Teaching quantum information science to high-school students (and early undergraduates)

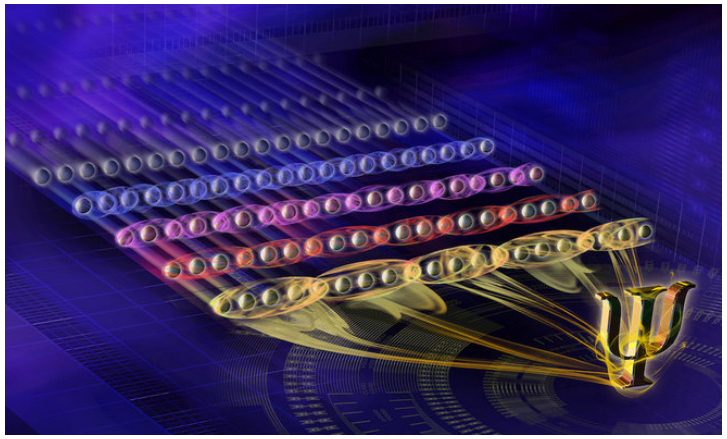
Ed Barnes (Virginia Tech)

1741656, 1847078

Economou, Rudolph, Barnes, arXiv:2005.07874

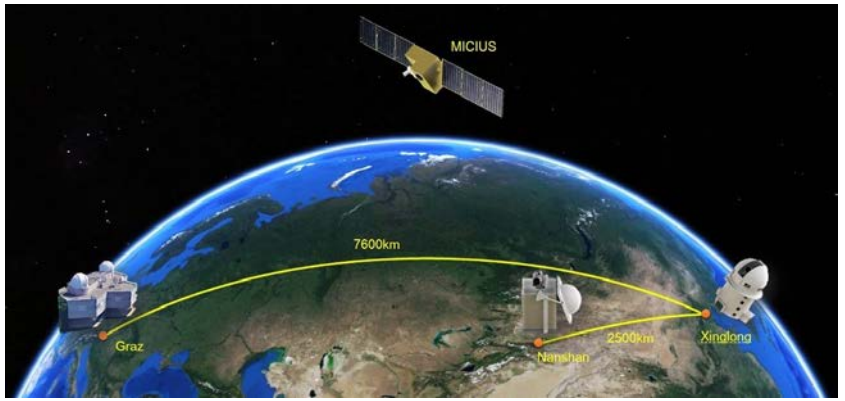
Quantum information science and engineering (QISE)

Quantum Computing



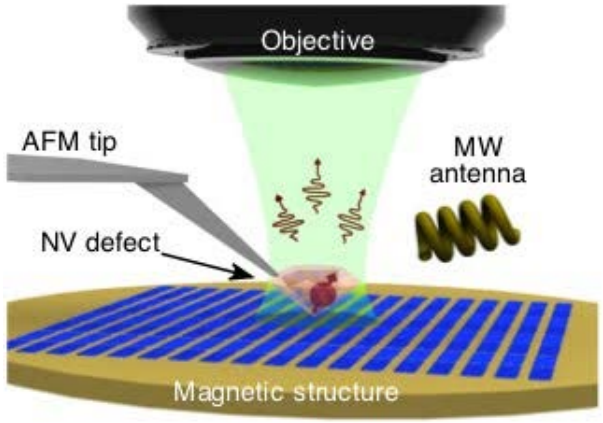
*Friis et al, Phys. Rev. X **8**, 021012 (2018)*

Quantum Communication



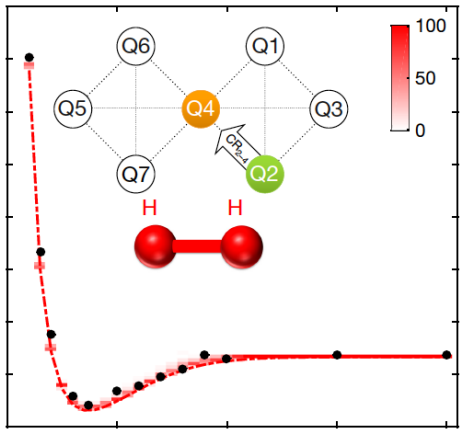
*Jian-Wei Pan et al, Nature **549**, 43 (2017)*

