

# Interactive Visualization of BB84 Protocol for Teaching Quantum Cryptography

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## 1. Introduction

The abstract and complex nature of quantum computing presents significant challenges for higher education, necessitating alternative didactic methods to improve teaching, particularly in sub-areas like quantum cryptography [Haghparast et al. 2024]. Quantum Key Distribution (QKD) protocols, such as the seminal BB84, are fundamental but often difficult for students to visualize and comprehend. While simulation tools have been shown to reduce cognitive barriers in abstract topics [Angara et al. 2021], a gap remains in accessible, interactive resources for learning QKD. To address this, this work presents the development and evaluation of an interactive tool for visualizing the BB84 protocol. By combining the quantum simulation capabilities of Qiskit with the user-friendly interface of the Streamlit framework, we offer a didactic resource designed to enhance the practical understanding of quantum cryptography, whose pedagogical effectiveness was assessed through a case study with undergraduate students.

## 2. Proposed Application

Given the challenge of simplifying the visualization of the BB84 protocol for academic purposes, we propose an interactive application developed using technologies previously validated in related works. The approach leverages established technologies with a distinctive element: the utilization of the Streamlit framework, which is widely adopted in data science but repurposed here for pedagogical aims. This choice is grounded in Streamlit's ease of scalability, maintainability, and rapid development cycle [Khorasani et al. 2022]. The application was designed to illustrate each stage of the protocol, from bit and basis generation to eavesdropper detection, enhancing its pedagogical value with detailed textual explanations accompanying each visualization<sup>1</sup>.

To clarify the protocol's core security principle, the application allows users to visualize simulation results. In tests conducted for 100 qubits with a channel error rate of 5%, the Quantum Bit Error Rate (QBER) remained consistent with the channel's error rate in the absence of an eavesdropper (Eve). However, with an interceptor present, the QBER surged to approximately 26.5%. This significant increase makes interception evident, reinforcing the practical security of the BB84 protocol by visually demonstrating the disturbance detection principle.

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<sup>1</sup>The application is available at: <https://bb84interactivevisualization.streamlit.app/>

### 3. Case Study and Results

A case study was conducted with 23 undergraduate Information Systems students to evaluate the tool's pedagogical effectiveness. Participants first received a theoretical introduction to the quantum mechanics principles relevant to the protocol, followed by a guided presentation of the application's modules. To gather data on their learning experience, a form<sup>2</sup> was administered to 20 participants, utilizing a five-point Likert scale to measure their perceptions.

The results were significant: despite 60% of students having no prior knowledge of quantum cryptography, 95% fully or partially agreed that the hands-on application facilitated their understanding of the protocol. Furthermore, 90% felt confident enough to explain its basic concepts, at least partially. These findings suggest that a visual and interactive approach effectively addresses the need for new pedagogical tools identified by [Haghparast et al. 2024]. The positive reception highlights the utility of visual frameworks like the one proposed by [Ossorio et al. 2024], and in contrast to the difficulties with programming tools reported in other studies [Angara et al. 2021], our Streamlit-based visual representation proved to be a promising educational alternative.

### 4. Conclusion

This work successfully developed and evaluated an open-source didactic tool for teaching the BB84 QKD protocol. The core security principle of BB84—the detection of an eavesdropper through an increased QBER—was effectively demonstrated, and the tool was made publicly available to the academic community. The case study confirmed the value of our visual and interactive approach, showing that it might enhance students' understanding of complex quantum concepts, even for those with no prior background. Acknowledging the study's limitations, future work will focus on expanding the platform to include more advanced quantum phenomena, such as entanglement, which students often find challenging. Also, it is intent to conduct more rigorous evaluations, including studies with control groups, to further validate our pedagogical methodology. Ultimately, this work contributes a practical resource that helps make complex academic content more accessible and engaging for the student community.

### References

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<sup>2</sup>The questionnaire is available at: <https://shorturl.at/3hahH>