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QuantumLeap: Empowering Mobile Quantum Computing and Learning

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Abstract

Quantum computing holds immense potential but remains inaccessible due to its complexity and hardware requirements. This research aims to improve accessibility by developing a mobile application using Unity for the front-end and Qiskit for server-side quantum computations. The Unity-based interface offers an intuitive and interactive user experience, making quantum concepts more approachable. Qiskit handles the quantum computations on a server, allowing users to run quantum algorithms in real-time. This project seeks to democratize quantum computing, providing an engaging platform for educators, students, and enthusiasts to explore and learn about quantum technology.

Keywords: quantum computing, mobile application, Unity, Qiskit, accessibility, interactive learning

CHAPTER 1: THE PROBLEM AND ITS BACKGROUND

1.1. Introduction

Quantum computing, with its promise of exponential computational power, has emerged as a transformative technology with vast potential across various fields. However, the accessibility and intuitive learning resources for quantum computing remain significant challenges.[1] Presently, the execution of quantum computing tasks typically requires specialized hardware or non-mobile interfaces, limiting access for many aspiring learners and enthusiasts.[2] Moreover, the scarcity of comprehensive educational materials further compounds these barriers, hindering the widespread understanding and adoption of quantum computing.

To address these challenges, we present QuantumLeap, a pioneering mobile application designed to democratize access to quantum computing and facilitate intuitive learning experiences. QuantumLeap leverages the ubiquity and versatility of mobile devices, enabling users to perform quantum computing tasks directly on their smartphones or tablets. By eliminating the need for specialized hardware or non-mobile interfaces, QuantumLeap significantly lowers the entry barrier for individuals interested in exploring quantum computing.

Moreover, QuantumLeap goes beyond mere functionality by integrating a rich array of educational resources and interactive challenges. Through curated learning materials, tutorials, and hands-on exercises, users can navigate the complexities of quantum computing in a structured and accessible manner. Notably, QuantumLeap features the implementation of Grover's Algorithm solver, a fundamental quantum algorithm renowned for its efficiency in unstructured search tasks.[3] By incorporating this powerful algorithm within the application, QuantumLeap empowers users to experiment with quantum algorithms firsthand, fostering a deeper understanding of quantum computing principles and applications.

1.2. Background of the Study

Quantum computing is an emerging technology that comprises aspects of computer science, physics, and mathematics, utilizing quantum mechanics for the faster solving of complex problems compared to a classical computer. It is a vast multidisciplinary field of study that will continually be further developed and relevant as technology progresses. Quantum computing has a wide range of applications, such as Drug Discovery and Molecular Simulation, as through quantum computing, modeling of complex chemical reactions, prediction of drug interactions, and acceleration of discovery processes would be possible. Another important application of quantum computing would be in the improvement of Security and Cryptography, as it has the potential to break classical encryption algorithms such as the RSA encryption and Elliptic Curve Cryptography (ECC) algorithms, which are some of the most secure and common used algorithms for secure communications and digital signatures.[4] In only about 25 years of development, quantum computing has already demonstrated numerous applications.

But despite its immense promise, accessibility to quantum computing remains limited to a few countries, some of which are the United States, Japan, and China, mostly first-world countries that are known for their power in economy and technology.[5] This limitation has motivated the researchers to conduct this study, to provide learners and enthusiasts with an opportunity to gain knowledge in quantum computing, as reliance on traditional education regarding theoretical explanations and complex mathematical formulations is challenging when physics and computer science are involved, where hands-on experiences are essential for these fields of study.

1.3. Statement of the Problem

Since the transition of society from traditional onsite learning to a remote modality because of the COVID-19 pandemic, education has never been the same, Solutions were implemented by governments worldwide to provide ease of access to students who found it challenging to continue their studies.[6] This same concept can be applied to the problem faced in this study being conducted. The limited number of quantum computers and facilities for experimentation further add difficulty in providing experiential learning to practice, this problem is also faced by the researchers of this study, being third-year students taking the BS Computer Engineering (BSCpE) Program, studying this emerging technology is helpful in the researchers' understanding and knowledge of the technology of tomorrow.

Learning about quantum computing is challenging due to its abstract concepts and lack of accessible educational resources. To address these challenges, there is a growing need for innovative solutions to cater to the demand for opportunities to learn quantum computing concepts and offer interactive learning experiences through experimentation using virtual environments. The development of mobile application software can be used to bridge the gap between theory and practical understanding of quantum computing.[7] By utilizing the capabilities of modern smartphone technologies, interactive visualizations, simulations, and educational resources would be possible. As this study continues to be conducted, the further picture of the significance and relevance of developing this software can fully be grasped, the impactful initiative of this study can be revolutionary to the improvement of quantum education, and the inspiring of individuals to explore the beauty of quantum computing anytime and anywhere.

