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**Original Research Article**

# Investigation on the Significance of Incorporating Quantum Computing Technology into the Prevailing Curriculum

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**Abstract:** In conventional data processing, the use of binary bits is required. Online education is most beneficial to those who are already comfortable with technology. It's possible that classical mechanics will be replaced by quantum mechanics in near future. The processing speed of quantum computers is million times faster than that of traditional computer. Qubits are quantum bits. In the quantum technology, superposition and entanglement are important concepts. Traditional computers can benefit from the complex computational problems that are solved by quantum computing. Astrology, cryptography, and weather forecasting can all be simplified using quantum technology. Quantum theory should be studied by students majoring in Science, Technology, Engineering and Mathematics related fields. This paper discusses the advantages, applications, and tactics that can be used to enhance graduate and undergraduate courses in this rapidly expanding field of work.

**Keywords:** Quantum computing, Quantum technology, Quantum education Superposition, Entanglement, Education program, Curriculum.



## 1. INTRODUCTION

Quantum computing is one of the emerging fields to study new computational standard. Quantum engineering is broad and requires to integrate knowledge of various subjects. This new domain requires attention of new generation to study and implement something which is not possible with currently available technology of classical computing. Quantum field of research can bring new way to represent computations, science and technology. To bring the attention of new generation, quantum education is required to introduce in curriculum of Science, Technology, Engineering and Mathematics students. STEM students (Science, Technology, Engineering and Mathematics) should get introduce with the subject step-by-step. Awareness among STEM students regarding new technology is really going to create interest among students to work on quantum computers. Next section of paper highlights on how planning of distribution of subject content will be done for High-schoolers, Under-graduates, Graduates students. Understanding of quantum computing is depends upon quantum mechanism to enhance the performance of classical computing mechanism. Classical computing mechanism work on Bit or Sequence of Bits called as Bit string. Every classical Bit is either 0 or 1 which has single state for representation. Quantum mechanism will combine state 0 and 1 to formulate superposition state. This superposition state of bits is called as Qubit. Qubit is nothing but quantum bit which will be used in quantum computing. Quantum computing foundations are built on knowledge of Physics, Mathematics, Linear algebra and Computer science. Early introduction of quantum computing in parallel with knowledge of this subjects can help students to learn and work on this new standard which will be future of advance computation. In case of introduction, we have discussed about quantum computing as new technology, comparison between classical and quantum technology, various concepts associate with quantum computing such as single qubit representation such as Bloch sphere, superposition state and quantum entanglement.

### 1.1 Classical vs. Quantum Computing

Classical computer works on the principal of zero and one that is binary language for processing. But quantum computer will combine the state zero and one and cumulative state will be used for processing the data. This combine state of zero and one is called as quantum state and this combine representation of bit is called as Qubit. Quantum state is superposition of multiple qubit states. This state will be input for the quantum device. Quantum state preparation and inputting the state to the processing is used in quantum mechanism. Coupling of qubits together and used for further processing is another mechanism of quantum computers that is called as

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entanglement. Superposition and entanglement are the two mechanisms used in quantum computers.

As discussed in earlier section quantum mechanism superposition and entanglement can change the sense of looking the computations standards and methods. As quantum computers are not available for handy use but circuit-based quantum computers are available by various vendors at free of cost on online mode. There are approaches are used to work on quantum domain as follows.

- Classical-quantum model: This is one of the types which helps to deal with current situation of unavailability of machines. In CQ approach classical digital data is converted in quantum space. Classical converted quantum data will be used for processing on quantum devices. Processing of data will use fully quantum approach. Conversion of data from classical to quantum space will use various methods such as basis, amplitude and hybrid encoding. Finally output of processed data will be presented on classical models.
- Quantum-quantum model: This approach is proposed and many researchers are working and proposing various advance techniques to bring into practice. This approach requires real devices and quantum data on to it for processing.

**Table 1: Comparison between classical and quantum technology**

| Classical Technology | Quantum Technology |
|---|---|
| Classical bit used to represent data is in terms of 0 and 1. | Quantum Bit (Qubit) is used to represent data in quantum states |
| Data bits represented in single and individual state. | Quantum bit is in the superposition of state 0 and 1. |
| Computation complexity is low. | Computation complexity is high. |
| Time complexity is high. | Time complexity surely would be less. |
| Complex data modelling is difficult. | Complex and weird data behavior would be easy to model. |

### 1.2 Quantum computing concepts

#### 1.2.1. Qubit and Bloch sphere representation

Bloch sphere is used to represent single qubit on three axis planes. Bloch sphere represents pure state of quantum system which has two states together with related probability of every state.

