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Quantum Computing in Education: A Quantum Leap in the 21st Century Learning

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Abstract:- Because of the ever-growing population in the world and the dire need for more area, quantum computing has been on a steep rise over the years. Matter is present in both states: particle and wave, and quantum computers (Fig 1) are based upon this phenomena. These engineering miracles make use of quantum entanglement and quantum superposition, using parts specifically designed for such computers.

Quantum computers could be of immense benefit to the world, and especially to the educational field. Recent developments have created fascinating new opportunities for teaching this quickly developing subject to the younger generation. This paper shall focus on all these benefits quantum technology can potentially provide to the educational sector of the world and revolutionize this industry in the coming future.

I. INTRODUCTION TO QUANTUM COMPUTERS

Although the whole concept of Quantum computing feels neoteric, the theory has actually been developing through centuries, with the most major breakthrough in 1920. These computers have been developed ever since and have been widely used in war cryptography, such as World War II and the Manhattan Project. However, the concept of *quantum parallelism* (the ability of quantum computers to process a problem for multiple inputs simultaneously) was proposed during 1994, which shaped the history of these machines.

Although these machines have gained massive popularity in the past, with public and private sectors showing an avid interest in the development of this sector, the practicality of such machines is still limited since these are of humungous sizes (although variable) and have to be stored at extreme temperatures of -459 degrees Fahrenheit to work properly. Yet, major financial superpowers such as Google, NASA, and IBM are in the race for these supercomputers because these are growing at an exponentially higher rate than any other platform in the world and can solve any complex problem in the world that couldn't be solved by any machine known to man.

Another phenomena used in quantum computing is quantum entanglement through which a relation is drawn between qubits such that irrespective of their state or distance, they can influence one another. These qubits can exist in superpositions of both 0 and 1 simultaneously, thereby these machines can solve insanely complex problems simultaneously.

Fig 1.

II. APPLICATION OF QUANTUM COMPUTING IN EDUCATION

Quantum computing is being used in multifarious fields of work, especially information technology and quantum mechanics, yet quantum computing has barely 'touched' the field of education due to its limitations in the present day and age.

Although still meager, quantum technology holds immense scope for the future generation. With the ongoing work in entanglement, these machines open up infinite possibilities for teaching and learning more about such phenomena. It is predicted due to the pace of its development, quantum computers will be everywhere by the year 2060, which provides more of an incentive for education departments to ensure that the upcoming generation shall learn more about this groundbreaking technology. The possibilities for quantum research in learning are immense.

These simulations could be extremely beneficial for students, especially those involved in research, and could help in problem-solving, learning the code (algorithms) of such technologies, and proficient multidisciplinary actions. With the help of such techniques, students could research on a higher scale than they did before, and find out the problems to certain questions which would have caused their previous computers to crash, but now using quantum technology can be found within a second.

Students are now being taught about Artificial Intelligence in schools, a technology which has remolded human beings. But not many know that quantum technology has the power to revolutionize this field as well. Machine learning models and optimization procedures can be trained more rigorously using quantum computing thanks to the performance of quantum algorithms over their classical counterparts. Considering AI is on a steep rise, students can use quantum technology to test out theories related to artificial intelligence, which could only have been thought of using classical computers but never successfully implemented.

Though this technology hasn't yet been excessively incorporated into the education system, several universities and established institutes are doing so by expanding the knowledge of students in such fields through seminars, innovation hubs, joint research projects, and specialized courses.

III. INTEGRATION INTO EDUCATION

Multiple Universities have already incorporated quantum technology into the students' curriculums. A significant number of colleges offer courses and programs for students to learn the fundamentals of quantum mechanics and computing, offering resources that enable students to understand the full potential of such technology.

The integration of these courses not only entails theory but also includes practical experiences. Students can directly interact with quantum hardware and software in laboratories and develop a practical grasp of quantum algorithms and comprehend their uses.

Furthermore, academic establishments are creating an all-encompassing Quantum Science curriculum that pertains to many subjects such as quantum cryptography, quantum computing, and quantum communication.

A lot of industrial tech giants have established partnerships and online platforms that are helping outspread quantum education to a global audience. Programs such as Microsoft Development Kit and IBM Quantum Educators Program have already been established which help teachers receive the necessary resources and instruments to properly teach quantum computing to students interested and enrolled in such platforms.

Quite a few institutes have also started offering courses in computer science which provide the student with the overall basics of quantum computing. Some of these colleges are MIT, Stanford University, Oxford University, ETH Zurich, and UCL – Berkeley. These universities are at the forefront of quantum computing and research and provide their students with holistic development in the same areas of research.

IV. COLLABORATIVE RESEARCH IN EDUCATION USING QUANTUM COMPUTING

A key principle of quantum computing: entanglement, has been exploited in group projects to discover new and better algorithms that would speed up quantum processes on an exponential scale. Schrödinger's equations (Fig 2) serve as the basis of the foundation for the development of quantum algorithms. These equations use the evolution and manipulation of quantum states to execute calculations on an unprecedented scale. Many students are provided with the opportunity to learn about such manipulations and deeply examine these equations by incorporating quantum computing in their education centers.

Methods such as the Variational Quantum Eigensolver (VQE) have been developed to predict molecular properties. This entails the students to approximate the quantum wavefunction |ψ>. Scholars have exhibited how quantum algorithms may effectively address issues that are unmanageable for classical computers.

