QUANTUM INFORMATION LABS FOR HIGH-SCHOOL STUDENTS

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University of Waterloo
iqc-outreach@uwaterloo.ca

OUTREACH @ IQC

Panels & Public Talks

Science Fairs, Open Houses, and School Visits

Travelling Museum Exhibits

USEQIP

Undergraduate School on Experimental Quantum Information Processing

QSYS

Quantum School

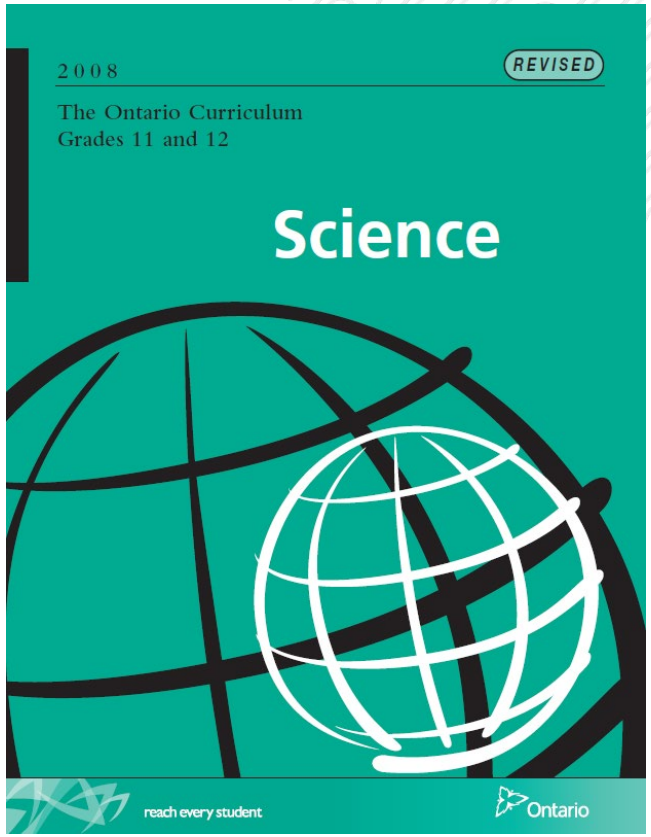
School for Young Students

SC

Schrödinger's Class

Quantum in the Curriculum

Case Study: Ontario SPH4U



Last topic of the university-prep Physics course.
(grouped with special relativity)

Topics include:

- The photoelectric effect
- Matter waves (de Broglie)
- Electron diffraction
- The Compton Effect
- Emission spectra
- Nuclear power and radiation
- Quantum medical technologies (MRI, CAT, PET)
- The standard model of elementary particles

Key Concepts for Future Quantum Information Science Learners

Identifies 9 key concepts tying into the National Quantum Initiative

1. Quantum information science
2. Quantum states
3. Measurement
4. Quantum bits / Qubits
5. Entanglement
6. Coherence
7. Quantum computing
8. Quantum communication
9. Quantum sensing

Details: https://qis-learners.research.illinois.edu/

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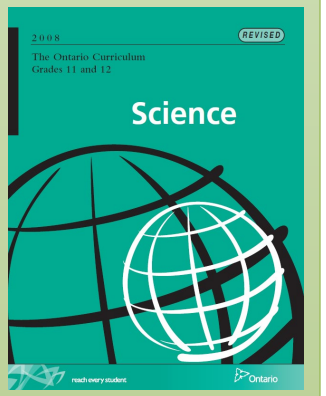

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Problems
- Course schedules are already packed
- Many teachers are uncomfortable with the material

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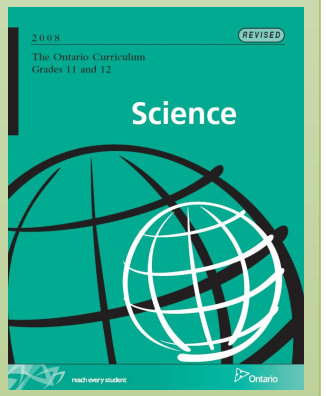

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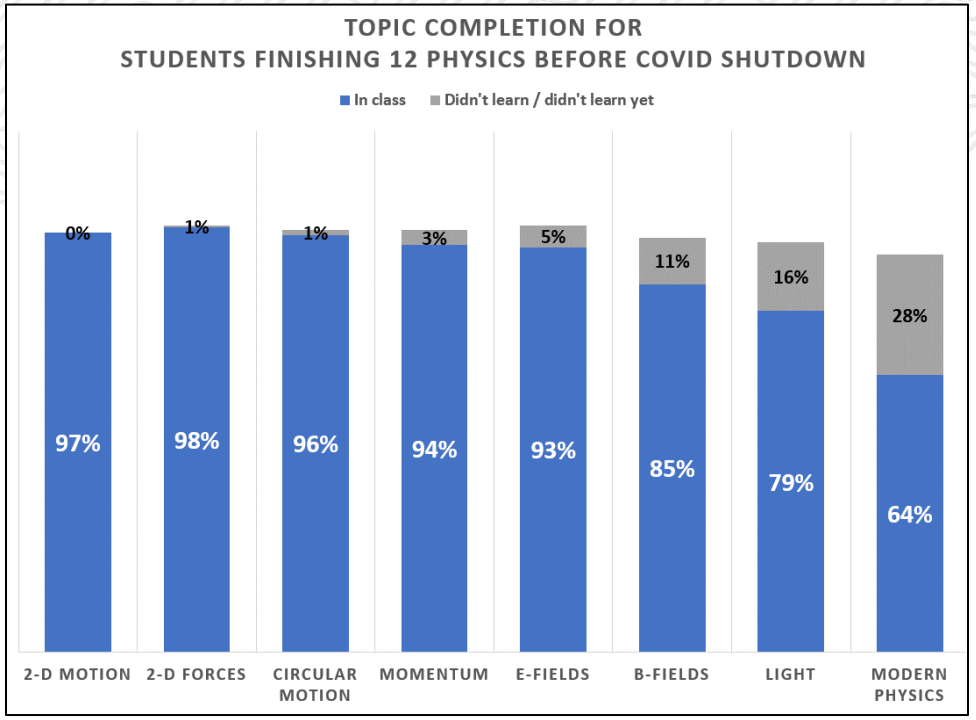

Source: Chris Meyer, Ontario Association of Physics Teachers
Pool: 432 incoming UofToronto Engineering Students
Link: http://newsletter.oapt.ca/files/effects-of-covid-shutdown.html

SCHRÖDINGER'S CLASS

Quantum Information for Physics Educators

Weekend workshop for high-school physics educators.

40 teachers invited, mostly from Canada and the USA.

Held annually since 2015.

Materials developed in collaboration with educators.

All costs covered by IQC, including substitutes coverage.

Schrödinger's Class Content

Key Lesson

Ensure that materials developed connect to both quantum technology and existing topics in the curriculum.

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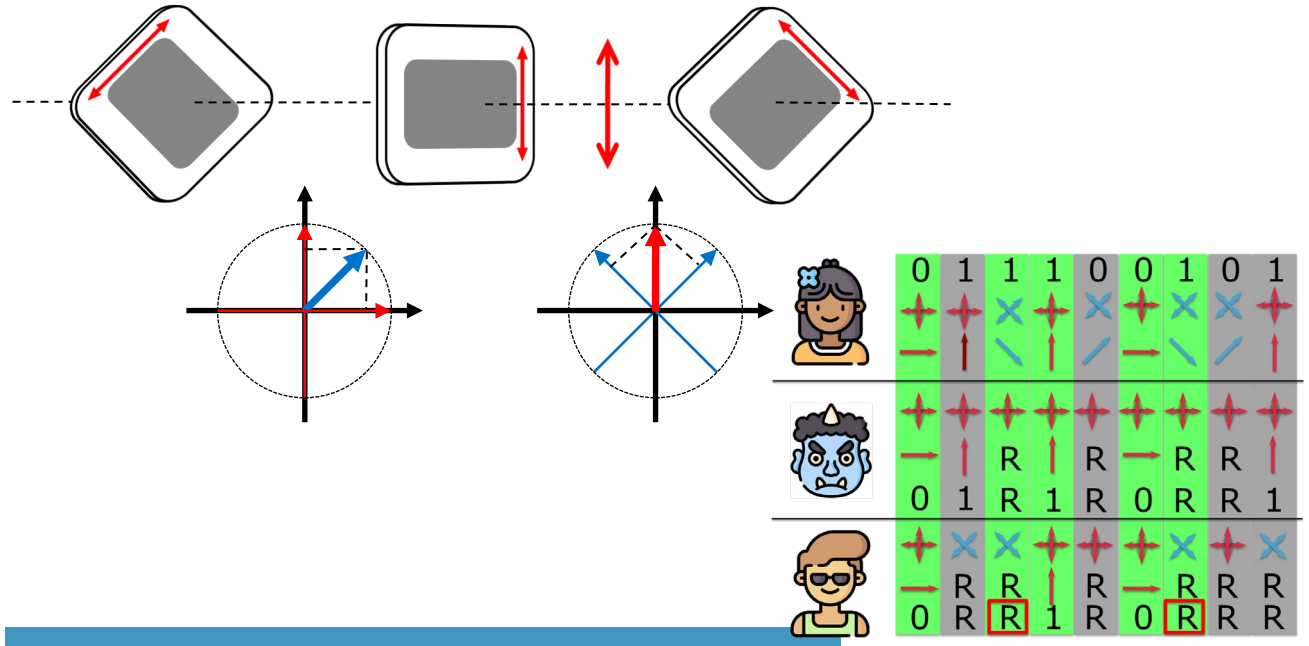