Quantum Sensing



*Rondin et al, Rep. Prog. Phys. **77**, 056503 (2014)*

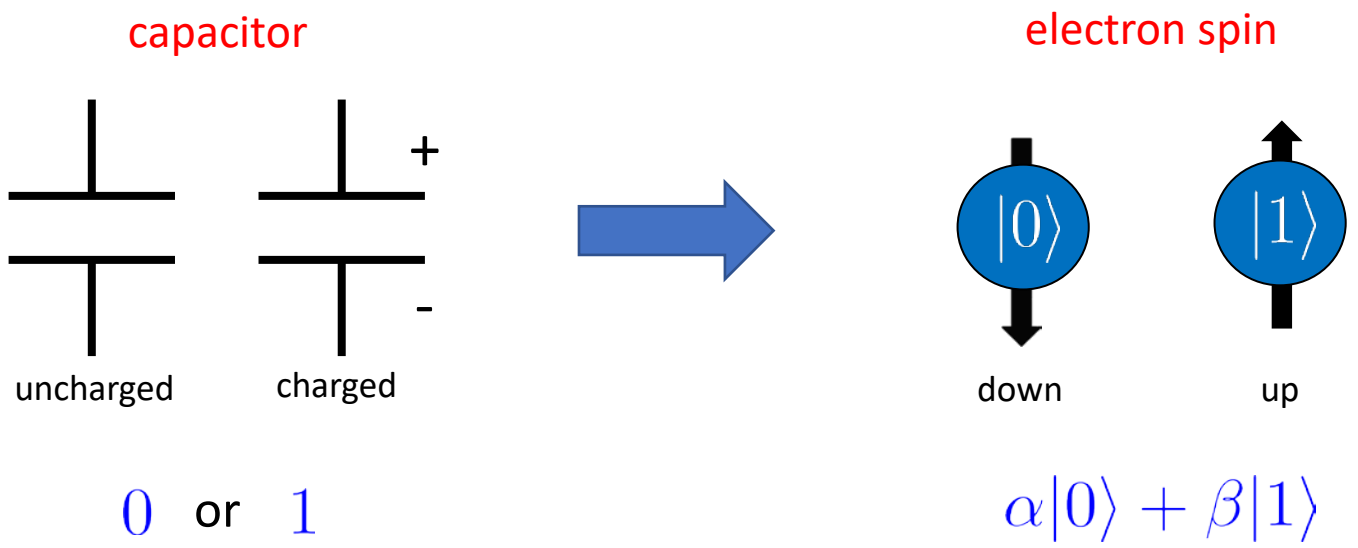
Quantum Simulation



*IBM, Nature **549**, 242 (2017)*

Quantum information

- Replace classical bit with a quantum two-level system (qubit)



- Concepts in quantum mechanics
  - Superposition
  - Entanglement
  - Measurement-induced ‘collapse’ of state

have changed fundamentally the way we perceive information

Virginia Tech Quantum Information Science and Engineering High-school-level Summer School

https://sites.google.com/vt.edu/qisesummerschool/home

- Hosted by VT Center for Quantum Information Science and Engineering in partnership with the Department of Energy's C2QA center
- 4-day event first launched in summer 2021 (~30 participants, including some HS teachers)
- This year takes place Aug 1-4, 2022 on zoom (if you are interested, please register using above link!)

Applications-first approach

- High-school (even middle-school) students and university freshman: first familiarity

- Applications-first approach
  - Starting with linear algebra and building the mathematical formalism first not the most appealing approach, especially for younger students
  - Applications can excite students, peak their interest

- Do not sacrifice rigor!

