
Massey Fellow Journalists	11/3/10	10

Group	Date	Participants
The Woodlands Public School	11/17/10	28
The Woodlands Public School	11/19/10	29
Perimeter Scholars International	11/26/10	34
Wilfrid Laurier Students	12/3/10	12
Sherbrooke University, Quebec Delegation	2/18/11	4
University of Toronto	2/23/11	3
Laurentian University/Science North graduate program in science communication	3/2/11	16
The Waterloo Space Society	3/10/11	10
Wilfrid Laurier Students	3/11/11	20
University of Waterloo, 1st year Physics Students	3/22/11	20
University of Waterloo	3/23/11	20
University of Guelph	3/25/11	23
The Woodlands Public School	3/25/11	27
Introduction to Quantum Information Processing Class	3/29/11	20
University of Waterloo, General Physics & Computer Science Students	4/6/11	15
Taiwan Delegation	4/14/11	12
Georgian Bay Secondary School	4/15/11	50

Government Tour Groups

Group	Date	Participants
Jim Flaherty, Peter Braid, Stephen Woodworth and Kenneth Tam	9/9/10	4
Advanced Leadership Tour Deputy Minister's Office	9/30/10	9
The Government of Ontario: The Honourable Glen Murray, Tom Allison, and Mark Hazelden	10/7/11	3

Group	Date	Participants
Government of Japan: Dr. Masuo Aizawa and Mr. Shiro Numajiri	11/19/11	2
Ambassador of Czech Republic	2/16/11	4
Dr. Gustav Kalbe, European Commission	3/25/11	3
Russian Delegation	3/30/11	5
Ontario Lieutenant Governor, the Honourable David C. Onley	4/11/11	3

Business/Industry Tour Groups

Group	Date	Participants
Michael Goodkin	7/19/10	2
RIM Tour Group	8/6/10	10
RIM Tour Group	9/3/10	6
Lockheed Martin: Ned Allen, Dr. Edward Allen and Mark Elliot	11/11/11	3
Moloney Electric Inc: John Cheng, Nilesh Sarode, Venkat Yechuri and Alife Rivera	11/19/11	4
Jason Sanabia	1/1/11	1
Waterloo Chapter of the Canadian Forum of the International Womens Forum	1/13/11	12
Royal Bank of Canada	2/10/11	4
Mario Tokoro, President and CEO of Sony Computer Science Laboratories	2/24/11	1

Q. News Releases & Website Updates

iqc.uwaterloo.ca

05/02/10	Still time to sign up for QCSYS 2010
05/06/10	IQC postdoc and international collaborators probe quantum correlations
05/11/10	Can quantum mechanics get you out of a speeding ticket
05/12/10	QISS workshop kicks off next week
05/14/10	IQC student wins prestigious national scholarship
05/17/10	David Cory joins IQC as Canada Excellence Research Chair
05/31/10	Undergrad quantum workshop underway at IQC
05/31/10	Researcher gets major grant to pursue multi-qubit systems
07/15/10	IQC director to discuss mentor Stephen Hawking on TVO
06/21/10	Watch Hawking's Universe online
06/22/10	The boomerang of life reunites Hawking and Laflamme
07/05/10	Explore the quantum revolution during IQC's open house
07/27/10	Research team tests fundamental rule in Science paper
07/29/10	IQC-led research team achieves quantum optics breakthrough
08/06/10	Canadian government unveils prestigious postdoctoral fellowships
08/17/10	Research team achieves milestone in superconducting qubits
08/19/10	Watch Born to Rule - A fundamental experiment explained
09/10/11	Finance Minister Flaherty visits IQC
09/14/11	IQC faculty member named Royal Society Fellow
09/17/11	IQC Welcomes new research assistant professors
09/20/11	Big crowds explore quantum science at IQC Open House
09/22/11	IQC bids good luck to Governor General-designate
09/30/11	Postdoctoral positions available at IQC
10/01/11	Physics alumni explore quantum future
10/08/11	New IQC research assistant professor co-authors key papers
10/20/11	IQC optics team advances measurement-based quantum computing

11/24/11	IQC accepting faculty applications
11/29/11	IQC postdoc earns prestigious Polanyi Prize
12/15/11	Seth Lloyd, quantum mechanic, talks shop at IQC
01/28/11	Broadbent to speak at "Ladies Night Out"
01/28/11	Faculty recognized with Outstanding Performance Award
01/28/11	IQC postdoc brings quantum computing to Ladies' Night Out
02/01/11	Hamed Majedi receives Distinguished Performance Award
03/10/11	Researchers achieve "important building block" in quantum error correction
12/23/11	The amazing possibilities of quantum devices
02/15/11	IQC researcher "spins" a good yarn
03/15/11	Graduate Program in Quantum Information
02/16/11	Leading physicist joins IQC Scientific Advisory Board
02/24/11	Researcher earns prestigious Sloan Fellowship
02/24/11	Joseph Emerson named among 40 Under 40
03/15/11	Quantum entanglement as a game-changer
04/06/11	Nanotech pioneer kicks off IQC's Distinguished Lecture Series
04/28/11	IQC deputy director wins national award

