C^2QA Virtual Quantum Information Science (QIS) Self-Study Program on Quantum Characterization, Verification, and Validation

The C^2QA Virtual QIS Program is intended to provide advanced undergraduate and graduate students and postdocs with the knowledge needed to understand and characterize noise processes and decoherence in quantum hardware. The lectures will assume basic familiarity with the unitary gate model of quantum computation but will otherwise be a self-contained introduction to the concept of quantum channels for describing noise and decoherence.

Lecture Title	Learning Objectives	Instructor
1. Opening Remarks	Introduction to the Co-design Center for Quantum Advantage	Nathan Wiebe, Professor, University of Toronto, and C^2QA Software Sub-thrust Leader nathanwiebe@gmail.com
1. Introduction to Density Matrices	Introduce students to classical mixtures of quantum states. Motivation in terms of noise and errors in time evolution. Expectation values of operators related to trace rho. Rho has trace 1, is Hermitian and positive semidefinite. States in the ensemble need not be orthogonal.	Nathan Wiebe, Professor, University of Toronto, and C^2QA Software Sub-thrust Leader nathanwiebe@gmail.com
2. Density Matrices	Interpretation of the eigenvalues of density matrices. Purity and von Neuman entropy. All density matrices can be viewed as reduced density matrices of a larger system that is pure. Entanglement entropy. Mutual information. Full projective measurement of the environment always produces a pure state for the system by removing all entanglement.	Nathan Wiebe, Professor, University of Toronto, and C^2QA Software Sub-thrust Leader nathanwiebe@gmail.com
3. Quantum Channels	Introduce students to the open quantum systems formalism (Kraus operators, super operator formalism). Concept of Kraus dimension. Master equation derivation from Kraus map for short times.	Isaac Chuang, Professor of Physics, Professor of Electrical Engineering and Computer Science Senior Associate Dean of Digital Learning, MIT ichuang@mit.edu

4. Noise Channels	Learn canonical noise maps, decoherence, relaxation. Rabi/Ramsey experiments. Markovian and non-Markovian noise. T1, T2, T2*, T2echo, Tphi,	Riddhi Gupta - Research Staff Member at IBM Quantum riddhi.swaroop.gupta@ibm.com
5. Quantum State Tomography	Introduce QST	Chris Wood - Research Staff Member, IBM cjwood@us.ibm.com
6. Quantum Process Tomography	Show how channel tomography can be thought of as a special case of QST	Chris Wood - Research Staff Member, IBM cjwood@us.ibm.com
7. Gate set Tomography	Understand role of gauge freedoms in QCVV and strengths / weaknesses of GST.	Erik Nielsen, PhD, Sandia National Lab enielse@sandia.gov
8. Randomized Benchmarking Part 1	Understand unitary designs and provide background into vanilla RB and interleaved RB.	Dave McKay - Research Staff Member, IBM dcmckay@us.ibm.com
9. Randomized Benchmarking Part 2	Interleaved RB; What can go wrong; cross-talk benchmarking. Cycle benchmarking; quantum volume (Honeywell paper)	Tim Proctor – Computer Scientist, Sandia National Laboratory tjproct@sandia.gov
10. Error mitigation and proxy app performance	Applications (proxy app performance). Error mitigation and correction. Are these benchmarks predictive of proxy app performance?	Sarah Sheldon - Research Staff Member, IBM ssheldo@us.ibm.com