Our outreach/early QISE education program in a nutshell

- Quantum Mechanics overview (short lecture)
- Quantum Information overview and formalism (hands-on activities)
- IBM Q experience (hands-on activities)
- Quantum applications and games (hands-on activities)

Economou, Rudolph, Barnes, arXiv:2005.07874

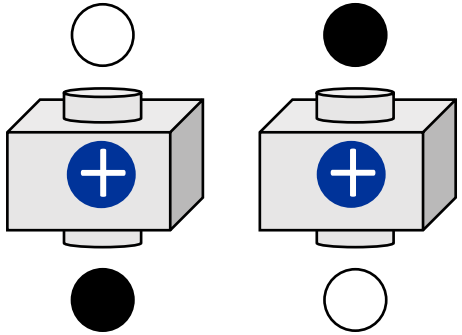
Qubits and gates

Modified version of formalism from Terry Rudolph's book "Q is for quantum"

Economou, Rudolph, Barnes, arXiv:2005.07874

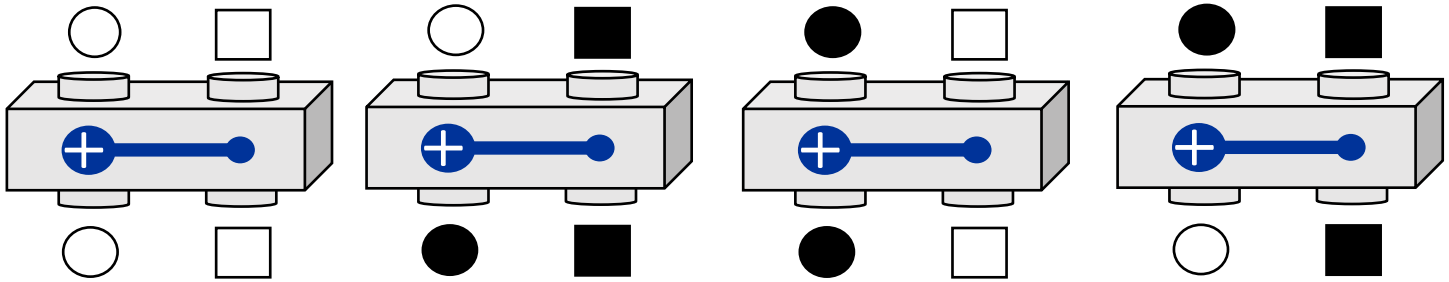
Use to motivate/introduce linear algebra, tensor product structure of Hilbert space

Black: 1; White: 0



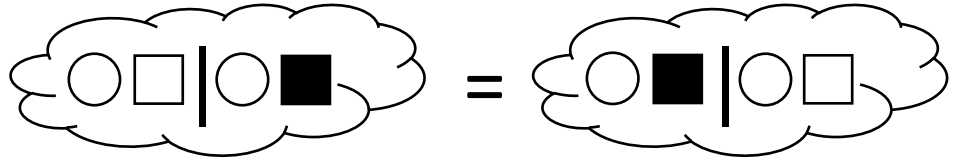
Single-(qu)bit gate: NOT (X)

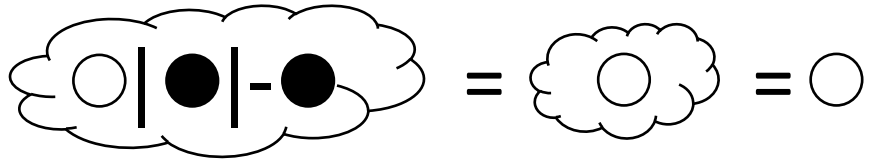
Two-(qu)bit gate: NOT (X)

