# National Junior Science & Humanities Symposium
## Statement of Outside Assistance

(Student finalists presenting their research paper at the National symposium must complete this form and submit with the final research Paper.)

Name: **Ayush Hariharan**

Regional Symposium: **Virginia Junior Science and Humanities Symposium**

Title of Paper: **Using a Quantum Genetic Algorithm to Optimize the Spending of a Cyber Security Budget**

1) Please explain your role in the development of the project idea.

> I developed the project idea independently. At the beginning of this research endeavor, I viewed different scientific journals and investigated the research in the field of quantum computing. At this time, I didn't know much about my project except for the field of study – quantum computing. Inspired by the complexities of this topic, I joined the Qiskit slack channel and started learning the Qiskit API. Eventually, I found a research paper describing the concept of weak measurement, which measured a qubit without breaking superposition. Although this was an intriguing topic, I eventually realized that the research was unfeasible. To find another project, I investigated the realm of genetic algorithms and quantum computing. Combining their idea for a quantum genetic algorithm with the IBM Qiskit API, I investigated the optimization of the Knapsack problem on the IBM Q32 simulator. Finally, inspired by my work over the summer in cybersecurity, I found two articles by Fielder et al. and Rakes et al. that helped me develop a methodology for budget allocation in a small-medium enterprise. I then adapted my quantum genetic algorithm towards this application.

2) What steps led you to formulate your research question? --or—What steps led you to develop the design for your engineering project?

> After developing and initiating the research, I had to design a procedure that would successfully answer the research question that my project was trying to tackle. I first attempted to replicate the work that Nowotniak accomplished on the IBM Q32 architecture. Due to the discrepancies in the architecture of the processors, some aspects of the quantum genetic algorithm didn't replicate easily. So, I incorporated ideas from the old algorithm, such as a qubit population and probability amplitude manipulation, but I implemented these ideas in a novel way. However, the similarities between the two algorithms end there. In order to deal with local maxima and minima common in genetic algorithms, I implemented a disaster algorithm. The disaster algorithm essentially resets the state of the quantum population after a certain generation. Throughout this first aspect, Duke Writer helped me understand the mathematics behind both quantum computing and the genetic algorithm, allowing me to make successful modifications. After the improvement of the quantum genetic algorithm, I started the cybersecurity budget allocation application. I developed a novel method to translate the vector representation of the real-life data to a scalar quantity that could be used in the quantum algorithm. I also made the scenario more realistic by utilizing different strategies for each CISO.

3) Where did you conduct the major part of your work? (i.e. home, school, or other institutional setting – university lab, medical center, etc.)

> I conducted all of my research either at home, or at the Academies of Loudoun, the high school in Loudoun County which I attend.

4) Describe the assistance that you received throughout the project.

> When starting this research project, I understood that quantum computing would be a field that required tremendous mathematical expertise. In order to prepare myself for this strenuous research project, Duke Writer advised that I investigate eigenvectors and Dirac notation so that I wouldn't be overwhelmed. On top of that, he asked me to read Quantum Computing: Lecture Notes by Ronald de Wolf, a Dutch computer scientist, in order to gain a deeper understanding about different quantum algorithms. I read about Grover's and Shor's algorithm that helped dramatically improve the speed of integer factorization and database sorting. These lecture notes introduced me to the field of quantum computing and helped me understand the different concepts addressed in the peer-reviewed research journals. On top of that, I read the Qiskit documentation before beginning this project in order to gain a better understanding of quantum logic gates such as the Hadamard. The documentation revealed the presence of two distinct quantum architectures -- the annealing model and the gate model. I used this knowledge and referred back to this documentation throughout the research endeavor. Finally, Dr. Matt Weber from UC Berkeley helped me in the cybersecurity aspect of my algorithm. He helped analyze the data which was collected and transform my project into a more theoretical phase. He explained the process behind asymptotic analysis and helped me generate a theoretical complexity proof for my algorithm. Dr. Weber truly broadened my algorithm's impact from simply experimental to more computer science theory.