Familiar Concept: Light polarization
New idea: Measurement bases
Application: Quantum Cryptography

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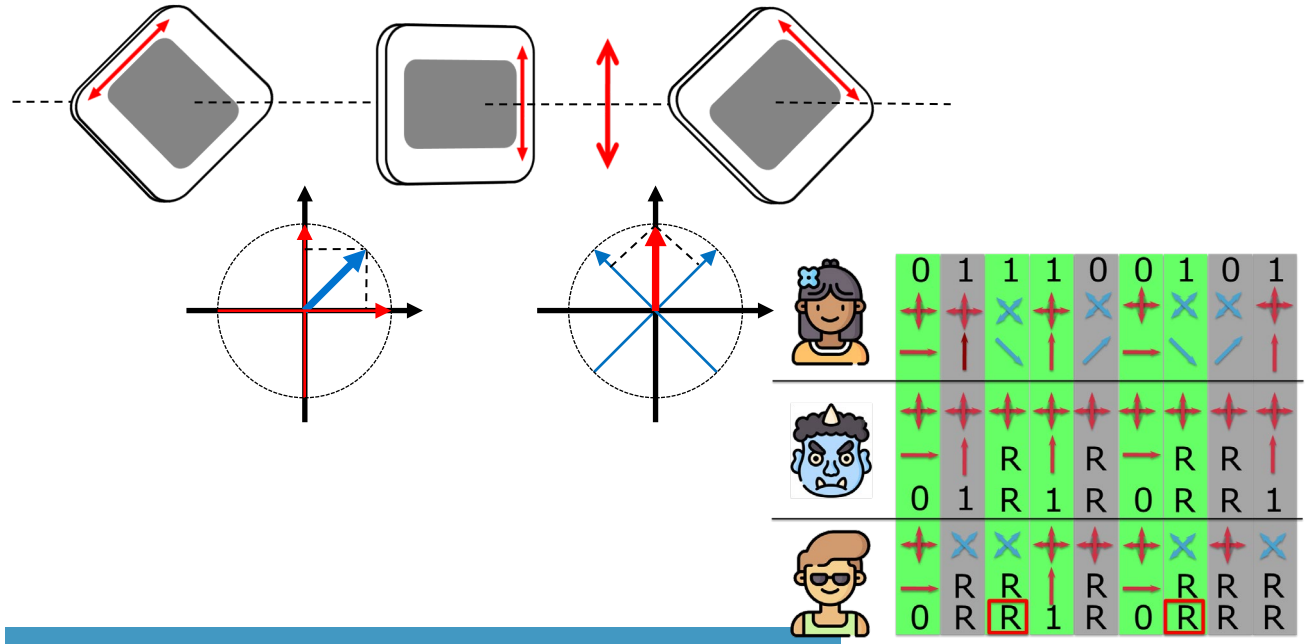
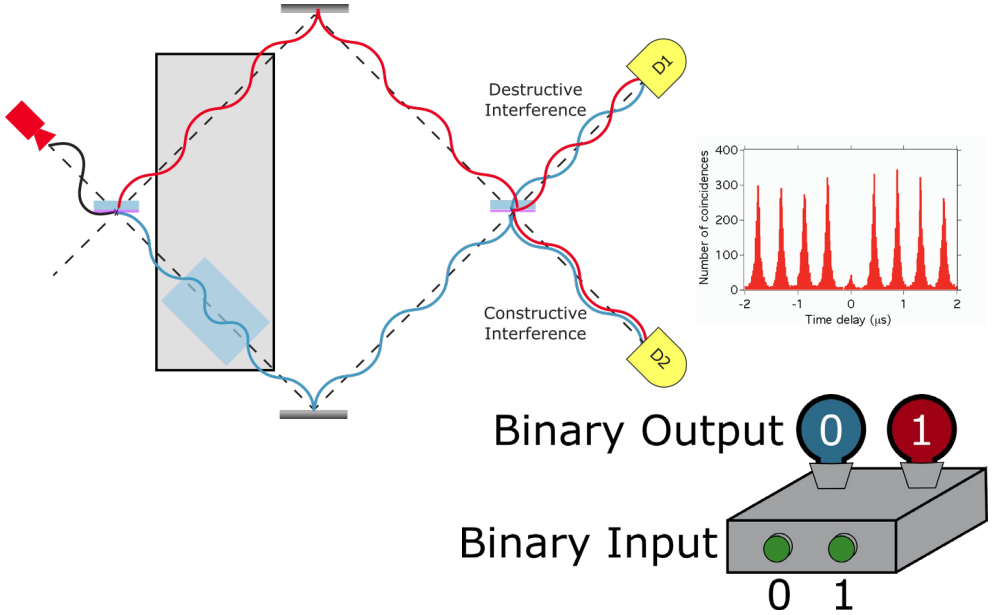


Familiar Concept: Light polarization
New idea: Measurement bases
Application: Quantum Cryptography

Familiar Concept: Wave-particle duality
New idea: Mach-Zehnder Interferometers
Application: Quantum Computing



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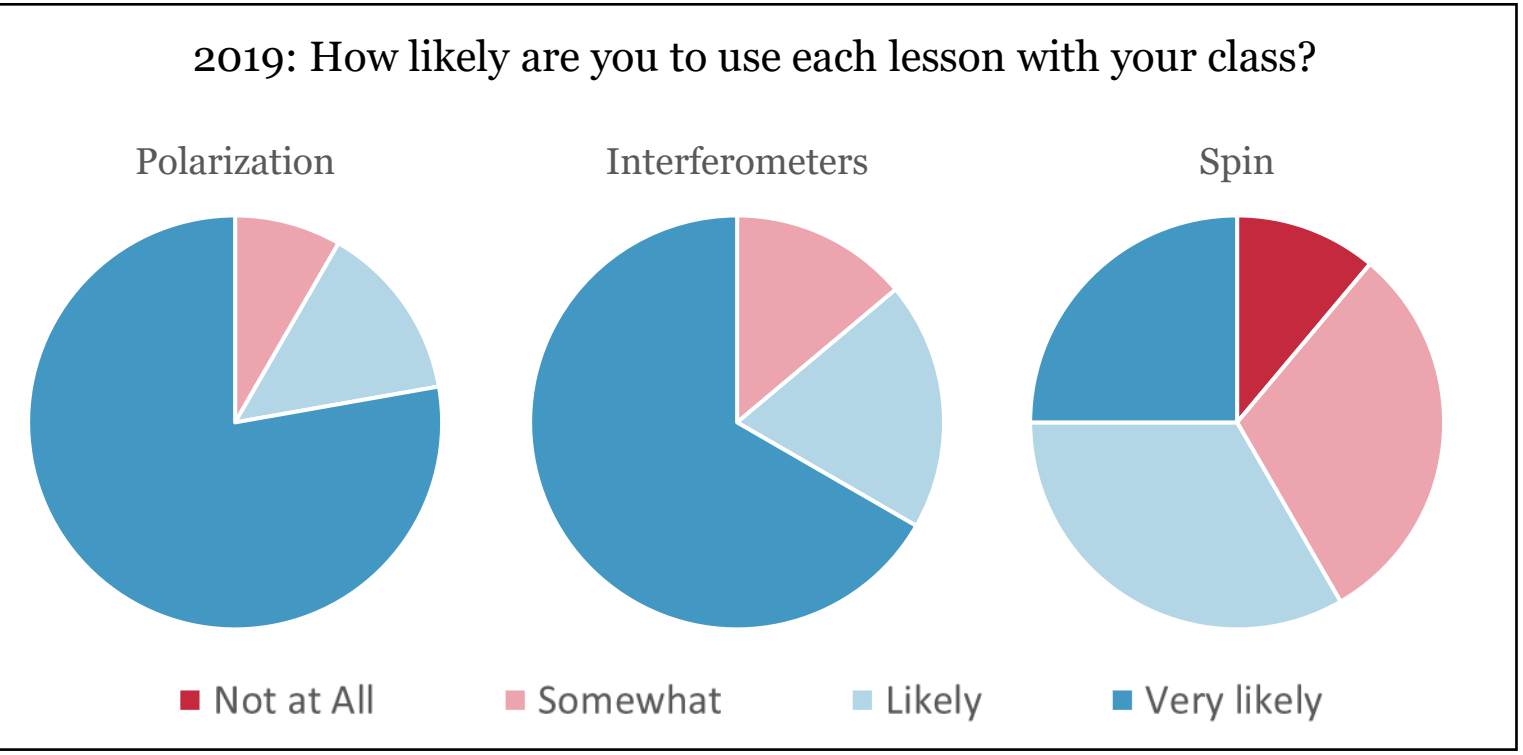