Students have also made new groundbreaking discoveries in the field of quantum computing. An excellent example would be IBM's Quantum Educator Program (QEP) which promotes fruitful discussions between students and teachers. These programs not only teach the students the theory of quantum mechanics and quantum algorithms such as Grover's and Shor's algorithms but also permit them access to use IBM quantum computers and observe the research of certain IBM professionals.

$$\frac{\partial^2 \Psi}{\partial x^2} + \frac{\partial^2 \Psi}{\partial y^2} + \frac{\partial^2 \Psi}{\partial z^2} + \frac{8\pi^2 m}{h^2}(E - V)\Psi = 0$$

$$\nabla^2 \Psi + \frac{8\pi^2 m}{h^2}(E - V)\ \Psi = 0$$

Fig 2 Schrödinger's equations

V. CHALLENGES

Although quantum technology does seem very attractive on paper, it includes a myriad of intricate challenges to be successfully implemented into the education system of a student. Thorough research is being conducted regularly, yet scientists have not yet been able to come up with a counter to quantum noise and errors which always tend to occur during quantum processing. It becomes crucial to eliminate such errors using the Steane code or the surface code (Fig 2) before such machines are made available for the students to experiment.

Furthermore, the characteristics of quantum mechanisms and quantum parallelism depend upon determining and controlling the superposition of several states coherently, carefully studying quantum gate sequences and patterns, as demonstrated by the Grover search method, which is searched through unsorted data at a quadratic speedup. However, applying such algorithms into practice requires deft handling of qubit entanglement, without which students cannot successfully experiment on such machines.

From a practical viewpoint, it is very difficult to provide students with a thorough education in quantum technology. Since they are still in their early stages, quantum computers are not widely available and usable. Even their physical structure does not make them popular since they are massive structures which are to be stored at extreme temperatures, that are not easy to access. The currently available quantum computers are fragile, and environment-sensitive which makes it difficult to integrate them into traditional learning styles.

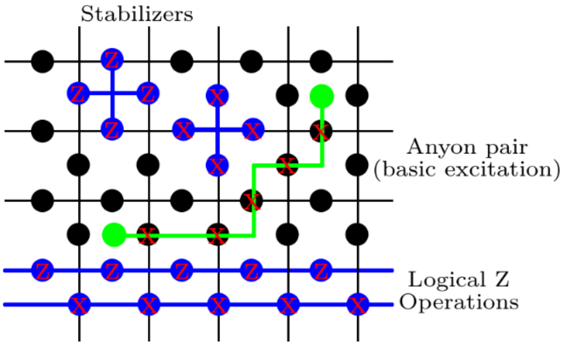

Fig 3 Steane code or the surface code

VI. SOLUTIONS

As time moves forward, industries and companies are going to look to expand into the field of quantum computing, making certain that they are the first ones to win the race, and they will be hiring individuals with a basic knowledge of quantum technology.

Schools, therefore, should take steps and ensure that their students are equipped with the basic information and practice in the same field to thrive in the quantum computing world.

Institutions can help students gain this information via two ways. Firstly, by providing the students with the resources of the latest quantum computing technologies and allowing them to use these resources to supplement their ideas and innovations. Secondly, by providing students with the opportunity to choose from a spectrum of courses related to quantum computing such as quantum mechanics, quantum algorithms, quantum programming, and quantum communication, and teaching the students the fundamental theories of these topics.

In order to counter the practical problems with the introduction of quantum computing in education, institutions can take advantage of cloud-based quantum computing platforms offered by business giants such as Microsoft and IBM. These platforms fuel the necessity of students by allowing them to be physically close to the quantum processors.

Universities can easily tackle the problem of expense by the development of quantum simulators which let students deal with quantum algorithms and learn about real-world quantum computers. Furthermore, such simulators could also potentially offer students the environment of working with an actual quantum computer.

Institutions should establish join-endeavors with leaders in the quantum business which shall help expedite the creation of Quantum Innovation Hubs (Fig 4) or related programs.

Fig 4 Quantum Innovation Hubs

VII. CASE STUDIES

The following are some of the many educational institutions where the education of quantum computing has been implemented and has turned out to be a success:

- **MIT –** The students at MIT along with the engineers currently working there discovered a new way to control atomic nuclei as qubits. Using lasers, researchers can directly control a property of nuclei called 'spin' which can encode quantum information (2023).

- **Stanford University –** The students at Stanford University in collaboration with Google Quantum AI and students at Oxford University created a 'time crystal' using Google's Sycamore quantum computing hardware. These time crystals are a type of non-equilibrium quantum phase of matter (2021).

Other such examples are entailed by many other universities such as ETH Zurich and UCL – Berkeley which have rigorous quantum computational hubs and have been recently successful in many such advancements in the same field.

VIII. CONCLUSION

In conclusion, the unstoppable expansion of quantum computing signals a revolutionary paradigm change in the field of computer science, and each institution shall ensure that its students are provided with the basic information about the field the world is progressing towards.

Quantum computing holds infinite value in cryptography, and as traditional cryptographical methods crumble, educational institutions shall face a seismic shift that will require them to incorporate such values into their students' curricula.

Teaching quantum computing in the classroom is now a need driven by the demands of individuals and industries of technological development, not merely a choice. The future of educational institutions must seriously take into consideration the elusive possibilities provided by quantum mechanics, qubits, quantum gates, and quantum circuits in order to transform the students' skills from learning about their theories to physically testing them out in laboratories.

Obviously, the inclusion of such advanced theories into the education sector cannot just happen at once, it is a slow process. But due to the innumerable capabilities and possibilities these machines hold, quantum computing shall one day become an important subject in every student's life.

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