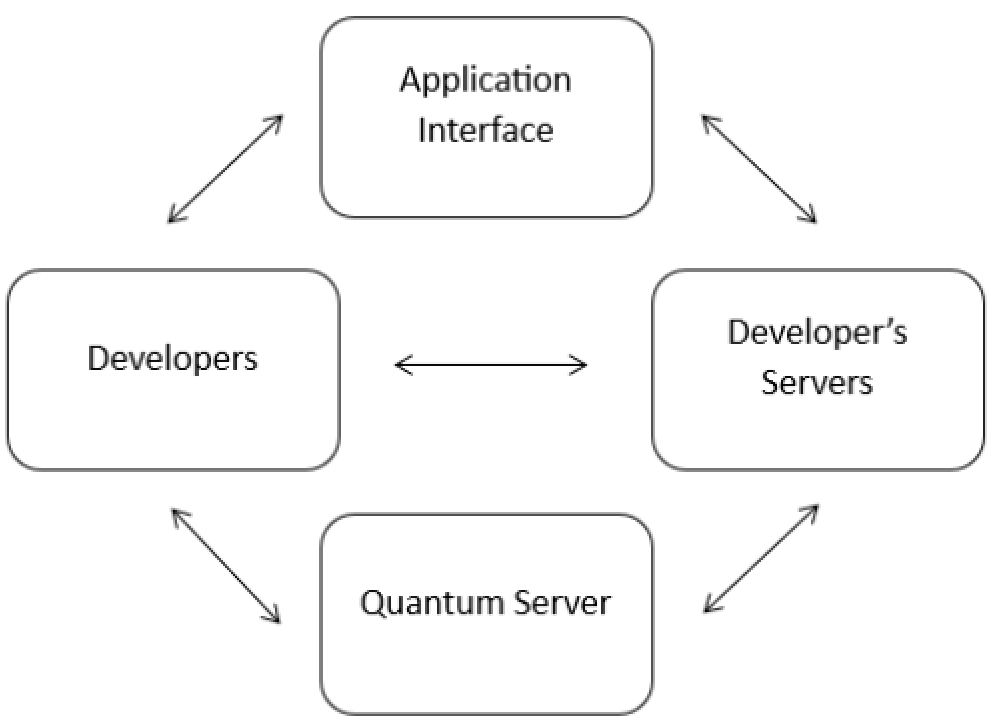
1.4. Objectives of the Study

The objective of this study is to develop a mobile application capable of emulating the fundamental principles of quantum computing.

1.5. Significance of the Study

For a Quantum computer to work, it needs to reach a state called superposition which represents all of the possible representations of qubits.[8] For a supercomputer to reach this state, it needs special apparatuses with the right configuration. With the emulation of this supercomputer performing quantum computing would be widely accessible and minimize the time to complete quantum-related tasks. This study enables students and non-physicists to access, perform, and demonstrate quantum computing-related tasks.

1.6 Conceptual Framework



This conceptual framework outlines a dynamic system where the mobile app serves as a gateway for users to interact with simulated quantum tasks hosted on a dedicated server. It emphasizes the collaboration between developers, computational resources, and user interaction to achieve the objective of emulating quantum computing fundamentals on a mobile platform.

1.7. Scope and Limitations of the Study

This research will focus on the systems of the application and on the implementation of the functionality inside the application relating to quantum computing, learning materials and challenges will be created to teach people with zero knowledge about quantum computing, and we will be implementing Grover's algorithm solver to verify that the application is working properly.

This study will not be covering problems relating to the unavailability of the simulation, we will be using IBM Composer for the simulation of quantum computing, we will also not be covering topics relating to device compatibility and internet connectivity issues.

CHAPTER 2: REVIEW OF RELATED LITERATURE AND STUDIES

2.1. Related Literatures and Studies

This literature review aims to survey existing studies and tools in the field of quantum computing, particularly focusing on mobile applications, unity as a learning tool, and quantum algorithms. By examining the strengths and limitations of previous studies, this review seeks to identify gaps in current offerings and opportunities for innovation in the development of a mobile application tailored for quantum computing simulation, education, and exploration.