5) If you worked in an institutional setting, describe your role on the team.

> I did not work in an institutional setting.

6) What role did each person play in the research investigation?

> This research project was done independently, except from some greatly appreciated guidance from research mentors such as Duke Writer and Dr. Matt Weber.

7) Describe what parts of the research you did on your own and what parts where you received help. (i.e. literature search, hypothesis, experimental design, use of special equipment, gathering data, evaluation of data, statistical analysis, conclusions, and preparation of written report (abstract and/or paper).

> As I mentioned above, I initiated literature search independently by looking at different research papers in the realm of quantum computing and the cybersecurity budget allocation process. I then developed my own hypothesis and designed the procedure by myself. However, Duke Writer helped me understand the mathematics behind both quantum computing and the genetic algorithm, allowing me to make successful modifications

> The development of the procedure is only the first step of performing research and the second is implementing the procedure that was designed. After drawing out all of the steps on the classroom

whiteboard, I had to write appropriate algorithms in order to perform the research. Using a custom URL with the Qiskit API, I connected to the IBM 32 qubit quantum computer and created 16 two-qubit quantum registers. Each quantum register was then paired with a classical register in the quantum circuit and the respective circuit was measured. After the measurement loop finished, I inputted the results into a special knapsack algorithm that takes in the measurement value and calculates a maximum profit. For the cybersecurity application, this function takes in the case study vectors (corresponding to mitigation of a countermeasure against different attacks) and outputs a scalar quantity corresponding to the amount of money saved. After the budget allocation is completed, the probability amplitudes of the system are stored and then manipulated locally before being imposed onto the qubits using a variety of Hadamard gates. Then, at around six generations, probability amplitudes of 0.5 are imposed onto each state of the qubits to signify the disaster algorithm.

After data collection, I performed an analysis to determine whether my modifications significantly improved the optimization of the knapsack problem. After the evolution of the population had been tested, I performed a one-sample t-test that compared the results of my algorithm to the results of previous research. Once this was completed, I performed an ANOVA test to determine whether the implementation of the final probability amplitude manipulation impacted the optimization of the knapsack problem. Then, another ANOVA test was performed to determine whether the implementation of the disaster algorithm significantly impacted the optimization of the knapsack problem. Duke Writer helped walk me through the statistics that would be needed for comparing the tuned hyperparameters.

For the cybersecurity budget allocation problem, I looked at the distribution of my algorithm's output at each input range. I then compared this distribution when compared to previous research. Dr. Matt Weber helped me interpret the results of this algorithm, specifically related to cybersecurity. Finally, I looked at the run time of my algorithm and analyzed the experimental data collected by myself. However, Dr. Matt Weber helped walk me through the theoretical proof behind complexity analysis so that I could target this issue from two different angles.

8) If this research is a continuation of an investigation that was previously submitted to a regional JSHS, describe how you have expanded your investigation.


**Comments by teacher and/or supervising mentor on the students' individual contributions to the research investigation or engineering/computer science project**


**Statement by the teacher or supervising mentor acknowledging that the student conducted the research in accordance with proper procedures and protocols for the conduct of animal research or human research.** Projects which were conducted without proper supervision will be disqualified from both regional and National competition. Further guidelines may be found at http://www.jshs.org

- Research activities involving non-human vertebrates or human subjects must be submitted for IRB review prior to the conduct of the research.

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- Research activities involving vertebrate animals must be conducted in compliance with local, state, and federal guidelines for the humane and ethical treatment of animals in the conduct of the research.

Please have the supervising teacher and/or supervising scientist sign below. If you did the work without a teacher or supervising scientist, you will need a signature from your parent and a brief description of their role in the research.

02/26/20 _____    Academies of Loudoun
Date      Signature of Student (Required)    High School

02/27/20 _____    ACADEMIES OF LOUDOUN
Date      Signature of Teacher            High School
              Duke Writer

_____  _____    _____
Date       Name of Supervising Scientist    Title of Supervising Scientist

           _____
           Institution of Supervising Scientist

           _____
           Signature of Supervising Scientist