- Superposition: This is one of quantum mechanism to represent qubit state. 1-qubit has 2 states in superposition that is 0 and 1. 2-qubit has 4 states in superposition such as 00, 01, 10, 11 and 3-qubit has 6 states in superposition such as 000, 001, 010, 011, 100, 101, 110, 111 and so on.
- Entanglement: This is another quantum mechanism which will perform coupling of qubits. Entanglement represents more than one qubit in single state. Entangled particles are having measured state, energy, momentum in perfect correlation

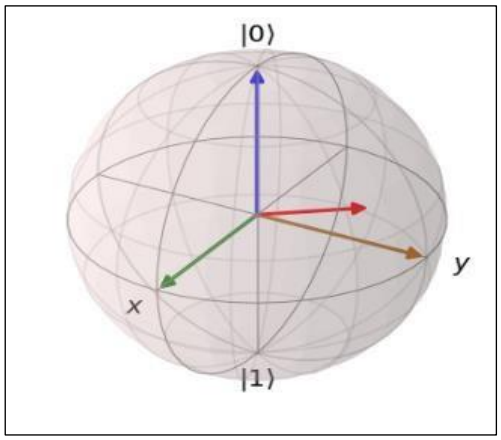


**Figure 1: Bloch Sphere Representation of Single Qubit**

Matrix representation of state $|0\rangle$ is $\begin{bmatrix}1\\0\end{bmatrix}$and $|1\rangle$ is $\begin{bmatrix}0\\1\end{bmatrix}$. State $|0\rangle$ and $|1\rangle$ in superposition represents as Eq. (1).

$$C1\begin{bmatrix}1\\0\end{bmatrix}+C2\begin{bmatrix}0\\1\end{bmatrix}=\begin{bmatrix}C1\\C2\end{bmatrix} \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Quantum physics deals with particle theory to highlights on particle state, energy and momentum. These are only the measurements of any computational standards. Qubit computation will take state and by selecting proper quantum gates measures observables is as follows.

$|0\rangle$ -----$|1\rangle$ $\begin{bmatrix}1\\0\end{bmatrix}\rightarrow\begin{bmatrix}0\\1\end{bmatrix}$ ----Quantumgates →Quantum Observables.

Quantum gates are taking qubit input and these gates are reversible in nature. There are various types of quantum gates such as Hadamard, Not, CNOT, AND, Toffoli and so on. These gates are either single, multiple qubits gates.

### 1.3 Quantum Circuit Design

#### 1.3.1 Analog quantum circuits require various gate and input data

Quantum computations are measured by performing several operations on qubit using various quantum gates. Quantum circuits are used to model the quantum computations using quantum circuits any algorithm development. Quantum circuit designed using IBM quantum circuit composer. Sample quantum circuit (Figure 2) for Bell state design using 2-qubits. Hadamard gate H is used to superposition on qubit q [0] wire and CNOT gate is used to entangle the qubit q [0] and qubit q [1].

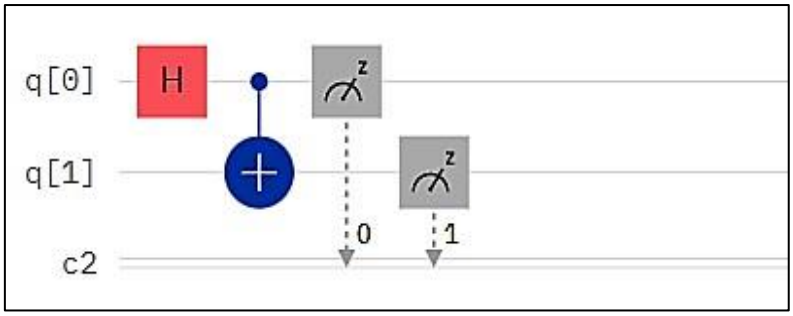


**Figure 2: Sample quantum circuit design using H-gate and CNOT gate**

This paper mainly highlights on fundamentals of quantum computations and how those can be introduced in curriculum for graduate and under-graduate students for early introduction of new and cutting-edge technology to understand its benefits and need. STEM students would get benefit about the knowledge and mechanism of these new systems and near future when commercial machines would be available, students would be able applied and use flexibly the new era of computations.