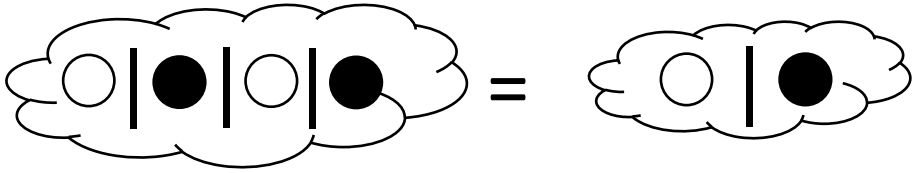


Superposition state (|+>):

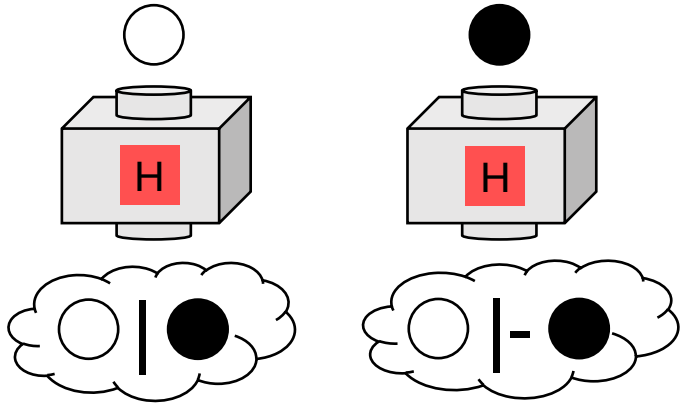
Rules



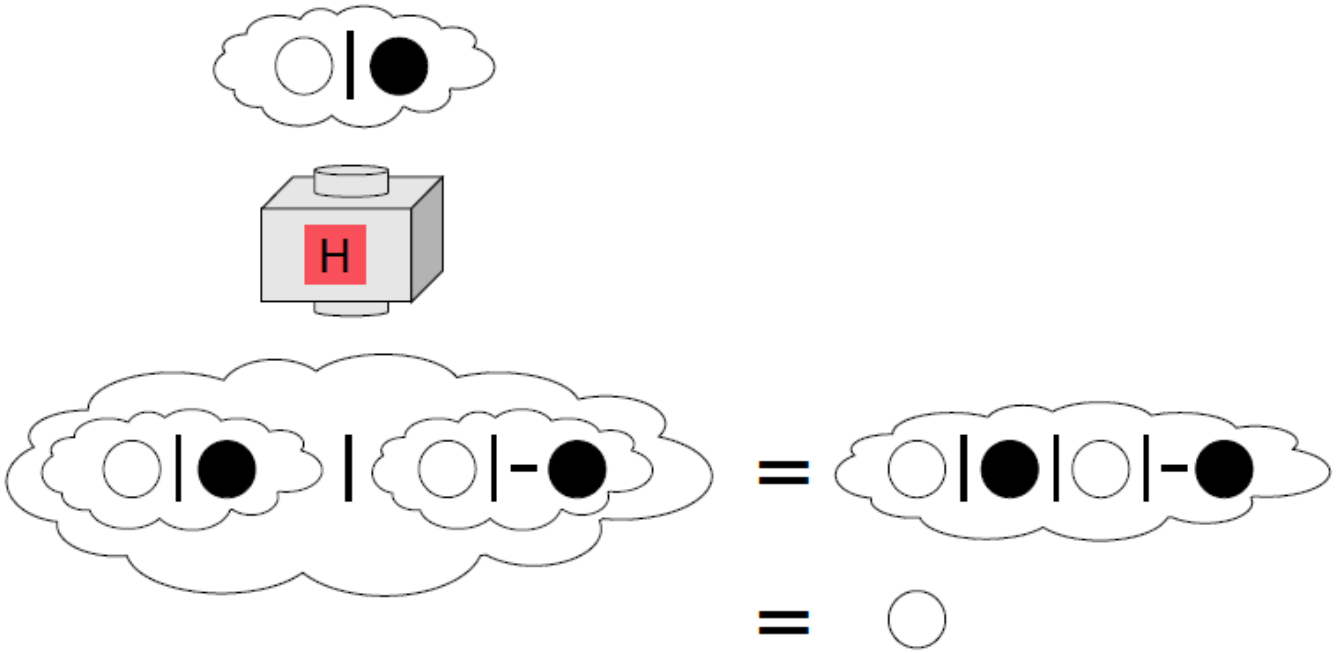


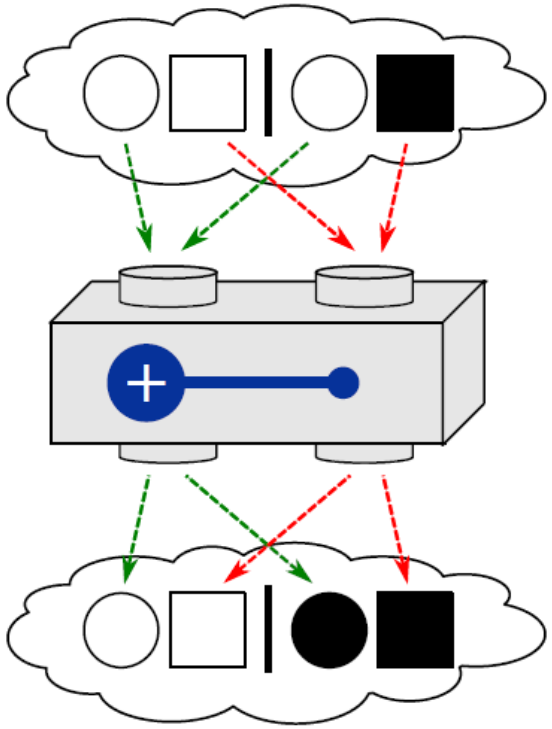


Hadamard gate:



Passing mists through boxes