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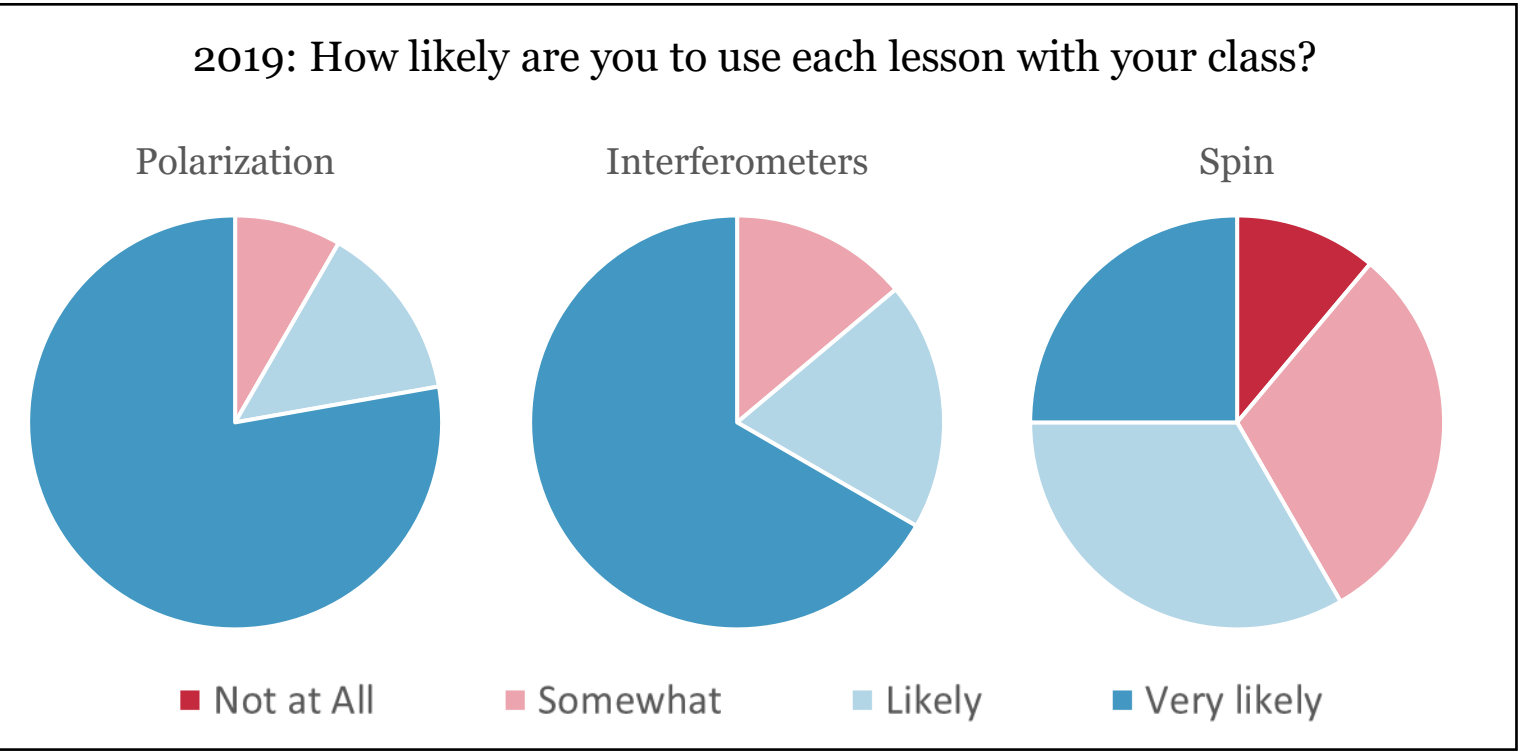
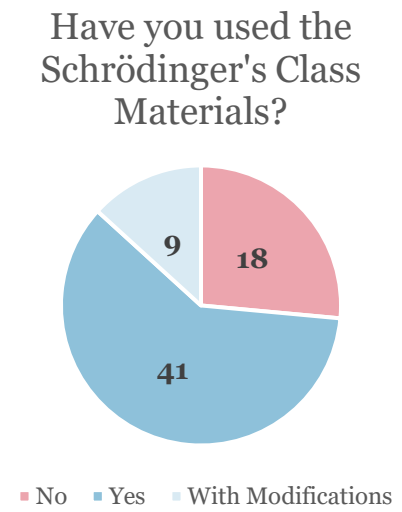
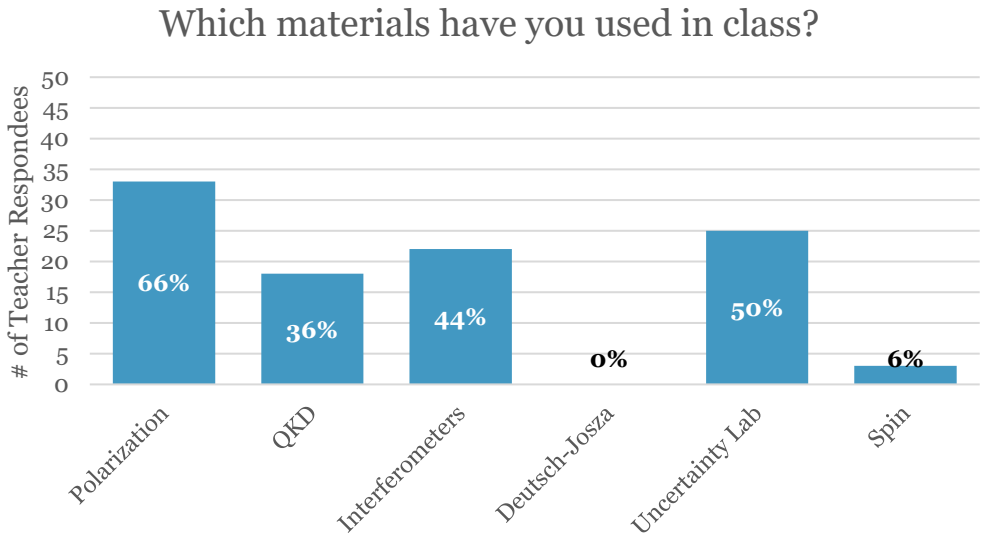


2022 Survey of 50 SchröClass alum





What materials are needed?

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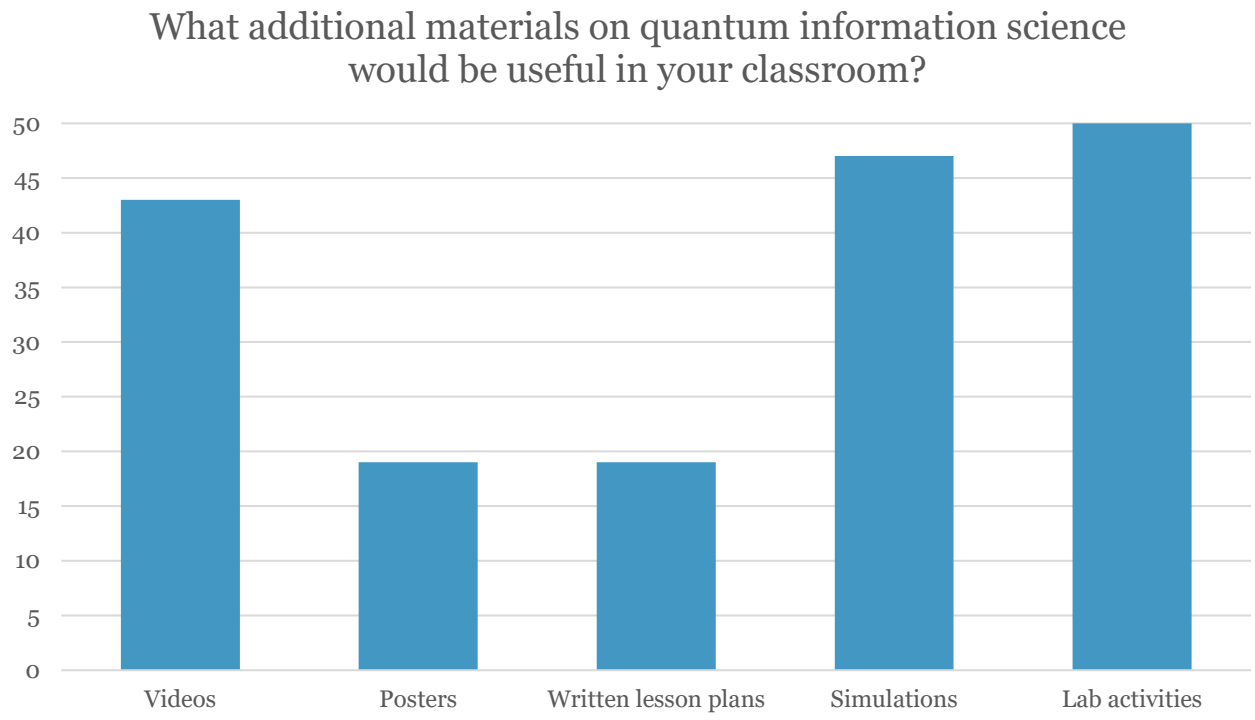