2.1.1 Introduction to Quantum Computing

Quantum computing (QC) represents a paradigm shift in computational science, harnessing the principles of quantum mechanics to potentially outperform classical computing in various domains [10]. Its applications span across industries, offering developing potential in cybersecurity, materials science, pharmaceuticals, finance, and advanced manufacturing [9]. This rapidly increasing field has prompted the formation of agencies like the Quantum Technology and Application Consortium (QUTAC), aimed at advancing the quantum computing ecosystem with members from multiple sectors of societies such as automotive manufacturing, pharmaceutical production, insurance, and technology [11]. Although promising, challenges in this emerging field persist, most notably in the area of quantum verification, where ensuring the accuracy and reliability of quantum computations remains a pressing concern [12], despite these difficulties, the great promise of quantum computers, along with the challenges and its usefulness, prove to be compelling as quantum computing development continues [13], particularly as what can be possible through the demonstration of what can be done by the collaborative power of a distributed quantum computing ecosystem [14]. Fields like computational chemistry and materials science are on their way to revolutionary advancements, empowered by the computational capabilities possible through quantum computing [15]. However, as shown by the growing demands on classical resources needed to support quantum systems, the road to scalability is filled with obstacles [18]. In this study, we will take a look at one of the real-world applications that can be used and be accessible to people, which can give us a glimpse into the ability to build systems that can go beyond the limits of what can be classically simulated[17], and which enable cloud-based research for a wide range of scientists, thus increasing the pool of talent exploring early quantum systems [16].

2.1.2 The Effectiveness of Blended Learning in Mobile Platform

Blended learning has become the preferred approach to teaching and learning in recent years, largely due to the global impact of COVID-19. This approach, which integrates traditional classroom instruction with online resources, has been particularly effective in fields like engineering and medicine when combined with mobile platforms [19]. Mobile education has evolved significantly, becoming more diverse, powerful, and complex, according to current research [20]. Studies, such as the one conducted by the University of Hradec Králové, have shown that studying languages via smartphones can enhance students' performance [21].

In higher education, the development of mobile applications has become crucial. Mobile technologies have become one of the most important areas of research for educators, offering new ways to engage students and enhance learning experiences [22].In a study by Delgado-Cepeda and Enríquez-Flores, mobile learning was used to attract students to quantum information research, yielding positive results by piquing students' interest in the subject [23].

Additionally, their research on "Quantum learning without quantum memory" simulated a fundamental instance of quantum state identification, highlighting the limitations of quantum computing without the necessary hardware and the importance of simulation applications for a better understanding of quantum states [24].

Quantum computing algorithms have found various applications, including Artificial Intelligence Mobile Network Optimization [25], Mobile Robot Order Picking and Batching Problem Solver Optimization [26], and Malware detection [27], among others. These applications are integrated into mobile devices, such as smartphones, but quantum computing itself occurs at an algorithmic level, requiring simulations of the actual hardware for understanding [28]. Therefore, there is a need for educational applications that can teach students how to understand quantum computing concepts.

2.1.3 Unity Platform as a Learning Tool

Recent years have witnessed a surge in the popularity of Unity, a versatile gaming engine renowned for its professional capabilities and multi-platform support [29]. Its suite of features, ranging from audio and video to advanced graphics and physics simulations, facilitates immersive user experiences [29]. Leveraging the widespread appeal of video games, studies suggest that gaming, when utilized effectively, holds immense potential for disseminating information [30]. Unity's animation module enables detailed storytelling within created games, enhancing narrative immersion [31]. Moreover, modern game engines like Unity 3D offer promising avenues for developing educational tools in fields such as computer science and engineering [32]. Combining situated learning approaches with tutorials, teacher guidance, and collaborative activities, Unity-based gamification emerges as a compelling method for education

[33, 34]. Unity's cross-platform capabilities further extend its utility, allowing learners to engage in block-based programming within immersive game environments [35]. Meanwhile, in the realm of quantum computing education, pioneering initiatives such as IBM's Q Experience and specialized tools like Qiskit, Cirq, QDK, and Forest are shaping the landscape [37, 38]. Digital game-based learning (DGBL) is increasingly recognized as an engaging approach to fostering student motivation and understanding [36]. With Unity's robust features and the advancing frontier of quantum learning tools, the synergy between gaming technology and education is poised for significant advancements.

2.1.4 The Future of Computing: Quantum Algorithms

Quantum Computing is the future since it is faster than classical computers. That is why people must have accessible learning materials. Recent studies have shown theories and applications of quantum computing in various fields. Improvements to quantum computing through [39] efficient quantum computing processing, [40] parallel and distributed quantum computing, and [41] multi-core quantum computing architectures.There are also proposed uses of quantum computing in different sectors, like [42] vehicle routing problems, and [43] revolutionizing space exploration. These studies too aim to improve the efficiency of computing applications that are used from day to day such as [44] implementation of Grover's algorithm in hash function which is used in cryptography, in [45] association rules mining used in machine learning, [46] using quantum computing in addressing challenges in chemical simulation and drug discovery and in [48] complex optimization problems from supply chain management [47]. In addition, some studies aim to provide quantum software as a service(QSaaS). These studies show how quantum computing can revolutionize different industries and increase productivity, which is why it is crucial to provide adequate learning platforms for quantum computing.