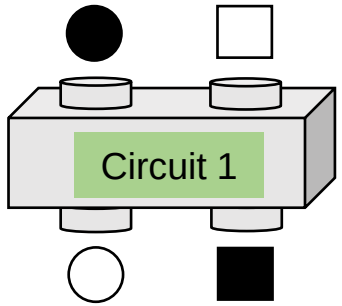




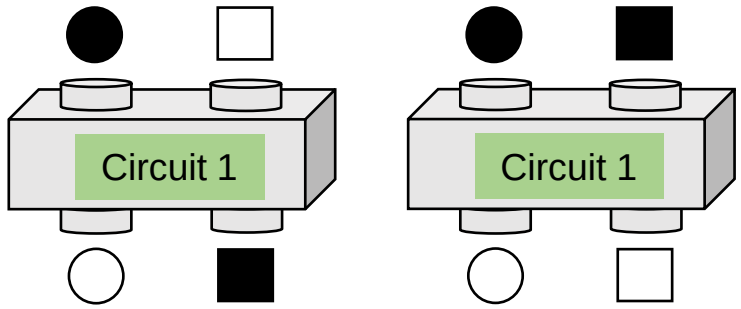
Sample hands-on exercises

What gates inside the box are consistent with (a)?
What about (b)?

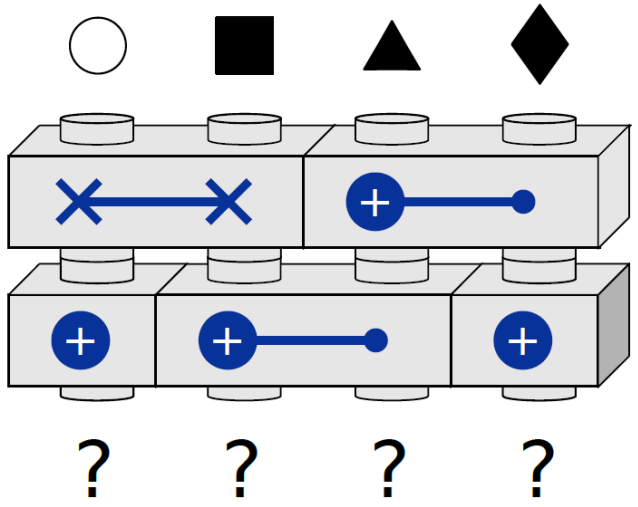
(a)