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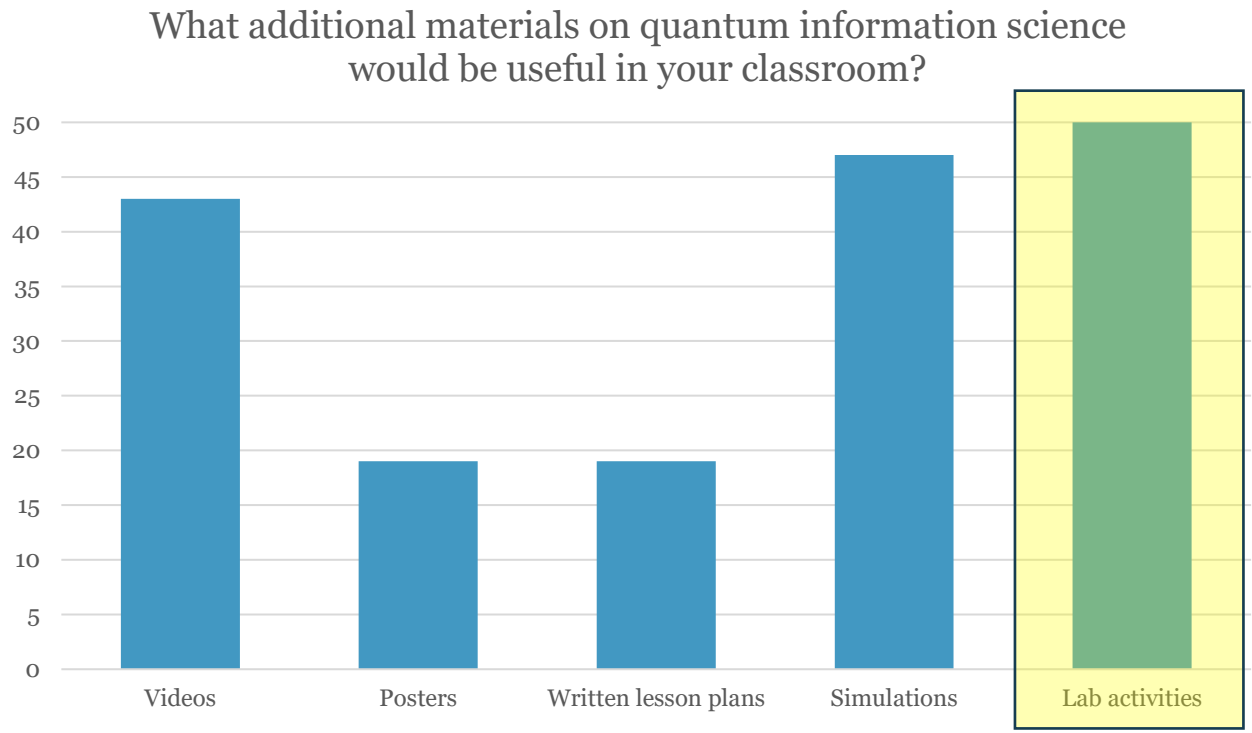


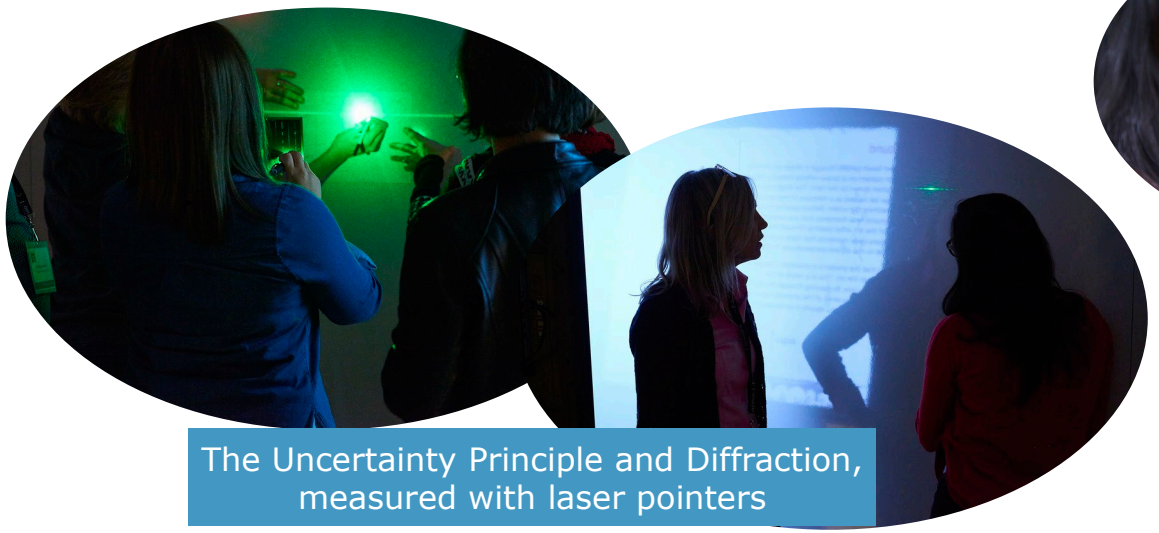
Hands-On Activities

Designed to be implemented in the classroom

Quantum Dots

Measuring Planck's Constant

3D movies



The Uncertainty Principle and Diffraction, measured with laser pointers

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Affordable for classrooms, but not Q-Info-centric

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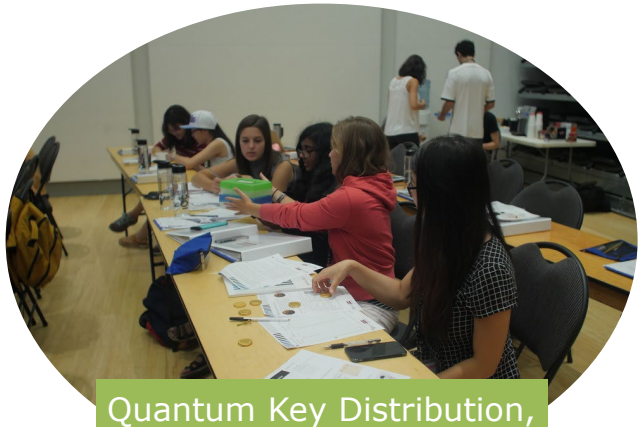

Quantum Key Distribution, coin-flipping activity

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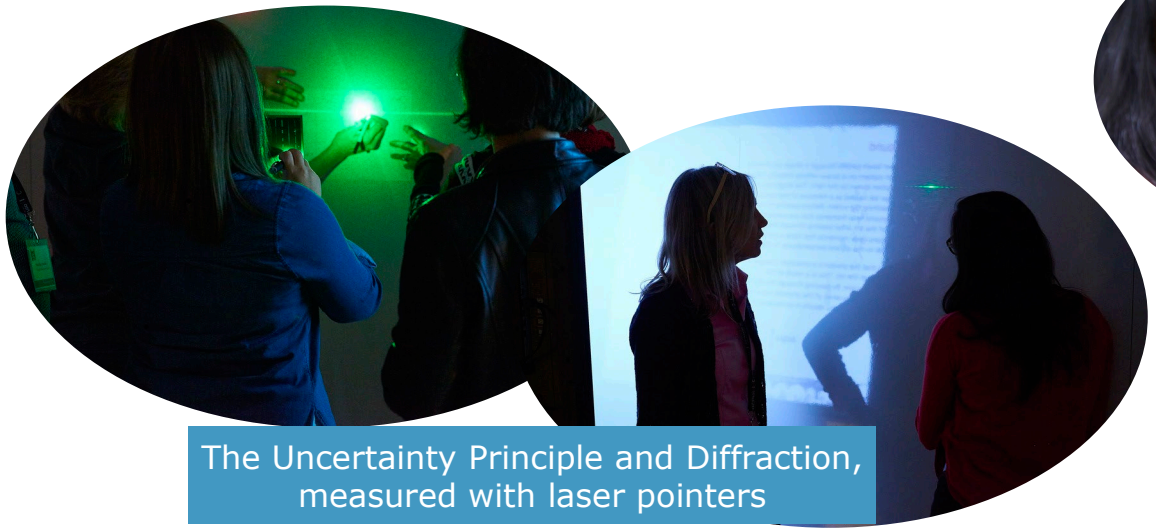

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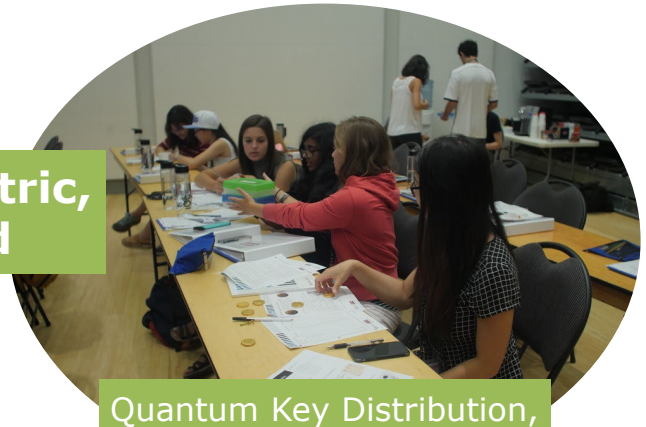
Designed to be implemented in the classroom