2.1.5 Conclusion

In summary, bringing mobile learning into education has been a big change, providing new ways for students to get involved and learn. There is a gap in quantum computing availability in mobile platforms. In the world of quantum information research, using mobile learning could help get students interested and help them understand difficult quantum ideas better. This could lead to progress in this advanced field.

2.2. Research Paradigm

Researchers opt for the design science research paradigm in the context of quantum computing on mobile devices due to its suitability for developing innovative technological solutions to complex problems. Design science research emphasizes the creation of practical artifacts to address real-world challenges, aligning perfectly with the objective of creating a mobile application for quantum computing emulation. This paradigm allows researchers to systematically design, implement, and evaluate the functionalities of the mobile application, ensuring that it accurately simulates fundamental principles of quantum computing while remaining user-friendly and efficient on mobile platforms. By following iterative cycles of design, implementation, evaluation, and refinement, researchers can iteratively improve the application's performance, usability, and relevance to the target users. The design science research paradigm's structured approach provides a clear framework for integrating theoretical knowledge of quantum computing with practical software development processes, ultimately leading to the creation of a functional and valuable tool for exploring quantum concepts on mobile devices.

2.3. Hypothesis

Null Hypothesis: The application was not able to emulate the fundamentals of quantum computing.

Alternative Hypothesis: The application was able to emulate the fundamentals of quantum computing.

2.4. Assumptions

2.4.1 Technical Assumptions

Computational Power: Mobile devices or connected servers have sufficient computational power for accurate quantum computing simulations.

Software Compatibility: Chosen programming languages, frameworks, and libraries are suitable for implementing quantum computing algorithms effectively.

User Interface: The mobile application's interface is intuitive and accessible for interacting with complex quantum computing concepts.

2.4.2 User Assumptions

User Interest: There is a user base interested in learning and experimenting with quantum computing through a mobile application.

User Proficiency: Users may have varying levels of familiarity with quantum computing, requiring adaptable app features.

Usability Expectations: Users expect meaningful insights into quantum computing principles while finding the app user-friendly.

2.5. Definition of Terminologies

Augmented Reality (AR): A technology that overlays digital information, such as images or text, onto the real-world environment, typically viewed through a device such as a smartphone or AR glasses.

Decoherence: The process by which a quantum system loses its coherence and becomes more like a classical system, often leading to errors in quantum computations.

Entanglement: A phenomenon in quantum mechanics where two or more particles become correlated in such a way that the state of one particle cannot be described independently of the state of the others, even when separated by large distances.

Grover's Algorithm: A quantum algorithm that can search an unsorted database of N items in $O(\sqrt{N})$ time, exponentially faster than classical algorithms.

Learning Management System (LMS): A software application or web-based platform used to manage, deliver, and track educational courses and training programs.

Mobile Application Development: The process of creating software applications that run on mobile devices, such as smartphones and tablets, often using specific programming languages and development environments.

Noisy Intermediate-Scale Quantum (NISQ) Computing: A term used to describe current quantum computers that are not yet fully error-corrected but are large enough to perform useful computations.

Quantum Circuit: A sequence of quantum gates applied to a set of qubits to perform a quantum computation.

Quantum Error Correction: Techniques used to mitigate errors in quantum computations caused by decoherence and other noise sources.

Quantum Gate: A basic building block of quantum circuits, similar to classical logic gates, that operates on qubits to perform quantum operations.

Quantum Supremacy: The hypothetical point at which a quantum computer can perform a task that is beyond the capabilities of the most powerful classical computer.

Quantum Teleportation: A process in which the quantum state of a qubit is transmitted from one location to another, without physically moving the qubit itself.

Quantum Volume: A metric used to quantify the computational power of a quantum computer, taking into account the number of qubits, error rates, and connectivity.

Qubit: The basic unit of quantum information, analogous to a classical bit but with the ability to be in a superposition of states, representing both 0 and 1 simultaneously.

Shor's Algorithm: A quantum algorithm that can factorize large integers exponentially faster than classical algorithms, with implications for breaking classical encryption schemes.

Synchronous Learning: A type of learning where students and instructors interact in real-time, such as in live online classes or webinars.

