**Impact on principal disciplines:**

The principal disciplines involved in this project are quantum computing and machine learning. The quantum computing component of the project has focused on quantum annealers while the machine learning component has focused on how to map machine learning problems onto a quantum architecture.

With respect to quantum computing, specifically quantum annealing, we achieved a new understanding of the limitations of quantum annealers (specifically for the D-Wave architecture) for sampling from complex probability distributions. The main new observation concerning that is that new generations of quantum annealing hardware, while showing well-documented in the literature improvements in the main task – finding the ground state – are likely to not improve concerning the sampling applications. This may justify hybrid approaches to sampling.

With respect to the machine learning component of the problem, we demonstrated that mapping a continuous-valued problem onto a discrete-valued problem can be done in a straightforward manner using linear quantization without a loss in performance. We also produced preliminary results that seem to suggest we can find good solutions to deep learning systems with less data and faster computation. This seems consistent with recent literature, though these results need to be more thoroughly validated on larger, more significant experiments.

**Impact on other disciplines:**

The ability to find good solutions for complex systems trained on small amounts of data will impact many applications of machine learning in the health sciences, were training data is often difficult to come by. It will enable many applications where large data sets do not exist or the cost of collecting data is prohibitive.

**Impact on human resources:**

Two graduate students and three undergraduate students have been trained on how to write software and run experiments on the two leading cloud-based quantum computing solutions – D-Wave and IBM. Students have also learned how to run quantum computing simulations of a Linux cluster, and how to implement sampling-based approaches to machine learning (e.g., Boltzmann machines). Students have also been studying contemporary algorithms based on transformers and attention mechanisms.

**Impact of teaching and educational experiences:**

The core architecture we have developed, a restricted Boltzmann machine, has been added to our open-source machine learning demonstration platform known as the ISIP Machine Learning Demo (IMLD). This is being used in our graduate-level machine learning course. We have also introduced lectures on quantum computing into this course. The course materials are also available as open source materials.

**Impact on institutional infrastructure:**

The Neuronix Linux cluster, which is our primary computing resource at Temple University, can now run a quantum computing simulation, and can be used to connect to cloud-based quantum computers to run experiments. We have gained a much better understanding of the challenges in integrating our vast archives of machine learning data into a quantum computing framework.

**What is the impact on information resources that form infrastructure?**

We have created a project web site that is used to disseminate information about the project and share our open source resources.

**Impact on technology transfer:**

We have produced reference implementations of our quantum algorithms that researchers in industry and academia can use to guide their research. The demonstration tool, IMLD, is a valuable resource for creating reference baselines doing quick comparisons of algorithms.

**What is the impact on society beyond science and technology?**

NTR

**What percentage of the award's budget was spent in a foreign country?**

No budget has been spent in a foreign country.