Affordable and Q-Info-centric, but somewhat contrived



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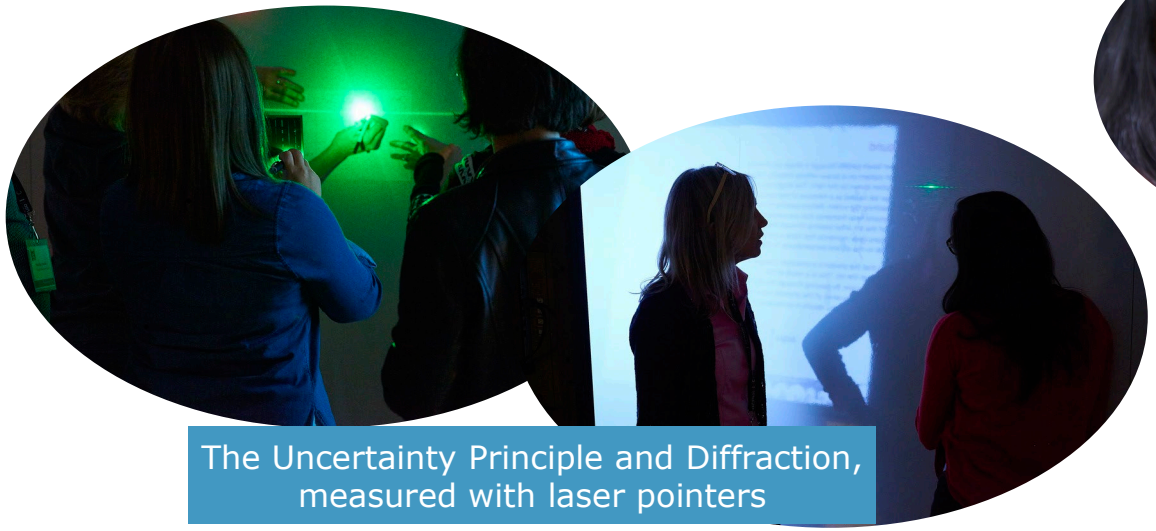

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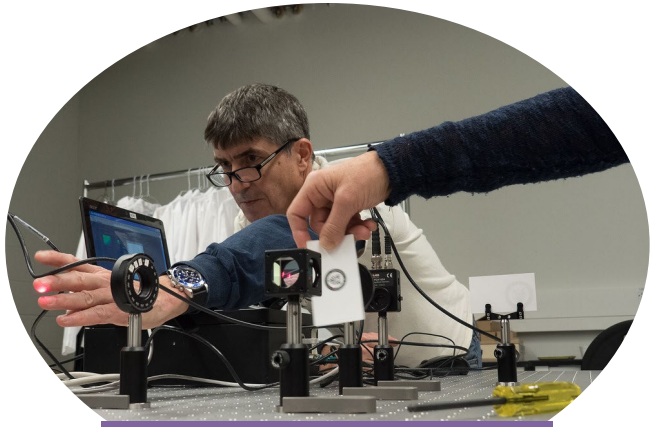

Quantum Key Distribution, build-it-yourself

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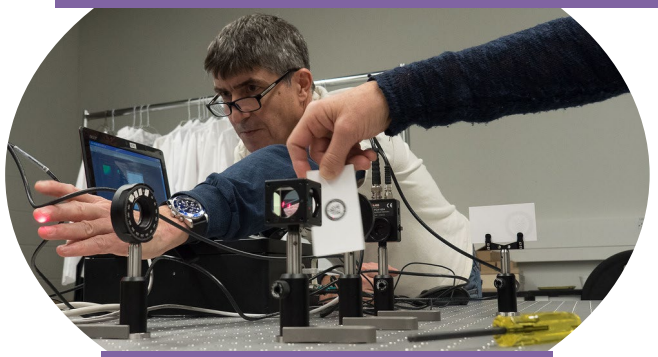
Q-Info-centric and close to real, but expensive



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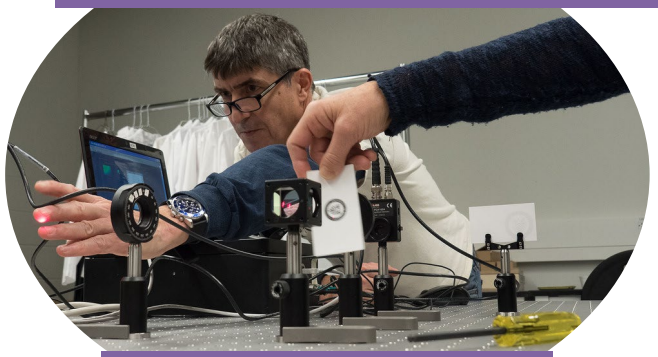

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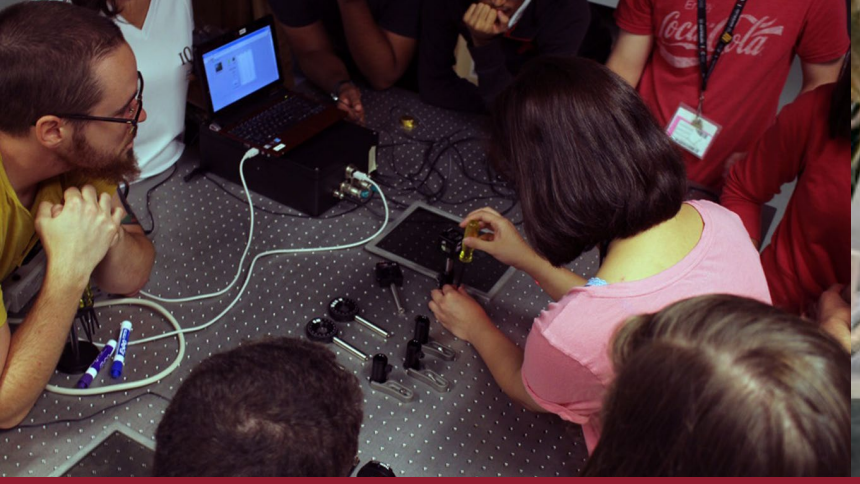
What about bringing the students to us?



QSYS Quantum School for Young Students

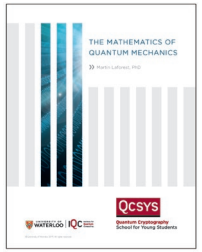
- Formerly known as the Quantum Cryptography School for Young Students.
- Held annually at the University of Waterloo since 2008 with 45 students per year, with over 950 alumni of the program.
- All costs, including meals and accommodation, are covered. Travel bursaries are available.
- Open to high-school students ages 15 and older from around the world.
- Lectures led principally by staff and graduate students.
- Requires Grade 11 mathematics (or equivalent).

Annually in August
Applications open November
Applications due April

uwaterloo.ca/iqc/qsys
iqc.qsys@uwaterloo.ca

UNIVERSITY OF WATERLOO | IQC Institute for Quantum Computing

QSYS Content



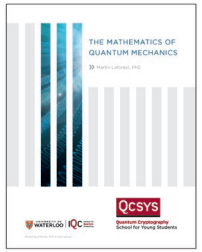
Primer
Text

Linear Algebra & Complex Numbers

Bra-Ket Notation

History of Quantum Mechanics

QSYS Content



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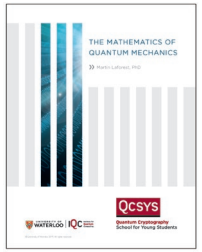

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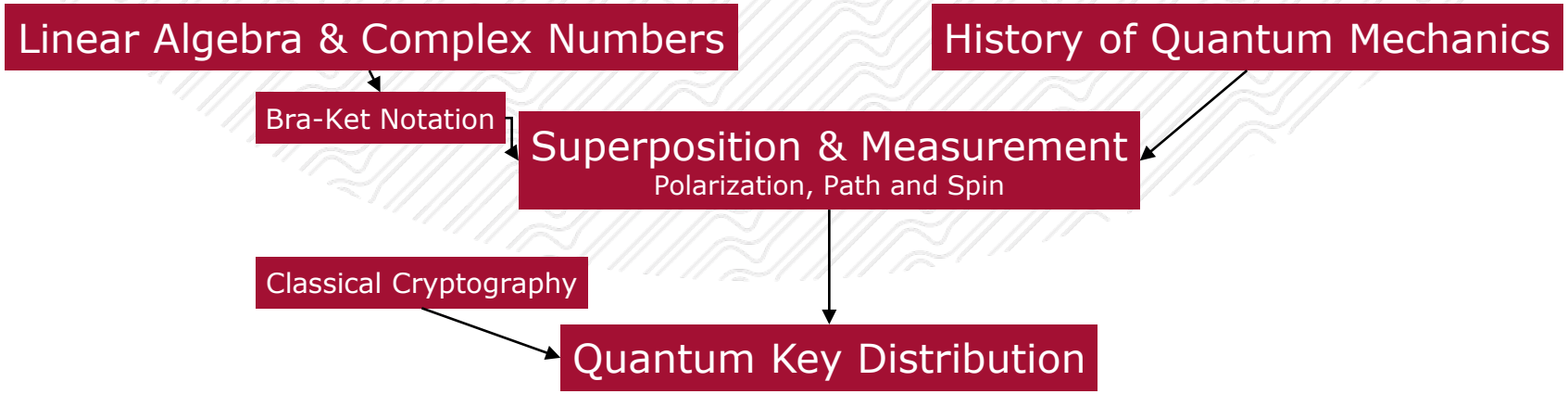

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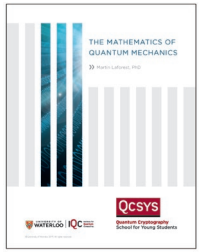

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History of Quantum Mechanics

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Superposition & Measurement
Polarization, Path and Spin