## 2. LITERATURE REVIEW

Quantum computing is going to provide solution to the highly complex problems in medical science and material science. Quantum models the solution to study weird behavior of any material and molecule. Classical solution based upon same thought can lead in terms of computational complexity. Graduate and undergraduates are learning many Physics, Chemistry courses. While learning the fundamental there is need of awareness to optimize the currently available computational solutions. Integration of any defined problem with currently available and futuristic system is need of todays curriculum. Workshops and hands-on can be conducted by experts to aware students about emerging technology. Currently quantum computers are not available on commercial basis but can be available in near future. Today's generation has more techno experts than manual thinking (Angara *et al.*, 2021). Teaching any technology is the skill in front expert but by introducing this advance technology, students would definitely develop the interest in quantum modelling. (Vishal *et al*., 2016) has suggested future developments using quantum computers. Near-term quantum devices are noisy in terms of modelling and developing solution. In this paper all the applications are discussed using quantum simulators. Distributed quantum computing is discussed in (Mingsheng, 2009) by making of algebraic language. In this manuscript, author have discussed about new technology and its benefits and available opportunities to work into it. (Vikas Haseja *et al*., 2015) discussed about emerging quantum computing and its application, platform for development and simulations. Author (Ding Gangyi, 2018) highlights on opportunities and challenged in this modern field of research. All these manuscripts are introducing need to understand quantum computer for new generation. Quantum development life cycle has several stages to begin on classical to quantum conversion of data, quantum processing and formation of analog quantum circuits is discussed by (Nivedita Dey *et al*., 2020). As we know that current computation standard is going to provide optimize solution. Discussion from classical to quantum computers requires many pre requisite courses such as Computers and its mechanism, Particle physics, mathematics, probability, Algebra. Classical computer works and mainly requires classical physics. Quantum computers work on quantum mechanism such as superposition and coupling between various superposition states such as entanglement (Shivam, 2015 and Adina, 2014). Quantum computers mainly requires to understand its weird mechanism. Paper (Aamir M, 2018) discussed about quantum algorithm and platform of implementation. IBM quantum platform is provided for hands on and real experimental work on quantum computers. IBM quantum lab provides all the resources online to work on quantum computers. IBM quantum has provided various quantum simulator on online mode. These simulators have configurations in terms of number of qubits, quantum gates, simulation types and instruction support. We have used for our experimental purpose QASM Simulator is of 32-qubit size, which is context aware and general-purpose simulator for simulating quantum circuits and also supports nose modelling. System configuration also has quantum values, circuit level operations per seconds (CLOPS), system status, number of jobs and pending job status. CLOPS basically measures the quality, speed and scales. Processor type reflects system topology and approximate qubit count. To access quantum lab, it requires to register and login to the online sources provided by IBM.

## 3. METHODOLOGY

### 3.1 Need to Include Subject in Curriculum

Need to introduce quantum computer at high-school and graduate-level studies. Fundamental and conceptual aspects are required to teach the students to improve their ability to understand the new technology. Fundamental and mathematical aspect of subject is required to add in curriculum of under-graduate and graduate studies.

### 3.2 Quantum Education for Graduates and Under-Graduates

Introduction of quantum education for Graduate, Under-graduates and high-schoolers is

challenging task because it requires to have knowledge and extensive background of several subjects such as Physics, Mathematics and Computer-science. Currently interested people are getting attracted towards this emerging field and researchers are making their groups to work on several topics in quantum computing domain. Quantum computers are next-generation computing devices which might get available in near future. This reason is sufficient to aware our younger- generation about technology by introducing curriculum in their basic studies.

### 3.3 Prerequisites and Knowledge

1. High school students: General physics with waveform, representation of digital data, Magnetic energy, power and advanced Physics should cover particle theory, particle behavior and probability.
2. Undergraduates and Graduates: Probability and method, data representation, linear algebra.

