Initial Learning Trajectories for K-12 Quantum Computing

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ABSTRACT

As quantum computation (QC) comes closer to reality, questions arise as to what elements to teach, how to teach it, and to what depth. QC instruction typically depends heavily on advanced math and/or physics. Our interdisciplinary science / computer science / education team co-created quantum computing (QC) learning trajectories (LT), zines, and activities, for young learners. We present the LT's (Superposition, Quantum State, Entanglement, Measurement, and Reversibility) and the iterative process that created them.

KEYWORDS

computational thinking; K-12 education; quantum computing

1 INTRODUCTION

Quantum computing (QC) has the potential to solve computational problems intractable using today's digital technology. Some of the most compelling algorithms proposed are: Shor's algorithm to factor prime numbers (Shor, 1997), to break modern cryptography; Grover's algorithm (Grover, 1996), for search and optimization; quantum simulation (Montaro, 2016); and quantum chemistry (Perruzzo, et al, 2014; Reiher, et al, 2017), to unlock the mysteries of nitrogen fixation to boost food production. Google, IBM, and Intel have announced machines from 9 to 72 qubits, yet there are few quantum algorithms (Shor, 2003), and there remains a gap between the large, perfect hardware algorithms assume and the small, unreliable current machines (Chong, Franklin, Martonosi, 2017).

Quantum computing courses are being developed for younger audiences. Dominant approaches, teaching via quantum physics or algebra, require extensive technical knowledge. We extracted essential QC principles and present them in contexts that broad audiences (children or non-technical adults) can understand.

1.1 Background / Related Work

LT's are hypothesized paths of knowledge building that students can move through on their learning journey (Simone, 1995) and are useful tools for building curriculum. Progress has been made on CS

Figure 1: Superposition Learning Trajectory

Figure 2: Figures illustrating quantum principles

LT's (Seiter & Foreman, 2013; Rich et al, 2017; Rich et al, 2018; Rich et al, 2019). QC LT's do not yet exist.

1.2 Methods & Results

Our team brainstormed analogies and activities, dissecting the ways in which they *did* and *did not* accurately reflect the QC concept, and identifying concepts that could be taught without technical dependencies. The zines and activities were used to draft the LT's. The LT's were then used to refine the zines and activities. This process resulted in 5 LT's (e.g. Fig. 1), 14 zines, and 6 activities.

Quantum bits (qubits) hold not just a 0 or 1, but a *superposition* of 0 and 1 that, at any given time, has a probability of being *measured* as either a 0 or 1 (Fig. 1). The old woman / young lady optical illusion (Fig. 2a) satisfies these two aspects. Quantum operations manipulate the probability of measuring one or the other (as well as some other factors), so an analogy with a spectrum is necessary (Fig. 2b). Finally, the measurement LT brings in the fact that measurement of a qubit collapses the superposition into a classical 0 or 1 which will remain static unless further QC operations are applied. Therefore, measurement fundamentally changes the state being measured, just as in a carnival game (Fig. 2c).

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