Classical Cryptography

Quantum Key Distribution

Entanglement

Quantum Optics

Teleportation & Paradoxes

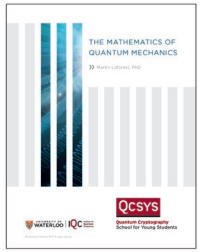
Quantum Computing

Quantum Circuits

Q. Error Correction

Atomic Physics

QSYS Content



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Quantum Computing

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Q. Error Correction

Atomic Physics

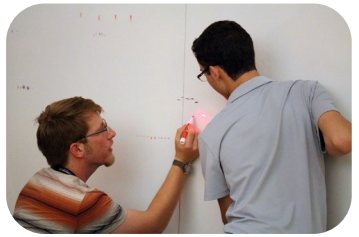
Mentoring Roundtables
Problem Sets
Social Activities
Labs

QSYS Labs

QM Fundamentals

Foundations of quantum mechanics commonly taught in school

Atomic spectra
Planck's constant with LEDs
Sound resonance and clocks
Diffraction and measurement
The uncertainty principle



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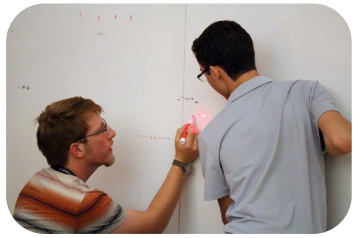
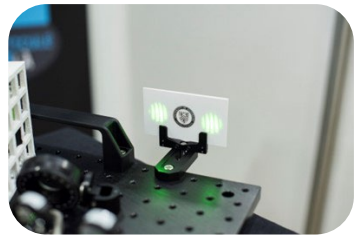
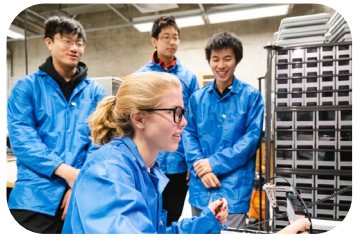
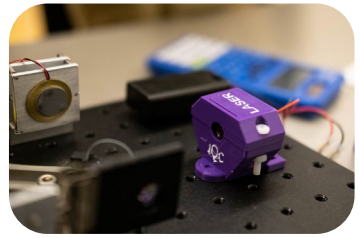


QI Components

Non-QI experiments that can be taught with QI language

Superconducting levitation
Circuit design
Building polarization gates
Interferometers

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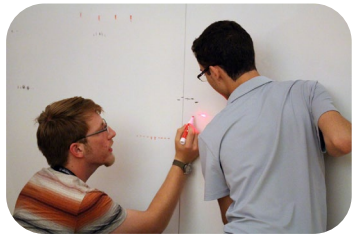

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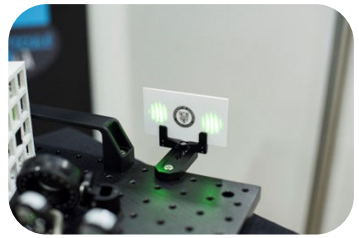

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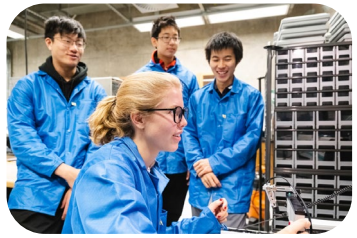
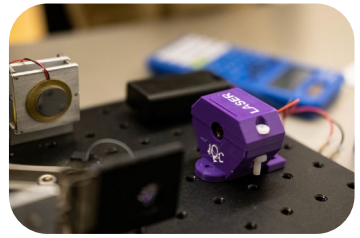
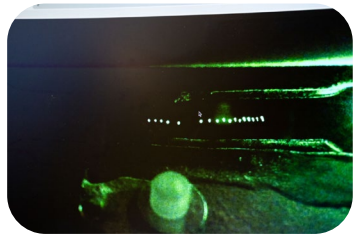



Quantum Information
Direct implementations of quantum-information topics


Quantum key distribution
Nuclear magnetic resonance
Trapping charged particles
Bell's inequalities

QSYS Lab Feedback 2022

4- Strongly Agree
3 – Agree
2 – Neutral
1 – Disagree
0 – Strongly Disagree

I found the experiment **interesting** and **engaging**	The experiment **connected to** and **helped clarify** lecture content	The experiment was **unlike other** activities I have seen before

QSYS Lab Feedback 2022

4- Strongly Agree
3 – Agree
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Ion Trap	**3.93**	**QKD**	**3.73**	**Ion Trap**	**4.00**
QKD	**3.80**	**Ion Trap**	**3.47**	**QKD**	**3.79**
Supercond. Levitiation	**3.57**	**Interferometers**	**3.33**	**NMR***	**3.57**

* Notable technical difficulties

QSYS Lab Feedback 2022

4- Strongly Agree
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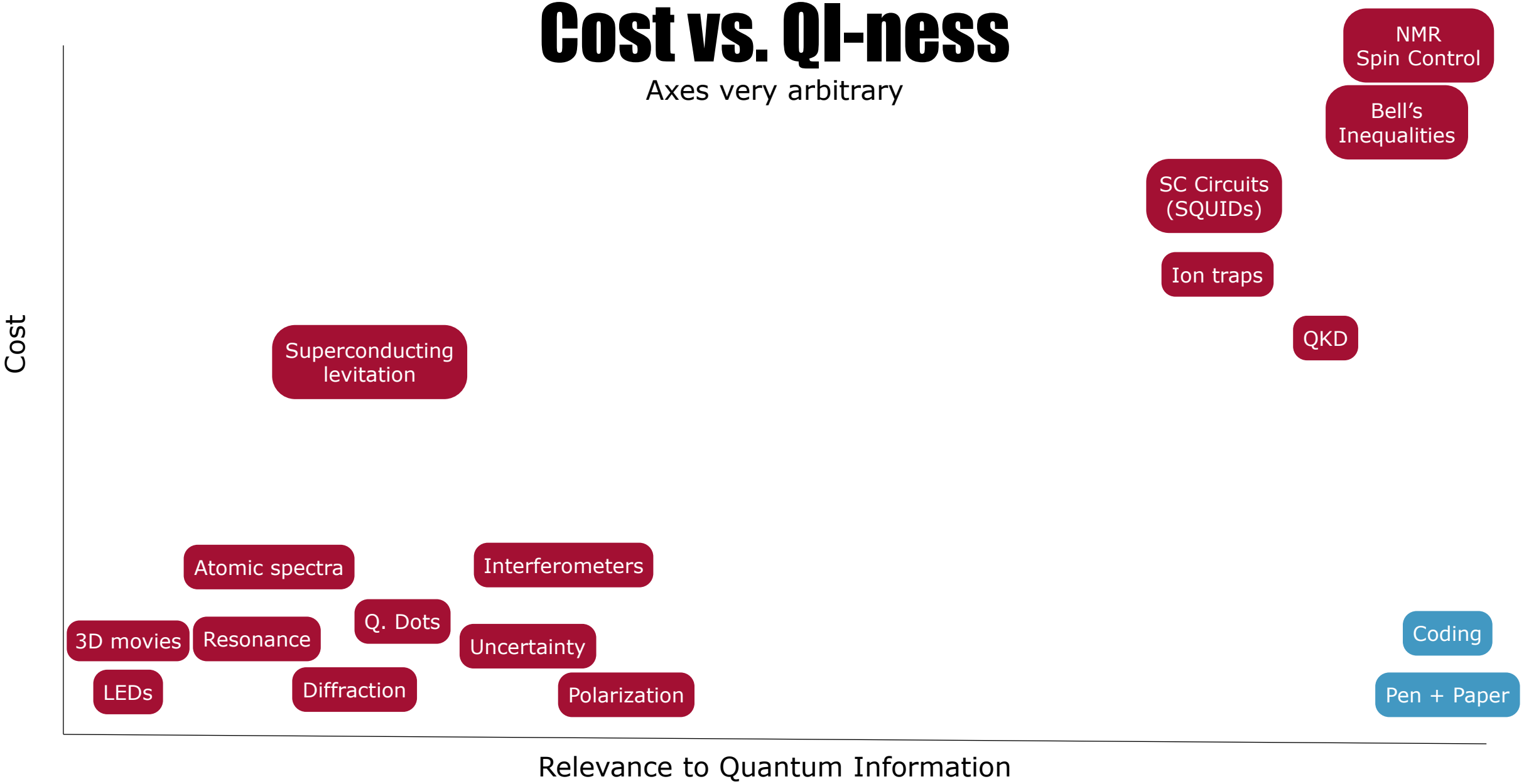
Supercond. Levitiation	**3.57**	**Interferometers**	**3.33**	**NMR***	**3.57**
LED Planck's Constant	3.50	LED Planck's Constant	3.06	LED Planck's Constant	3.53
Interferometers	3.50	Atomic Spectra	3.00	Interferometers	3.50
NMR*	3.07	NMR*	3.00	Polarization Gates*	3.50
Resonance Clocks	3.06	Uncertainty w/ Diffraction	2.94	Uncertainty w/ Diffraction	3.47
Atomic Spectra	2.94	Resonance Clocks	2.81	Resonance Clocks	3.33
Uncertainty w/ Diffraction	2.94	Supercond. Levitation	2.67	Supercond. Levitation	3.29
Polarization Gates*	2.73	Polarization Gates*	2.67	Atomic Spectra	1.80

Key Takeaway
QI-specific labs rank highly in student engagement and help clarify learning, but are uncommon