R. Media Coverage

External Media Coverage

Date	Title	Publication
05/13/10	Vanier Scholarships, Rewarding Excellence, fostering innovation, Strengthening Canada	Association of Universities and Colleges of Canada
05/17/10	UW lands two key research posts	Waterloo Region Record
05/17/10	New UW research chairs	570 News
05/17/10	Water, quantum computing get big research boost at UW	Waterloo Region Record

05/18/10	Waterloo earns two of 19 newly created Canada Excellence Research Chairs	Exchange Magazine
05/18/10	Canada Excellence Research Chairs	Government of Canada
05/18/10	Canada's brain gain - advertisement	The Globe and Mail
05/18/10	UW receives research boost	The Waterloo Region Record
05/18/10	Brain Gain: Federal investments in research attracts leading global researchers to Canada	The Globe and Mail
05/18/10	Canada's hub for research excellence	Globe and Mail
05/18/10	David Cory: Canada Excellence Research Chair in Quantum Information	CERC website
05/19/10	Fed grant big dollars to all-male research group	Toronto Star
05/19/10	Brain Gain: University of Waterloo scores a coup by attracting MIT quantum pioneer	Waterloo Chronicle
05/20/10	Waterloo students win prestigious Vanier Canada Graduate scholarships	Exchange Magazine
05/27/10	Incompetence as an impediment to commercialization	Communittechblog.ca
06/18/10	The man who proved Hawking wrong	Waterloo Region Record
06/01/10	UW earns Canada Excellence Research Chairs	SNAP KW
06/24/10	Giving Back to former mentor	Waterloo Region Record
06/27/10	Superstars could reverse innovation brain drain	CTV News
06/20/10	The boomerang of life reunites Hawking and Laflamme at IQC	Waterloo Chronicle
07/08/10	Johnston's career rooted in the law and academia	Waterloo Region Record
07/22/10	Photonics professor works on quantum computing	azonano.com
07/22/10	Quantum theory survives its latest ordeal	physicsworld.com
07/22/10	Quantum mechanics not in jeopardy	physorg.com
07/23/10	To be precise, from JU to physics feat	The Telegraph (India)

07/23/10	Quantum mechanics survives triple-slit test	arstechnica.com
07/23/10	Quantum mechanics not in jeopardy	Science Daily
07/22/10	Physicists confirm Born's Rule	photonics.com
07/22/10	Quantum mechanics is square	scienceblogs.com
07/27/10	Two is the magic number	sciencenews.org
07/27/10	Two is the magic number	Wired.com
07/28/10	IQC-led research team tests fundamental rule in Science paper	Exchange Magazine
07/29/10	Waterloo team gives birth to photon triplets	Waterloo Region Record
07/31/10	Quantum school helps the scientists of tomorrow	Waterloo Region Record
08/07/11	The Power of Two	Waterloo Region Record
08/13/10	The Indian-origin scientist who is shaking up the world of physics	India Abroad
08/20/11	Triple-Slit Experiment has quantum Implications	osa-opn.org
08/09/10	Untitled	anandabazar.com
08/24/11	Quantum movements for objects, giant leaps for research	The Reporter (McGill)
08/25/11	Filmpje: onderzoeker legt drie-spleten-experiment	kijk.nl
09/07/11	Open the Doors of History	London Free Press
09/07/11	Doors Open Waterloo Region -- Made in Waterloo Region	Waterloo Region Record
09/07/11	Doors Open Waterloo Region	heritageresources.blogspot.com
09/14/11	Open House at the Institute for Quantum Computing	Snapkw.com
09/16/11	Doors open into world of quantum computing	Waterloo Region Record
09/08/11	Exploring our past through doors open	Waterloo Region Record
09/10/11	A bit Cold: Physicists Devise a quantum particle refrigerator	Scientific American

