QTris: a new game for teaching quantum physics

Maria BONDANI (1), Massimiliano MALGIERI (2), Michela NAZZARO (3),
Irene MARZOLI (4), Sergio CAPRARA (5), Maurizio DABBICCO (6), Alioscia HAMMA (3)

(1) Istituto di Fotonica e Nanotecnologie-CNR-IFN, Como, Italy
(2) Dipartimento di Fisica, Università di Pavia, Italy
(3) Dipartimento di Fisica `Ettore Pancini', Università degli Studi di Napoli Federico II, Italy
(4) Scuola di Scienze e Tecnologie, Università degli Studi di Camerino, Italy
(5) Dipartimento di Fisica, Università di Roma Sapienza, Italy
(6) Dipartimento di Fisica, Università degli Studi di Bari Aldo Moro, Italy

Abstract. In this workshop we present QTris, a novel game for teaching and learning quantum mechanics based on a consistent quantum extension of the classical game tic-tac-toe.

Introduction

In this workshop we propose participants to learn and play an educational game - called QTris - that replicates the entire conceptual and mathematical structure of quantum mechanics (QM). By playing the game, students will effectively learn all the rules of QM and how to apply them. The game was developed by one of the organizers of this workshop (AH) as part of the Italian initiative *National Quantum Science and Technology Institute* (NQSTI) and is currently offered in teacher professional development courses. The game takes a modern perspective on QM, and its structure, especially due to cards representing possible operations on qubits, is naturally linked to technological applications such as quantum computing. QTris can be seen as the basis of a stand-alone proposal to introduce quantum physics and quantum technology (QT) or can be seamlessly integrated within existing two-state approaches to teaching QM.

Research on game-based learning of quantum physics

Several authors have proposed educational games for teaching and learning QM and QT. Some digital educational games are based on a wave function approach [1], while both digital [2] and board games [3] have been proposed that are specifically tailored to teach QT [4]. The game *Quantum-Tic-Tac-Toe* (QTTT) [5,6] deserves special mention as it is inspired by the same classical game (see later a discussion on the differences).

QTris: the game

As in classical Tic-Tac-Toe, the QTris game board is a 3 x 3 square matrix. The aim of both players is to achieve rows, columns, or diagonals with three identical symbols (represented by tiles with unique graphics of black and white cat’s paws): one player plays for the black and the other for the white and in the end each player awards a point for every single 3-lined set of their symbol.
In contrast to classical Tic-Tac-Toe, QTris is played in three stages:

1. **Preparation**, in which a tile from the game components is placed on each square of the board. The tiles can be distributed randomly or according to certain criteria, which will be explained in the workshop. This phase of the game represents the preparation of the quantum state of the qubits: the tiles represent the states and the squares represent the qubit.
2. **Players' moves**, in which the players can change the type and arrangement of the tiles on the board by playing some cards. The aim of the players in this phase is to maximize their

chances of forming complete rows, columns and diagonals of black or white paws in the following phase. This phase of the game represents the evolution of the quantum state of the qubits under a quantum algorithm.

3. **Resolution**, where the points are assigned in a probabilistic way: for each square, an outcome of black or white paws is assigned with a probability that depends on the tile present on the square. This phase of the game represents the measurement of the quantum state that changes its state in a probabilistic manner.

The main components of the game are:

- **Tiles** (representing the state of a board square) printed with different symbols. QTris has three types of "cat's paw" tiles: white, black and black and white (see Figure 1, left). For black or white paw tiles, orientation does not matter, whereas for black and white paw tiles, up or down orientation has a different meaning in the game and represents the superposition |+> and |-> states. In the advanced version of the game, QTris includes generic superposition states, designed by adding a special fuchsia tile, and entangled states, labelled by colored triangles.
- **Move cards** (representing quantum operations). The game includes a set of 52 move cards, each representing a quantum operation. These move cards are pivotal in allowing players to modify the actual state of the qubits. The action of the move cards for the basic version of QTris, with the exception of card *I*, which has no effect and is used to pass the turn, is displayed in the right panel of Figure 1.

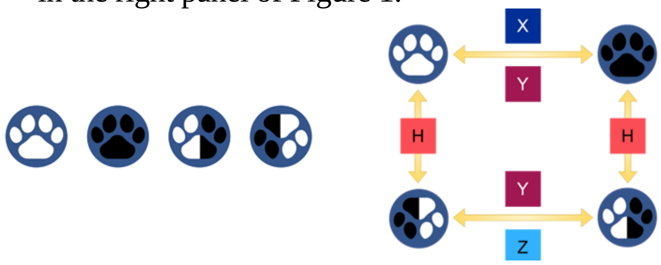

Figure 1: QTris' basic tiles (left) and summary of the algebra of the move cards (right).

Discussion

In contrast to QTTT, the rules of QTris exactly reproduce those of standard quantum mechanics and no additional mechanisms need to be included to resolve the game in certain cases, such as the *cyclic entanglement* in QTTT. Moreover, the QTris rules take into account the relative phase in superposition states, while it plays no role in QTTT. This helps against the well-known misconception [7] that the relative phase has no physical meaning.

References

[1] M. K. Pedersen, B. Skyum, R. Heck, R. Müller, M. Bason, A. Lieberoth, J. F. Sherson, *Phys. Rev. Phys. Educ. Res.* **12**(1) (2016) 013102.

[2] L. Nita, L. Mazzoli Smith, N. Chancellor, H. Cramman, *Res. Sci. Technol. Educ.* **41**(2) (2023) 564-580.

[3] J. D. Weisz, M. Ashoori, Z. Ashktorab, In *Proceedings of the 2018 Annual Symposium on Computer-Human Interaction in Play* (pp. 523-534)

[4] https://qplaylearn.com/

[5] A. Goff, *Am. J. Phys.* **74**(11) (2006) 962-973

[6] M. L. Chiofalo, C. Foti, M. Michelini, L. Santi and A. Stefanel, *Educ. Sci.* **12** (2022) 446.

[7] G. Passante, P. J. Emigh and P. S. Shaffer, *Phys. Rev. ST-Phys. Educ. Res.* **11**(2) (2015).