* Notable technical difficulties

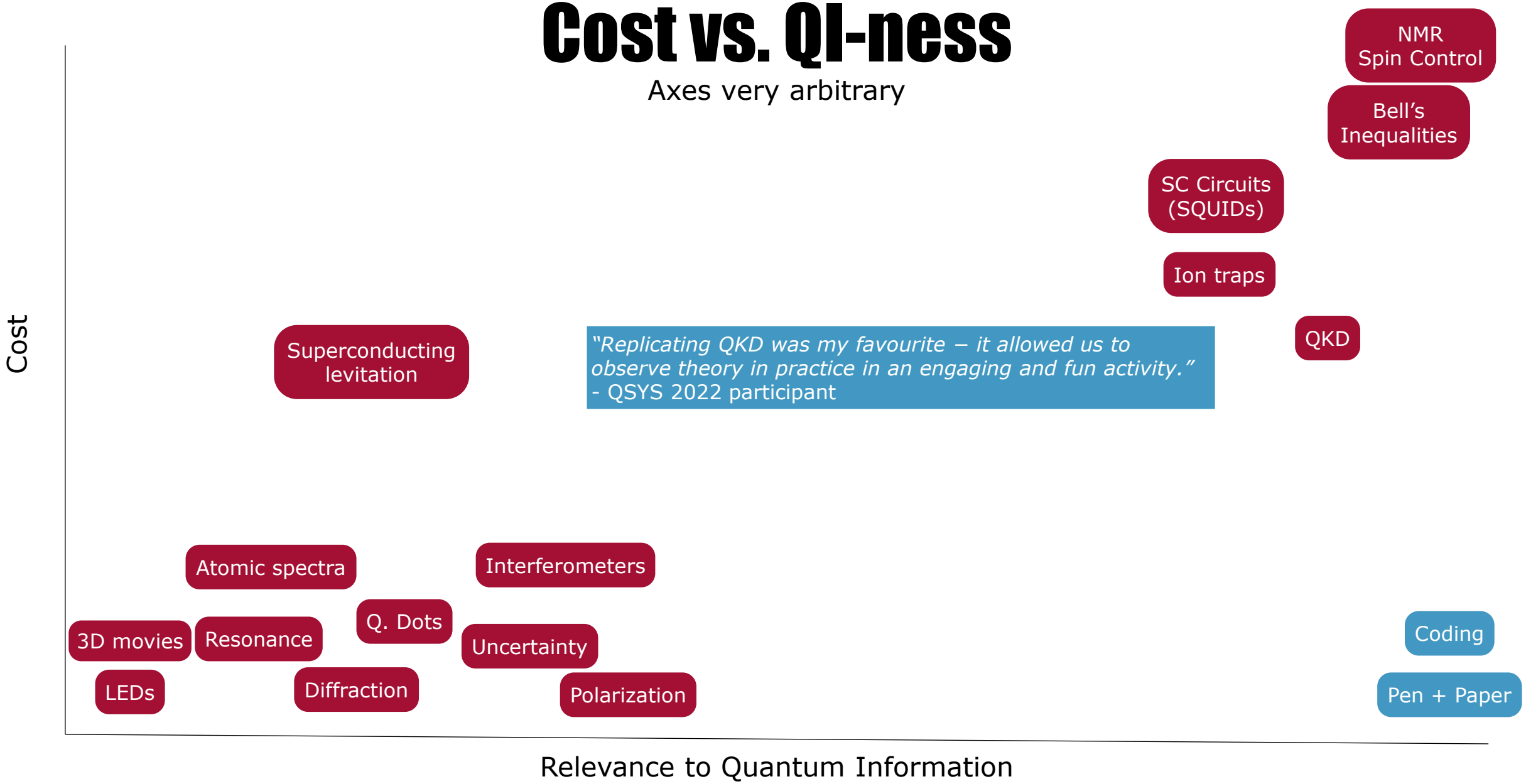
Cost vs. QI-ness

Axes very arbitrary



Cost vs. QI-ness

Axes very arbitrary



Cost vs. QI-ness

Axes very arbitrary

NMR Spin Control

Bell's Inequalities

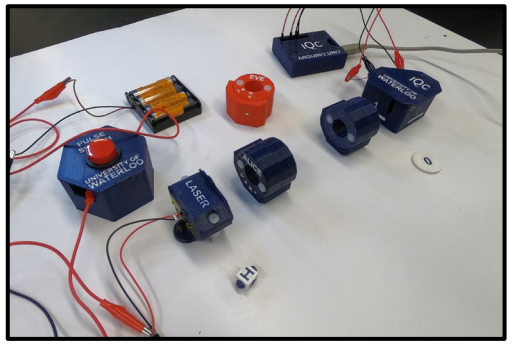
SC Circuits (SQUIDs)

Ion traps

QKD

Superconducting levitation

"Replicating QKD was my favourite – it allowed us to observe theory in practice in an engaging and fun activity."
- QSYS 2022 participant



3D-printed version
Cost ~ $200 CAD

QKD

Atomic spectra

Interferometers

Q. Dots

3D movies

Resonance

Uncertainty

LEDs

Diffraction

Polarization

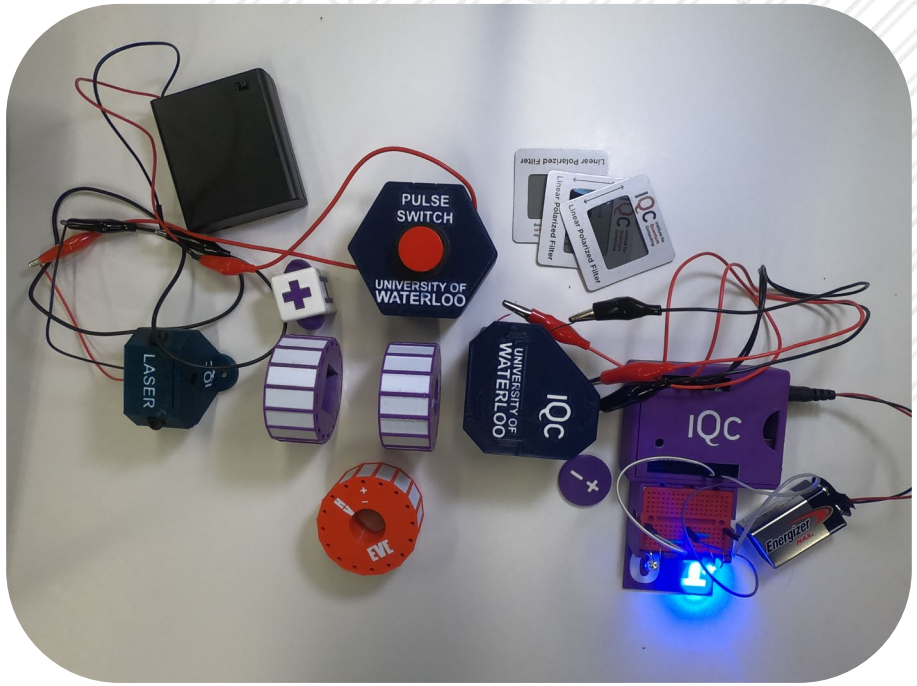
Coding

Pen + Paper

Cost

Relevance to Quantum Information

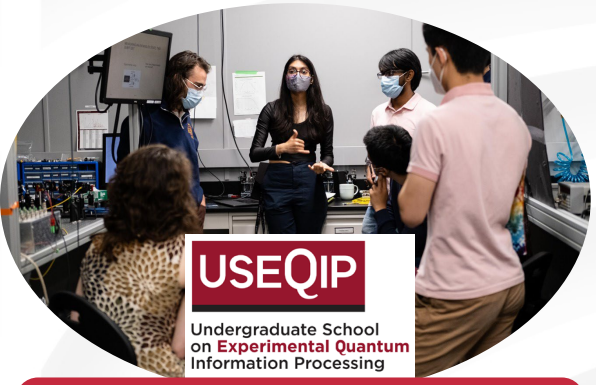
Low-Cost QKD Demo



Item	Role	~ Cost (CAD)
Beam Splitter	Measurement	$48
Arduino	Data Logging	$30
Laser	Photon Source	$27
3D filament	Structure	$5
Wave Plates	Gates	$4
Solar Panels	Detection	$3
Polarizers	Measurement	$3

Thank You!