### 3.4 Course Structure

Quantum computing should get introduce to STEM students and course requirements are mentioned in following manner:

1. Quantum computing for school: Introduction of classical and quantum computing. Comparison with classical computer and quantum technology.
2. Quantum computing for Under- Graduate students: Quantum mechanics and Comparison with classical mechanism.
3. Quantum computing for Graduate students: Introduction to basic concepts in quantum computing. Physic and Mathematics required for quantum computing. Quantum models. Quantum hardware and basic programming to learn quantum devices. Small case study on application using quantum computing.

## 4. IMPLEMENTATION

Curriculum can be designed in executed in step-by-step manner that is going to boost overall research interest and confidence in younger generation. Quantum computing curriculum design steps (Figure 3) are discussed. Diagram describes how various levels of students can learn quantum computing. High schoolers, Under Graduates and Graduate should know computational theory with basic computation mechanism of classical computer, applications of classical standard. Awareness of classical computational theory and mathematics is need to fundamentals. Next level student should get introduced with quantum computing concepts and mechanism includes fundamental such as qubit introduction, superposition, entanglement and at this level students are able to compare classical and quantum theory. Then next step as per their level they should learn quantum physics, mathematics, linear algebra and computer science. Based on above knowledge students can be able to apply and build quantum models on specific problems. Quantum models' development should require to understand need of quantum solution, classical solution for same problem, and quantum benefits of problem definitions. Ahead of all this survey algorithm analysis and implementation should be done. At next higher-level student will be able to understand and select quantum applications from various domains such as cryptography, security, communication, forecasting, big data and manufacturing.

### 4.1 Learning Objectives and Outcomes

Following learning objective and outcomes are defined for betterment of outcome-based attainment.

#### *4.1.1 Objectives*

1. Introduction of quantum technology and its use.
2. Comparison between classical and quantum computing mechanism.
3. Understanding of quantum mechanism of physics and mathematics behind the quantum principles.
4. Knowledge and understanding of quantum need for any problem specific solution.
5. Analyze and design complex models those are classically unsolved.
6. Quantum computing and its applications in various domains.

#### *4.1.2 Outcome*

1. Understanding of basic quantum mechanism and quantum computing concepts.
2. Compare classical and quantum mechanism.
3. Apply quantum mechanism depending on need of solutions.
4. Elaborate quantum benefits for classically hard problem statement.
5. Compare complex quantum solution with classical solution.
6. Analysis of resource requirement to work on quantum computing.

#### *4.1.3 Challenges*

1. Lack of knowledgeable personnel in cross disciplines such as Physics, Mathematics and Computer science.
2. Quantum devices and hardware are not commercially available.
3. Lack of expertism in this integrated domain.
4. Fear about domain and its requirements.