Superposition: A fundamental principle of quantum mechanics where a quantum system can exist in multiple states simultaneously until measured, unlike classical systems which can only be in one state at a time.

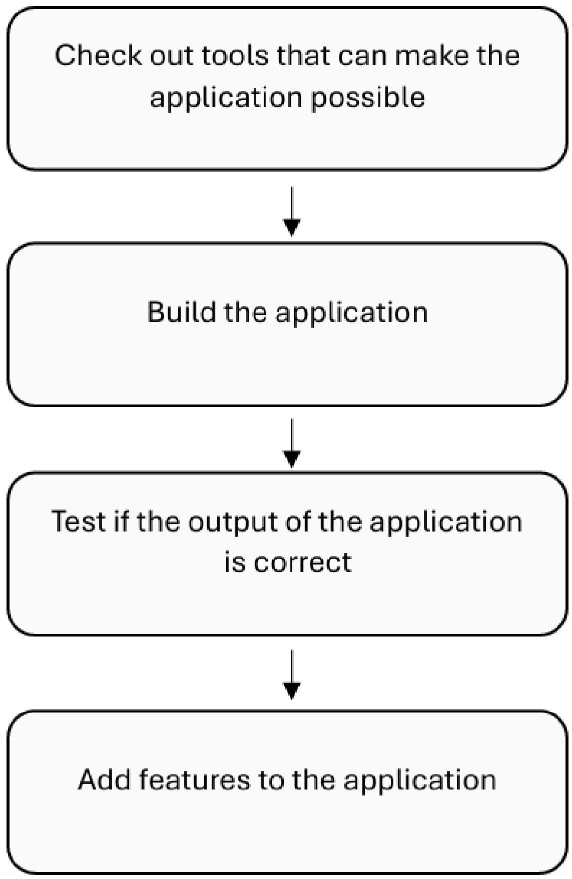
Unity Asset Store: An online marketplace where developers can buy and sell assets, tools, and plugins for use in Unity projects.

Unity Scripting: The programming language used in Unity to create interactive behaviors and functionality for games and simulations.

Virtual Reality (VR): A technology that immerses users in a simulated environment, typically viewed through a head-mounted display, providing a sense of presence in the virtual world.

CHAPTER 3: METHODOLOGIES

3.1. Research Design



The research design entails an iterative process beginning with tool selection such as Qiskit for quantum computing functionalities, Python for backend logic, Unity for user interface development, and socket connections for communication. Integration of these tools forms the foundation for developing a mobile application to emulate quantum computing principles. Initial development focuses on core functionalities, testing rigorously to ensure accurate quantum computations, and validating outputs against expected results. Upon successful validation, iterative feature additions follow, guided by user feedback and research insights to enhance simulation capabilities, improve user interface elements, and overall user experience. Continuous testing, feedback loops, and performance optimizations drive ongoing improvements, allowing for a stable and effective mobile application that remains at the forefront of quantum emulation on mobile devices.

3.2. Research Locale

The testing and validation of the mobile application were conducted within the familiar environments of our personal homes, utilizing both personal computers and mobile devices. This approach ensured a comprehensive assessment of the application's functionality, performance, and user experience across different platforms. By leveraging our personal computing setups, which include a range of devices and operating systems, we were able to simulate real-world usage scenarios and gather valuable insights into the application's behavior under varied conditions.

3.3. Methodologies

The data collection methodology in this research involved direct interactions with both the developed mobile application and its corresponding web browser-based tool. This encompassed coding, debugging, and testing processes aimed at ensuring the accurate emulation of quantum computing principles. Validation procedures were employed to verify algorithm correctness and computational outputs against established quantum principles. Systematic testing and retesting procedures were then conducted to validate result consistency across platforms. The evaluation process entailed qualitative analysis of outputs to assess accuracy and performance, providing valuable insights into the efficacy of the mobile application in emulating quantum computing principles compared to the web browser tool.