Contact jdonohue@uwaterloo.ca



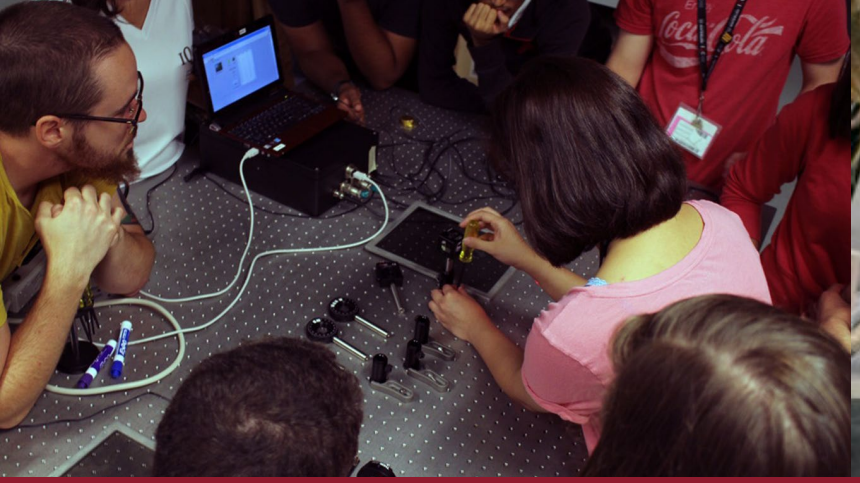
June 2024
Applications due January

Aug 8-18 2023
2024 applications due March

Dec 1-3 2023
Applications open soon

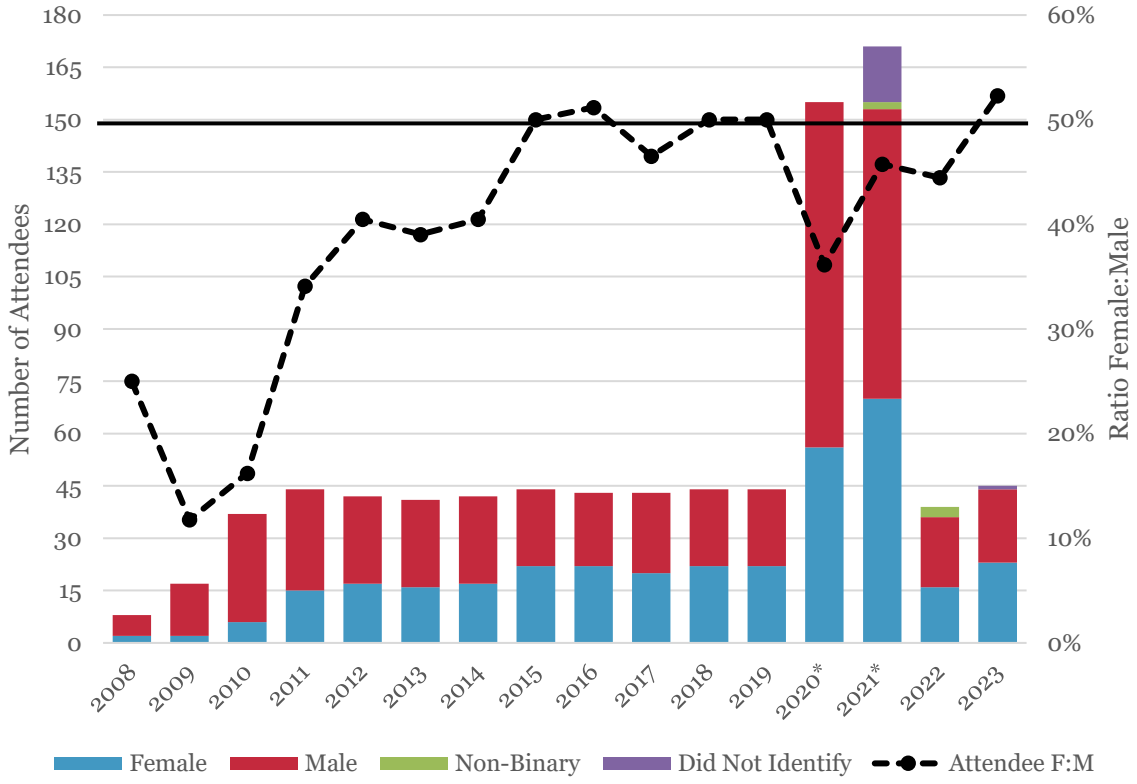
Download QKD
project files

IQC high-school
educator resources

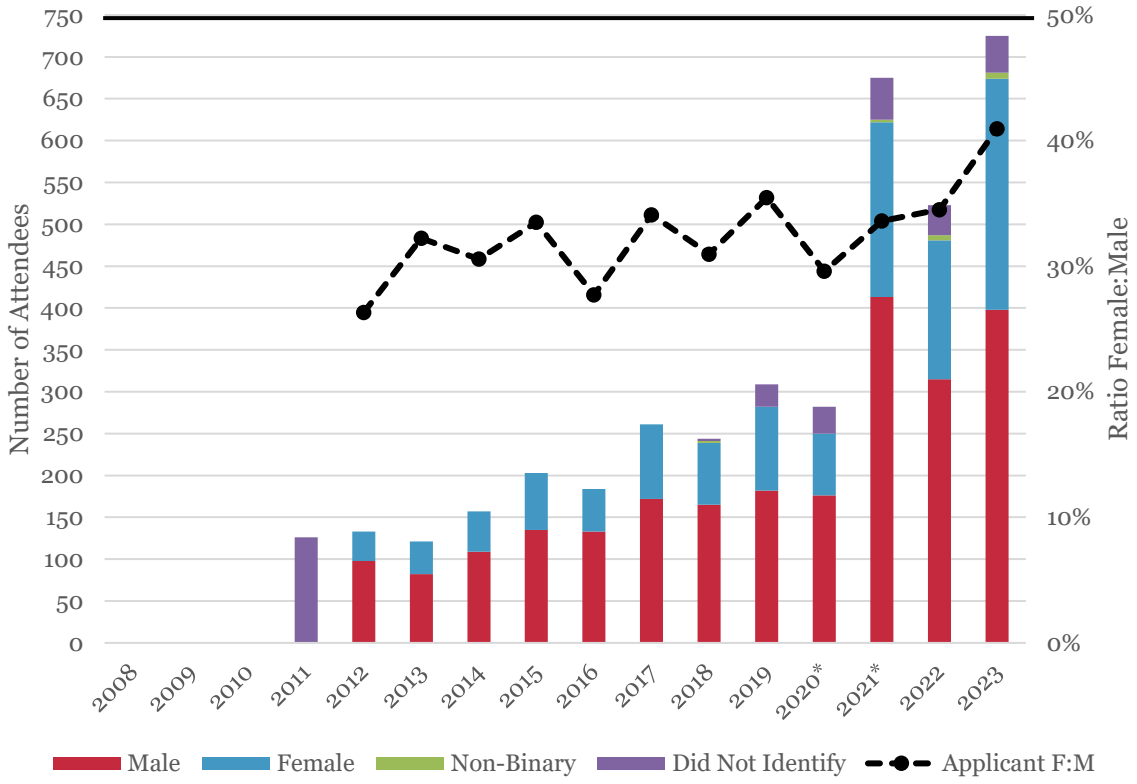


QSYS

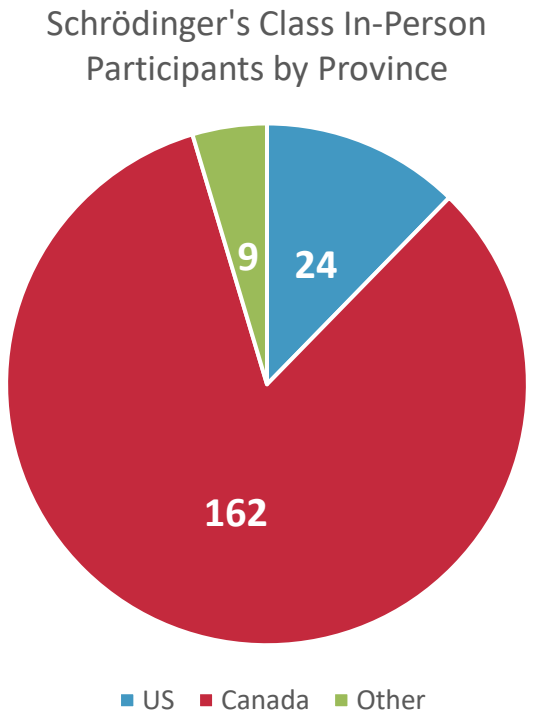
Q(C)SYS Participants

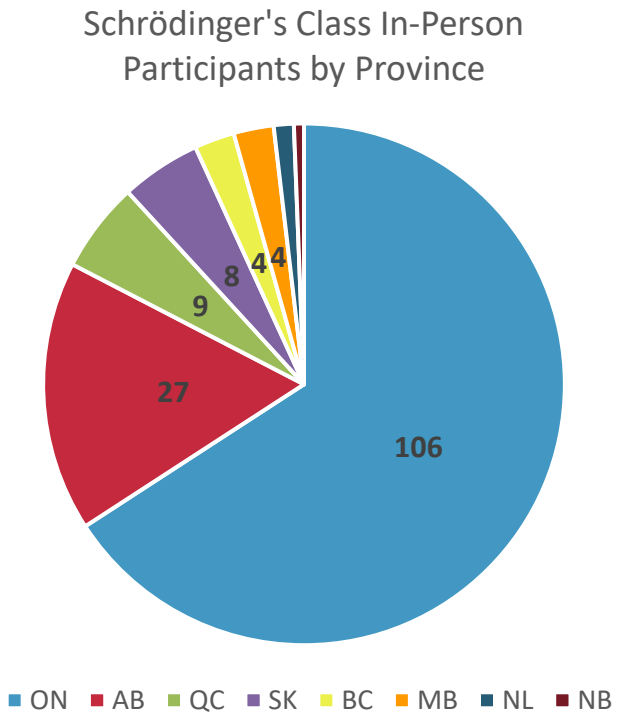


Q(C)SYS Applications



Schrödinger's Class Regional Breakdown





Teachers from regions with quantum ideas in the curriculum more likely to introduce them in their class.

↓

Main fight is to get quantum in the curriculum