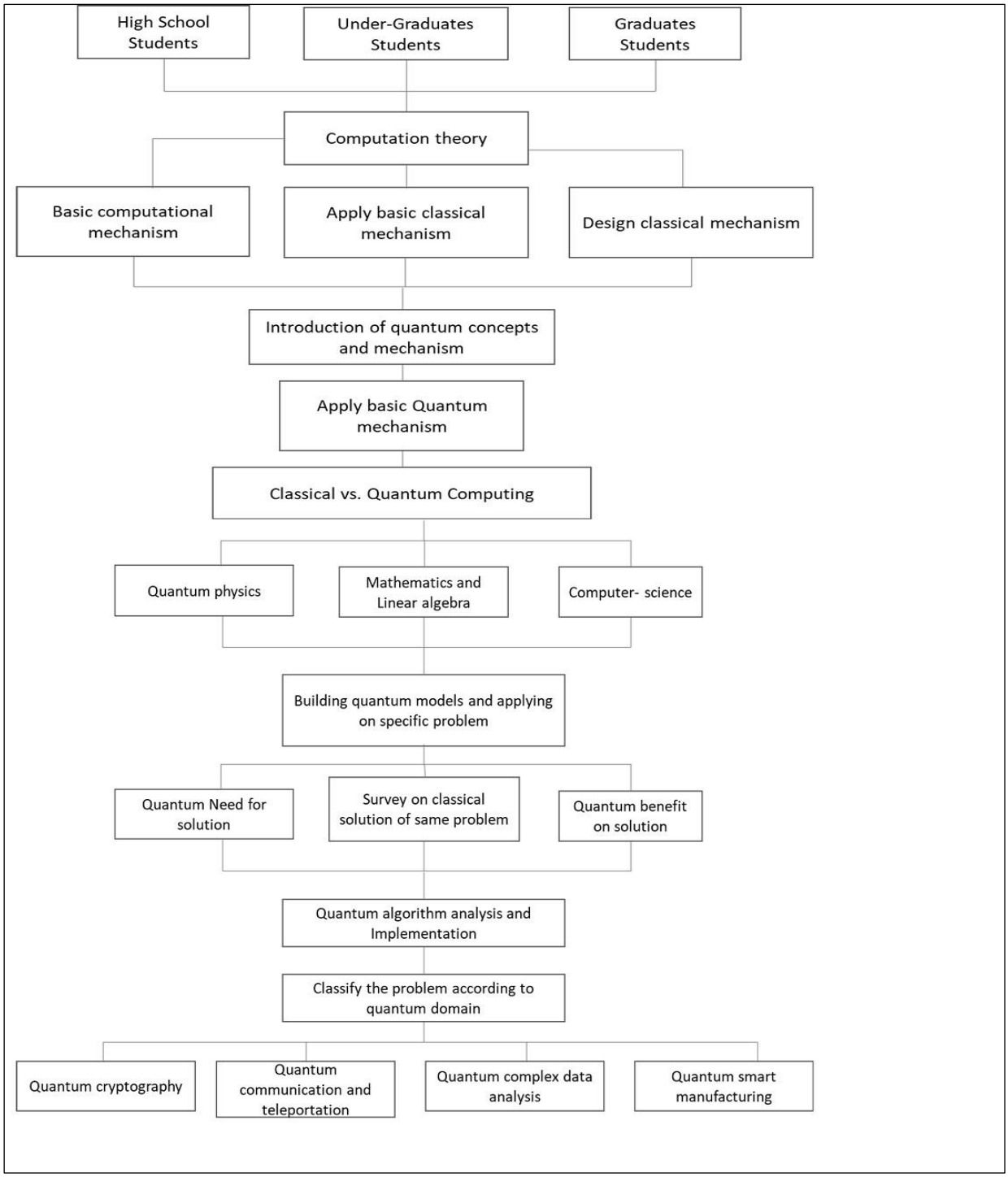


**Figure 3: Curriculum design steps for STEM education**

Curriculum design for various level of students and apply those in terms of various applications building. As quantum computing impacts the sectors like cryptography, networking, complex data analysis, material formation, medicines, molecular science and weather data analysis for accurate prediction.

## 5. FINDINGS

Our finding includes the steps to motivate students for research-based learning. In every semester with foundation course, Project based learning would be offered. Graduate should not only prepare for their theoretical presentation but they have to show their practical skills to model research-based learning.

### 5.1 Project-based learning

#### 5.1.1 Assign the project topics those are related to the cutting-edge technologies.

Students should be able to work on modelling their theoretical and fundamental skills in terms of practical knowledge by utilizing their technical skills, by

making use of available technology and high-speed computational methods.

### *5.1.2 Use of Classical-Quantum model for articulation of the system*

Classical-quantum approach is used to model and to work on the system (Figure 4). In this approach classical data is given as input and converted in quantum space by making use of various encoding methods. As mentioned above. Quantum cloud access required to register online on Quantum lab. Various cloud quantum service providers are available. We can login to their devices and perform working on quantum services. Quantum programming tools are also available. This is another subject perquisite in terms to understand how code can written to by using various programming platform to work on quantum computers. Students can learn various programming languages to code on quantum computer to simulate their task and ideas.

Quantum computing concepts such as qubit, Bloch sphere, superposition and entanglement are base to work on domain. Following equations are used to represents qubit and superposition states. Quantum data input requires state preparation of classical data. Q-data is prepared and fed to the quantum states for further processing**.**