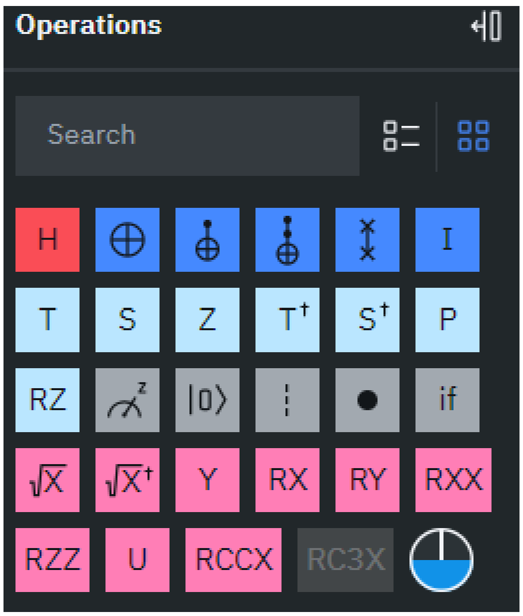
3.4. Statistical Treatment Used

The statistical treatment used in this study involved a comparative analysis of results obtained from the mobile application and web browser versions of the quantum computing emulation tool. Given the nature of the research, which primarily focused on assessing result consistency across platforms, statistical methods such as descriptive statistics and correlation analysis were not applicable. Instead, the study relied on qualitative assessments of similarities and differences in outputs to determine the equivalence of computational results between the two environments.

CHAPTER 4: DATA PRESENTATION, ANALYSIS AND INTERPRETATION

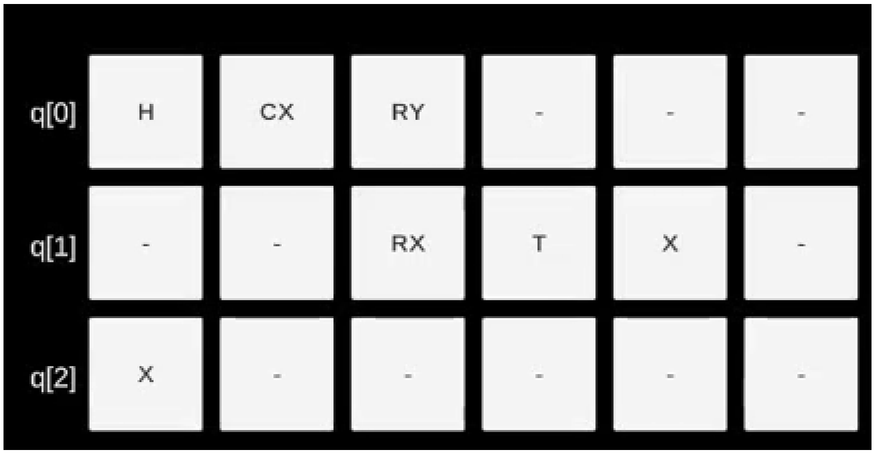
4.1. Presentation of Data

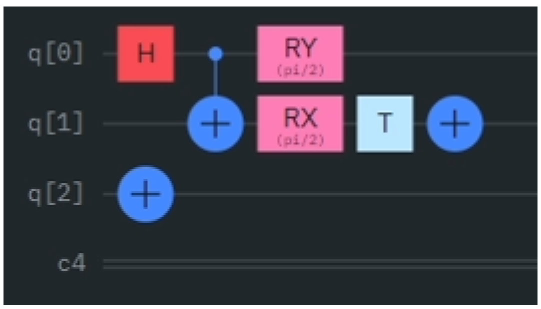
4.1.1 Operations

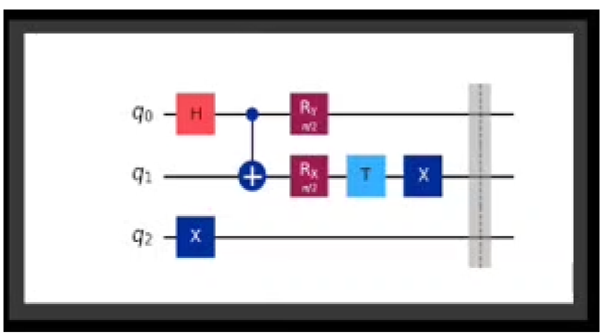


The 1st image is from IBM Quantum Composer and the second image is from the app. We are able to select the gates by pressing what type of gate we want.