09/15/11	Come on in: Doors Open invites public for behind the scenes look	Waterloo Chronicle
09/18/11	Area institutes throw open doors to public	www.therecord.com
09/20/11	World's tiniest fridge could chill quantum computers	Dailyindia.com
10/28/11	Campaign Waterloo makes 613.2 million impact on Canada	nanotech-now.com
09/26/11	Ideas Having Sex	yourlearningcurve.com
11/03/11	IQC optics team at Waterloo advances measurement-based quantum computing	
11/01/11	Campaign Waterloo makes 613.2 million impact on Canada	Exchange Magazine
11/04/11	IQC optics team at Waterloo advances measurement-based quantum computing	Waterlootechnews.com
11/04/11	IQC optics team at Waterloo advances measurement-based quantum computing	Exchange Magazine
11/09/11	High profile visit sparks war of words	570 News
11/02/11	Jim Balsillie and Mike Lazaridis set standards in smart-phone market	Globe and Mail
11/22/11	Minister Clement Updates Canadians on Canada's Digital Economy Strategy	sys-con.com
12/04/11	Freewheeling in the snow	Waterloo Region Record
12/15/11	Mike Lazaridis profile	greekgateway.com
12/17/11	quantum unicorns	portabledigitalvideorecorder.com
12/17/11	The Clock is Ticking on Encryption	Computerworld
12/24/11	Classical computing can match quantum computing speed	topnews.us
12/02/10	Researcher wins innovation prize	Waterloo Region Record
12/06/10	Rankings and Reputation of Waterloo University	AAA Study Abroad
12/23/10	Software Said to Match Quantum Computing Speed	Itworld

12/17/10	Bound Entanglement Mysterious Invention of Nature	europhysicsnews
02/07/11	New in Canada's Economic Plan	Action Plan
01/08/11	Best Brains' Quantum of Solace Physics Meet on Philosophy of the Universe	The Telegraph (India)
01/19/11	Silicon Quantum Computer a Possibility	Nature News
01/20/11	First USC Student to Receive Churchill Scholarship	USC News
01/20/11	Billions of Entangled Particles Advance Quantum Computing	The New York Times
01/25/11	Experimental Magic State Distillation for Fault-Tolerant Quantum Computing	Nature News
02/24/11	The Kitchener-Waterloo Symphony	Exchange Magazine
02/25/11	Minister Clement Issues Statement on Digital Economy Round Table in Waterloo	marketwire.com/Industry Canada
02/25/11	Local Tech Leaders Meet with Industry Minister	570 News
03/08/11	A Crown of Quantum Entanglements	IEEE Spectrum
01/28/11	Second TEDxWaterloo Looks to the Future	The Record
01/22/11	A Quantum Spin on Life	The Record
02/17/11	Czech Ambassador Visits Region Promoting Partnerships	The Record
02/23/11	Outwater to Bring Fresh Sounds to Symphony's New Season	The Record
02/24/11	Joseph Emerson - 40 Under 40	The Record
02/25/11	Clement Leaves Door Open While Slamming Internet Usage Based Billing	The Record
03/24/11	Kids' Summer Programs - QCSYS	The Record
03/35/11	Russians visit city for ideas	The Record
04/15/11	RIM makes a play for its future	Globe and Mail
04/20/11	RIM's hope, the region's future	The Record

04/28/11	The Impact Players -- Top 40 Under 40	Globe and Mail
04/28/11	Kitchener-Waterloo Debate	570 News

UW Media Coverage

05/01/10	People and Places : Quantum Computing	Watch magazine
05/17/10	Waterloo Earns two of 19 newly created CERC chairs	UW news release
05/17/10	Waterloo earns two new research chairs	UW news release
05/18/10	Two multi-million-dollar federal chairs	UW Daily Bulletin
06/02/10	Thirteen exceptional undergraduates	UW Daily Bulletin
06/04/10	UW wins a \$10 million federal lottery	Imprint
06/25/10	Astronomer Hawking pays a visit to IQC	UW Daily Bulletin
07/23/10	IQC-led research team tests fundamental rule in Science paper	UW news release
07/26/10	Quantum researchers test Born's rule	UW Daily Bulletin
07/28/10	Waterloo-led team achieves breakthrough in quantum optics	UW news release
08/23/11	Born to Rule video	UW Daily Bulletin
09/13/11	Finance Minister Flaherty visits IQC	UW Daily Bulletin
09/24/11	Fun with Science	Imprint
09/30/11	Johnston leaves today -- his name remains	UW Daily Bulletin
11/03/11	IQC optics team advances measurement-based quantum computing	UW news release
11/30/11	Polanyi prize for postdoc physicist	UW Daily Bulletin
03/01/11	Quantum Computing and Physics	UW Daily Bulletin
04/01/11	Quantum Frontiers Distinguished Lecture	UW Daily Bulletin

04/15/11	A Magnet for Talent: UW Science Annual Report	Science Annual Report
04/21/11	Pushing Science Forward: Martin Laforest	Watch magazine
04/21/11	Pushing Science Forward: David Cory	Watch magazine
04/21/11	For the Love of Math: Anne Broadbent	Watch magazine
04/29/11	Top 40 honor for quantum physics prof	UW Daily Bulletin
04/29/11	IQC deputy director wins national award	Waterloo Science website

S. Strategic Research Model

The model integrates IQC's strategic objectives, its mission, vision and the eight activities listed above to illustrate how IQC will achieve short and long term goals. The model was prepared in collaboration with Industry Canada.