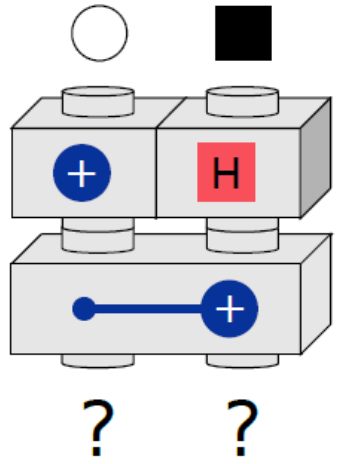


(b)



What is the quantum state that
comes out of the circuits below?

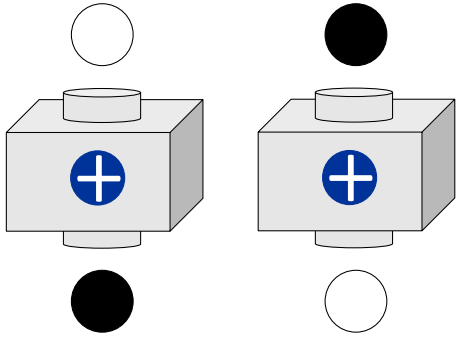


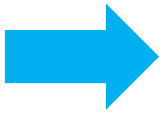


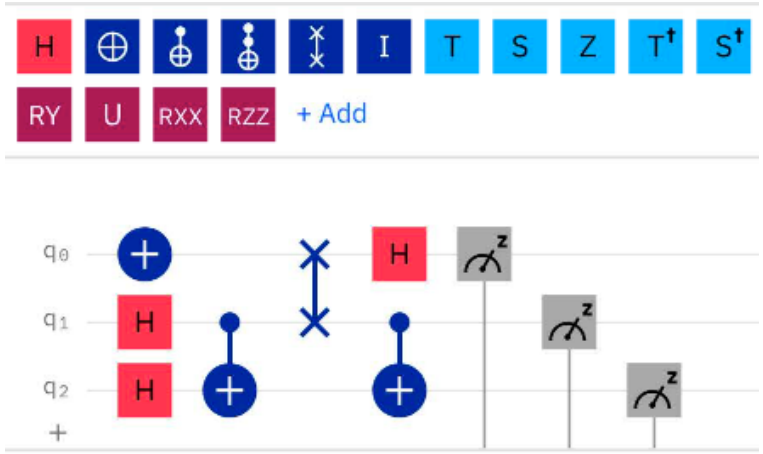
IBM quantum experience

https://quantum-computing.ibm.com/

- Access is free (need to create account)
- Easy drag and drop creation of circuits