4.1.2 Circuits

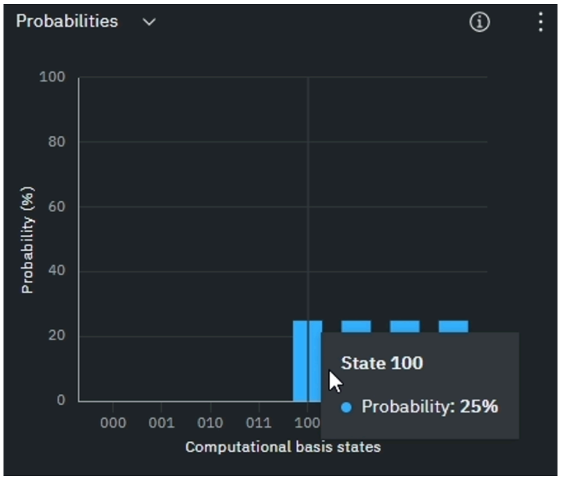


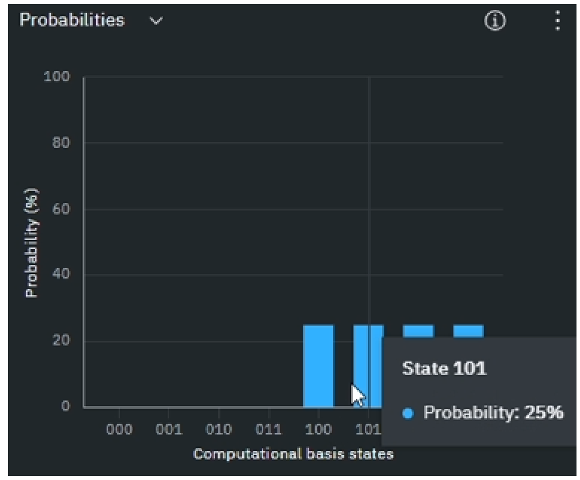


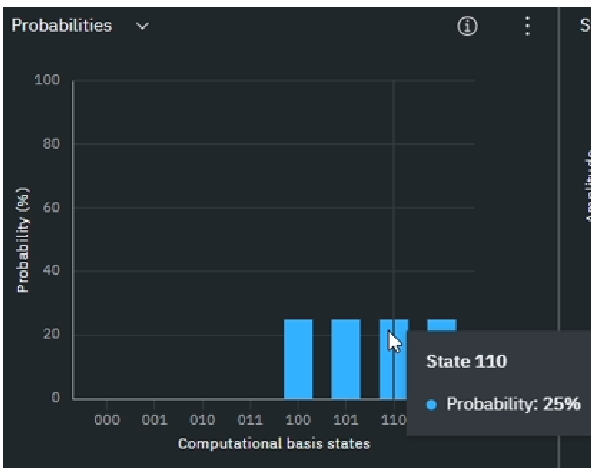


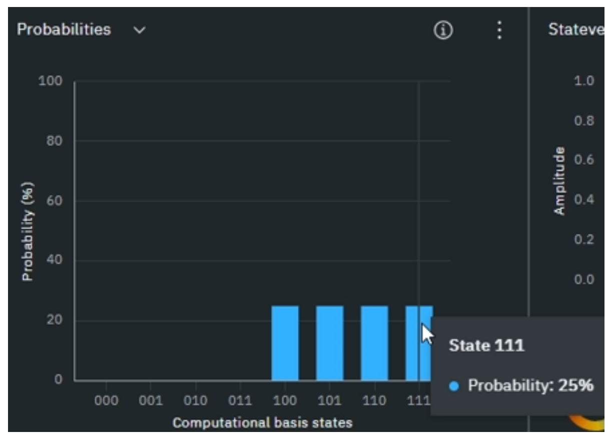
The 1st image is from the app after we select the gate we select the part of the circuit we would like it to be. The 2nd image is from IBM Quantum Composer it uses a drag-and-drop system. The 3rd image is from the app it is the resulting image from the server.