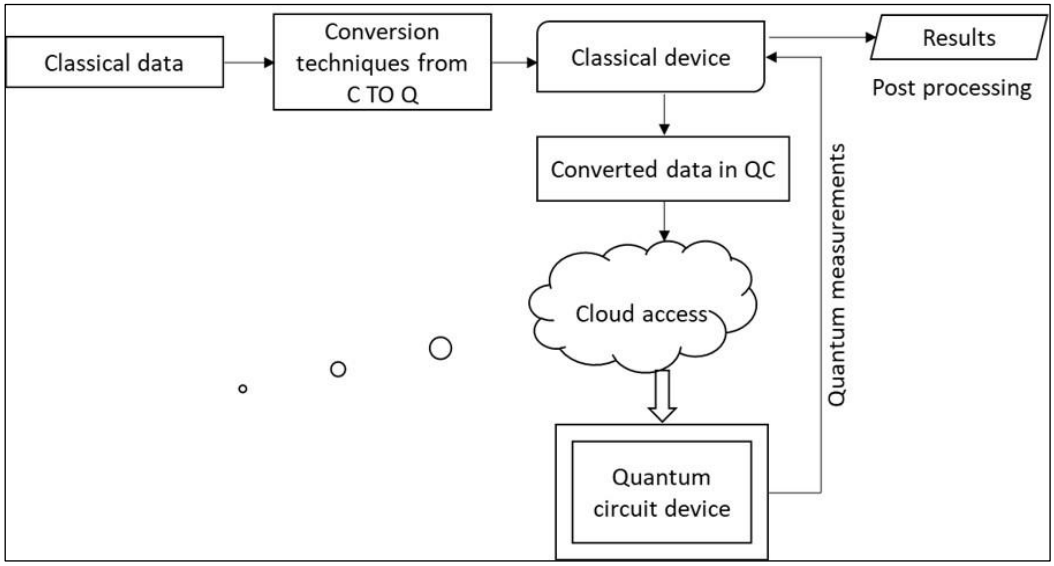


**Figure 4: Classical-Quantum model**

### 5.2 Evaluation Criteria

Graduate would be able to perform their practical skills in defined problem statement. Students would be evaluated for knowledge in the obtained domain, skills, practical knowledge, literature review, accurate gap findings, system modelling and technology used (specially quantum mechanism). Marks given based upon the problem definition, analysis, system design, modern tool selected, societal use of model, ethics and finance, documentation, life-long learning skill attained (Table 2).

**Table 2: Evaluation criteria for project-based learning using cutting-edge technology**

| Parameters for evaluation | Students' attainment |
|---|---|
| Problem formulation and its scope | Students should be able to write problem formulation accurately. |
| Analysis and feasibility study | Defined prototype should be feasible and accurate literature analysis would be done for proper gap findings. |
| Design and implementation of given problem | Design the system model and implement the same for deployment and use. |
| Modern technology and its benefit | Selection of modern tool and its uses to benefit the system in terms of time and space complexity. |
| Societal aspect and environmental impact | Graduate would be able to define system's societal benefit and consequences and also environment impact analysis. |
| Ethics and finance | Assurance about ethics is followed and also cost estimation for idea and implementation would be measured. |
| Documentation and Reporting and presentation skills | Reporting and presentation skills would be tested at this level of evaluation. |
| Life-long learning skills attained | Lifelong learning from given modelling is evaluated at last level of evaluation. |

## 6. DISCUSSION

### 6.1 Future of quantum technology

Educating more students with quantum computing is definitely the need. Understanding and learning technology among students can lead to find more discoveries with new technology. World is changing its need in case digitization in kore faster manner and to fulfil the need of advance technology for faster computations and communications quantum computing is the answer. Complex calculations for weird and unanalyzed formats can be studied using quantum solutions. Quantum computing can provide solution in such aspects where classical solution will not work. Several computation requirements are failing because of current technology. So, every school, academic institute, university should introduce students with quantum computing and its benefits.

### *6.2 Tools for study*

Various vendors are coming ahead and investing into quantum hardware. Leading companies such as IBM, Microsoft, Google, Riggetti are the one who are making available their services online. Quantum computing documentation and internships are also conducted by their researcher team or instructors on online and offline mode. IBM quantum team of researchers are lead in providing all new theories and updating related to quantum digital world for students. IBM qiskit platform can be used to simulate on quantum machines. These simulators can work like real quantum devices to work and experiment on it. To understand the quantum hardware IBM quantum cloud services are the best medium to work on quantum computers.