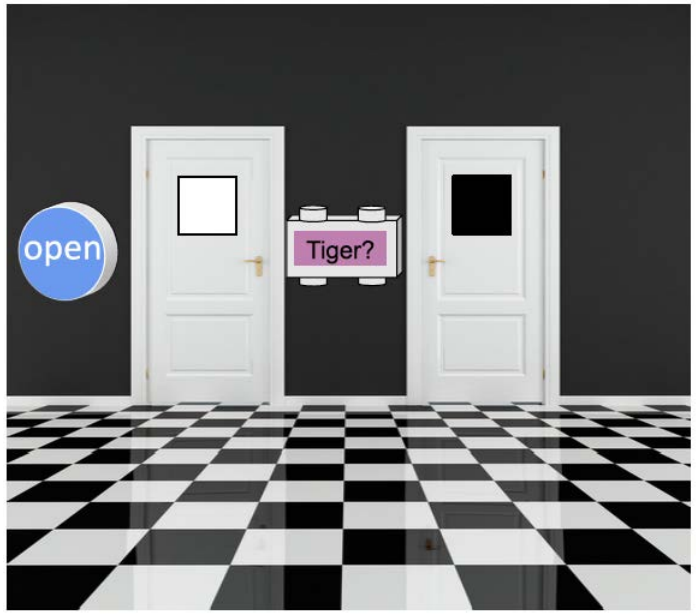




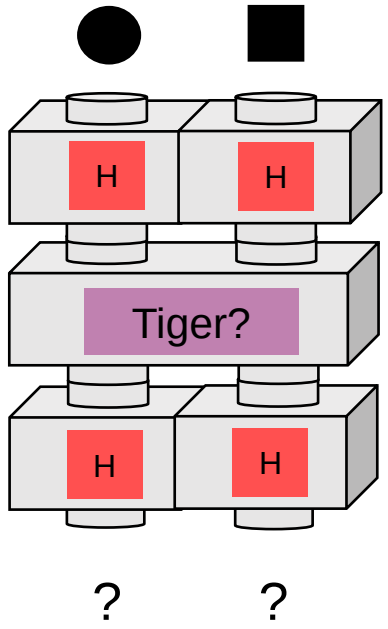


- Use both simulators & hardware
- Hardware allows them to see errors, which hints at difficulty of QC

Money or tiger? A quantum game



there are 3 possibilities



Quantum computing allows us to determine if either door has a tiger ***in one try***

- Analog of Deutsch's algorithm
- Allows students to see a concrete example of something that can be done with quantum but not classical bits

Economou, Rudolph, Barnes, arXiv:2005.07874

Quantum Teleportation

Alice (Sender)
(circle qubit)

Bob (Receiver)
(triangle qubit)

Bell state generator

Ψ

Alice's box

z z

365 million miles

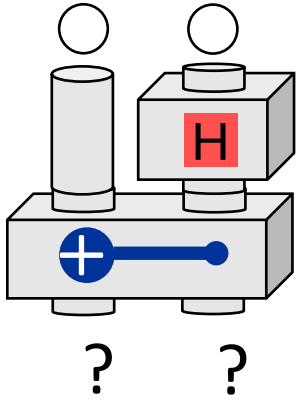
State adjuster

Send measurement outcomes using classical communication
(via phone, email, etc.)

Ψ

New freshman-level QISE course at VT (Hello Quantum World!) (part of QISE minor)

- No linear algebra is needed!
- Key QISE ideas are taught with this formalism
  - Measurement in different bases
  - Entanglement
  - Orthogonality
  - No cloning theorem
  - Quantum key distribution
  - Quantum teleportation
  - Deutsch-Jozsa and Grover algorithms
  - …
- Used as gateway to linear-algebra approach by easing students into concepts
  - Application-first, visual approach motivates matrices and vectors
  - Tensor product nature of Hilbert space
  - Non-commutativity of gates
  - …



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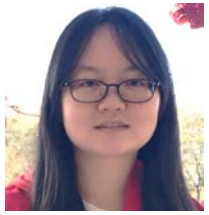
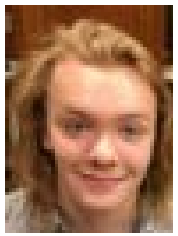
Acknowledgments


Eva Takou


Linghua Zhu


Bryan Gard


Kyle Connelly

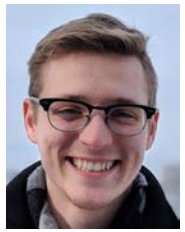

Ada Warren


Arian Vezvaee


Zahra Raissi


John Van Dyke


Kevin Smith
(Yale/Brookhaven)


Sam Barron


Connor Hann
(Yale/Amazon)


Christian Pedersen
(U Washington)


Danny Rosen


Nooshin Estakhri


Prof. Sophia Economou


Prof. Jamie Sikora

Prof. Terry Rudolph
(Imperial College)

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