# Keep it secret, keep it safe: Teaching quantum cryptography in high-school

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**Abstract.** Quantum physics offers numerous technological applications, yet their complexity poses challenges for teaching secondary-level students. Quantum cryptography, grounded in fundamental quantum principles, presents a contemporary and accessible subject. This study investigates the impact of teaching quantum cryptography as part of the Discipline-Culture approach. We analyse the responses of $12^{th}$-grade students to open questions and final test problems to gauge their understanding of the principles of quantum physics and their motivation. Our results show that students succeed in applying the core concepts of quantum physics to new quantitative problem-solving and that teaching quantum cryptography induced motivation for learning quantum physics.

## Introduction

In recent years, the teaching of quantum physics (QP) in high school (HS) has changed in many countries. Many curricula and a variety of studies present a multitude of approaches to teaching the subject [e.g., 1-2]. QP is very applicable, and a lot of modern technology is based on its principles [3]. However, it is difficult to teach these applications in HS, due to the required technological background and the high-level mathematics required for this purpose. Quantum cryptography (QC) is different since teaching it conceptually does not require understanding complicated technical systems. For example, BB84 protocol [4] relies mostly on understanding photon-polarization and the effect of a measurement on a quantum state. Additionally, it enables demonstrating several key core principles in quantum physics [5], such as superposition, uncertainty, and wave-function collapse [6-7]. It enables a quantitative approach to teaching QP, which helps in understanding [8] and self-efficacy [7,9]. Quantitative problems in QC can be with low complexity if confined to 50-50 probability calculations, but can be more complex without this confinement, nevertheless, requiring appropriate tools like the use of Dirac notation.

### *Research questions*

QC, therefore, seems a promising topic in teaching QP, yet its implementation in teaching still requires answering the following questions:

- To what extent do $12^{th}$-grade students succeed in applying core QP concepts to solve quantitative and phenomenological problems dealing with QC?
- What is the effect that teaching QC has on the students' motivation to learn QP?

## Method

***Population and Educational context:*** Three teachers of different schools taught the total of 43 students of $12^{th}$ grade, with the curriculum based on the Discipline-Culture approach [10]. In this approach, they learn core principles of QP [7,10]. They also encountered quantum phenomena such as interference, polarization, the Stern Gerlach experiment and more [10]. They were introduced with Dirac notation for quantitative problem solving. As part of the curriculum, the students learned QC by the BB84 protocol, including problem solving in this topic.

***Data collection and analysis:*** We use qualitative content analysis to analyze students' responses to open quantitative and qualitative questions in the final test and in addition, their answers to an open questionnaire regarding their motivation to learn QP. Specifically, we scrutinized their answers for reflections on learning QC.

## Findings

Most of the students used the principles of QP to explain QC. Most of them showed transfer of knowledge, as they were able to correctly answer questions they did not encounter before regarding QC. Additionally, most of the students used Dirac notation for their calculations, even though it was not required for the solution. The reflection questionnaire showed that the students consider QC as being very important topic to learn or at least with medium importance. About 25% of the students even defined the topic as "cool". Although a minority of students claimed the topic did not help them in understanding QP, most students stated that this is an interesting topic and it demonstrates the implications of QP. For example, one student said:

> "Quantum cryptography is an interesting topic in my opinion and very relevant to our everyday life. It is also relatively simple to learn, so I think it is good to have it ((in the curriculum))".

## Conclusion

QC is a subject that can be taught in HS. The students presented conceptual understanding by formulating their answers using the core principles of QP, and quantitative skills by using Dirac notation. This suggests their assimilation of using Dirac notation to represent quantum states and for quantitative problem-solving. It is evident that QC interests the students, and it might foster motivation. QC supports the understanding of the principles of QP and it could assist researchers to test students' understanding of these principles.

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