### *6.3 Quantum research in India*

Indian government announced big budget for research on quantum computer for span of five years. Quantum researchers are grouped under the Q-India Slack Platform. They share their thought and work strategies with quantum knowledge seekers through this platform. Quantum computer can supercharge artificial intelligence at larger scale. Research in quantum computing is really going to change our lives. Quantum work will be proposed in such manner of computations where classical solution is hard to implement. Following points will highlight how quantum computer will change our lives.

1. Diagnose illness at early stage.
2. Quantum algorithm with exponential speed-up.
3. Quantum communication and networks.
4. Quantum weather prediction.
5. Secure financial transactions.
6. Health and agricultural sector.

United State, China, Japan, Germany and Canada are leading investors for research in this field.

### 6.4 Quantum Supremacy

Quantum supremacy is announced by various countries and their respective brands. They are claiming as quantum computers are trillion times powerful than world's fastest supercomputer. Google quantum computers publish quantum supremacy on cryptography algorithms implementation. Quantum computers are not available on commercial basis but IBM quantum have provided the platform learners and researchers to experience hands on using quantum simulators. By accessing the quantum cloud hardware on online mode, they can experience real quantum device for experimental work. IBM quantum machines are available on online cloud platform mode. General public can access and learn quantum computer by registering on IBM quantum lab. IBM quantum also provided with basic documentation and IBM is in lead to provide quantum education to worldwide students those are interested in quantum education and research. Global school on Quantum computing and Quantum machine learning is organized in 2020 and 2021 respectively by IBM.

### 6.5 Quantum computing scope and applications

Complex field of research like simulation and analysis of molecules for drug development on various complex disease, material design, Quantum cryptography, quantum simulation, Quantum effective AI, Complex data analysis, big data processing, Quantum communication, whether forecasting and climate science are elaborated further.

1. Drug development and molecular science: Quantum computing will help in this domain to analyze complex molecules for drug development which will either predict disease early or cure the patient at any stage of disease.
2. Material science and design: Quantum computing help to design new material and change this domain by helping in discovery of new material.
3. Quantum cryptography: Cryptography will establish secure data transfer between sender a receiver. Quantum cryptography will secure key distribution between both parties using Quantum key distribution (QKD).
4. Quantum simulators: Programmable digital devices can solve large and complex task using quantum mechanism.
5. Big and complex data analysis: Quantum computer can be used to process big data and also from complex data analysis, we can be able to analyze the weird patterns that can be computable by classical computer.
6. Quantum effective AI and ML: Quantum computers can boost artificial intelligence and machine learning by enhancing currently available ML techniques.
7. Quantum communication: Information processing and teleportation can be achieved using classical and quantum channels to propose faster and more secure communication by using entanglement effect.

8. Quantum Whether forecasting and climate science: Whether prediction and result analysis are still time complex on classical devices. Quantum computing in near future can do accurate and timely forecast which can be used for predictive managements on natural disasters.
9. Quantum machine learning provides the optimized solution to current classical machine learning. As QML is using high-dimensional feature space for data representation which is classically complex task. Data encoded from classical to quantum states by using quantum feature space by applying rotations on features, entanglement methods for coupling between the features. The enhanced feature set provides very deep learning on given data. QML represents data on very dimensional feature space which helps to understand data on its depth. Classical computers are not able to perform certain data processing which is mentioned here. Therefore, Quantum computers are the solution.

## 7. CONCLUSION

World is moving towards digitization and automation of each task to complete in faster and convenient manner. Schoolers to professional at every stage requires to be super-active and techno savvy while using technology. We have seen during Global pandemic situation, the importance to digital devices and communication. Technology will prepare us to fight with same kinds of situations in future to get better prepared for it. We are aiming towards various cutting-edge technologies to understand and use in day-to-day life. Upgradation in new digital world is required to reach all generations in timely manner. Quantum computing is not just an emerging technology but this standard will change our live in broader scale. Understanding and awareness of new technology from schoolers to college graduates to professional by one and other way is need of future education of any country. Motivation behind quantum education in our country is appreciable. Researchers and knowledge seekers should take benefit of this and help to discover more knowledge and opportunities. Quantum computing in current education impact on awareness of new technology for current generation students. As quantum computers are becoming the technology innovation and how students will grasp this new computational model to perform computer implementations. Our idea is going to create awareness among students through today's education system regarding modern quantum computers those are going to solve the computationally difficult and challenging problems.

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