4.1.2 Probabilities





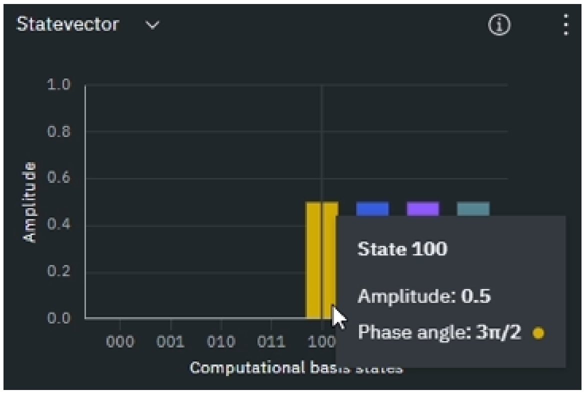


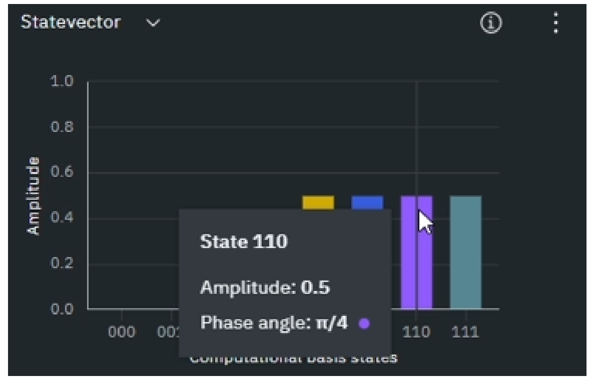


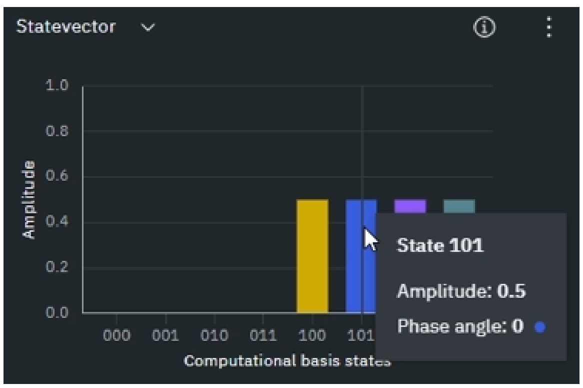
Basis State	Probability	Amplitude	Phase Angle
|000>	0.0	0.0	0
|001>	0.0	0.0	0
|010>	0.0	0.0	0
|011>	0.0	0.0	0
|100>	24.96	0.5	6π/4
|101>	24.79	0.5	0
|110>	25.08	0.5	1π/4
|111>	25.17	0.5	7π/4

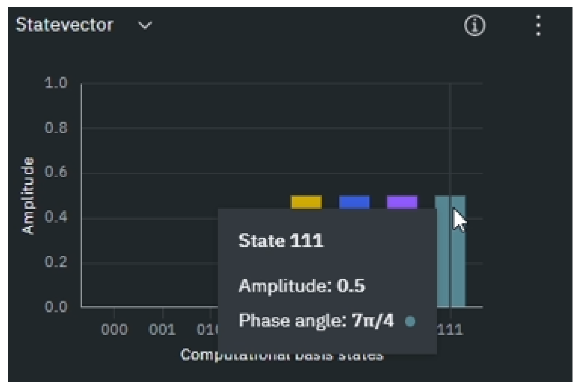
The 1st 4 image are from IBM Quantum Composer and when we compare it to the 5th image from our app the probabilities are the same. Not exactly 25% because it is a simulation with 100,000 shots.

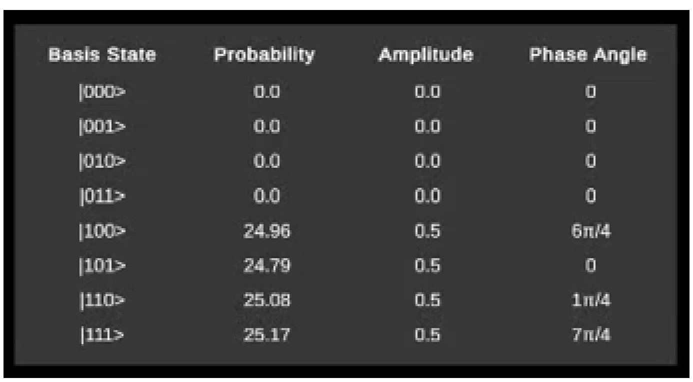
4.1.2 Statevector











Basis State	Probability	Amplitude	Phase Angle
|000>	0.0	0.0	0
|001>	0.0	0.0	0
|010>	0.0	0.0	0
|011>	0.0	0.0	0
|100>	24.96	0.5	6π/4
|101>	24.79	0.5	0
|110>	25.08	0.5	1π/4
|111>	25.17	0.5	7π/4

The 1st 4 image are from IBM Quantum Composer and when we compare it to the 5th image from our app the amplitude and phase angle are the same. Note that 3pi/2 and 6pi/4 are the same.

CHAPTER 5: SUMMARY OF FINDINGS, CONCLUSIONS AND RECOMMENDATIONS

5.1. Summary of Findings

The findings in Chapter 5 confirm that the mobile application's results align closely with those from the IBM Quantum Composer, demonstrating consistency in probability, amplitude, phase angle calculations, and circuit image presentation.

5.2. Conclusions

In conclusion, we have successfully developed a mobile application that enables users to compose a quantum circuit within the app, transmit it to a server for quantum computation, and receive the processed results back onto the mobile platform.

5.3. Recommendations

Our recommendation includes enhancing the quantum circuit creation process by incorporating additional types of gates and offering increased customization options for gate parameters.

5.4. Areas for Further Study

Explore Quantum Machine Learning at the intersection of quantum computing and mobile platforms, crafting algorithms for enhanced machine learning tasks. This fusion harnesses quantum capabilities to optimize learning processes and computational efficiency on mobile devices, promising novel advancements at the nexus of quantum computing and artificial intelligence.

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