Demonstration of Quantum Computing Concepts via Quantum Chess

1 How to Play Chess?

1.1 How to setup the board?

Figure 1: The initial position in a complete chess game.

- 16 pieces for each player
- Players alternate play turns and can only make one move
- Each trying to trap and capture the opposite king (checkmate)
- Often easier by one player have more pieces than the other
- Goal: Achieve a positional/material advantage to perform checkmate
1.2 How to move the pieces?

Figure 2: The allowed movements for each piece type in the game of chess. Capturing a piece can be done by moving into a square of an opposing player’s piece.

1.3 How to capture?

Capture by occupying the same square as a piece of the opposite player. When and how to capture is an important part of strategy:
1.4 What is checkmate?

To win, one must threaten to capture the opposite king, while it has no spaces to escape. This is illustrated in figure 3 using a queen and king to deliver the checkmate. Because kings must not be under threat in any gameturn, they also cannot be adjacent to each other.

![Figure 3: Left: One move before checkmate; the queen’s moves are highlighted, with the arrow indicating a move that delivers checkmate. Right: A final checkmate position: the dark king cannot move towards the white king (as kings cannot be adjacent in a game of chess). Furthermore the white queen is threatening capture of the king (hence the red highlight). The king cannot move left or right due to the queen also threatening capturing in those squares.](image-url)
2 How to play Quantum Chess?

2.1 How to access Quantum Chess via the Webbrowser App?

Use the link [https://quantumchess.net/play/](https://quantumchess.net/play/) It has been tested with Chrome, Safari and Firefox and on Windows, Mac and Linux (Ubuntu) operative systems.

![Quantum Chess interface](quantumchess.png)

Figure 4: Quantum Chess interface when accessed at the link [https://quantumchess.net/play/](https://quantumchess.net/play/)

3 How is the activity structured?

3.1 Tutorial

We will start with a walkthrough of the tutorial, which can be accessed via the menu button 'Tutorial’. We will help cover each of the steps and troubleshoot any technology issues at this time.

3.2 Activity

Similarly, the puzzles we will be covering today can be selected via the menu button 'Puzzles’ and then selecting the appropriately numbered puzzle. We will cover a subset, consisting of puzzles three, five and seven, but walkthrough number two together.
3.3 Puzzle 2

Quantum Fork with a knight, where each rook can be threatened by the knight in one move (however the rook can move away after that happens). Hint: Superposition may help

Figure 5: Quantum Fork

3.4 Puzzle 3

Analogous to the prior puzzle.

Figure 6: Quantum Fork 2
### 3.5 Puzzle 5

The rook is supporting itself via superposition (so it cannot be captured by the king directly or cant it?). This problem harnesses **entanglement**: the result of one move is determined by the result of another move on the board.

![Figure 7: Save The King](image)

### 3.6 Puzzle 7

In typical chess, this would be a drawn position. However, the king in f1 can attempt a win via **superposition** sacrifice.

![Figure 8: Quantum For The Win](image)
3.7 Quantum Chess Moves Reference

The allowed moves are highlighted with a blue halo and the principles of quantum chess are demonstrated through the tutorial. This is just a quick reference for the moves highlighted in the tutorial.

Figure 9: Example of the moves being highlighted in the Quantum Chess Web Application.

Specifically, split moves need to be used to generate superpositions, by dragging the mouse cursor along two squares allowed by chess.

Figure 10: How to perform the split move: click a square, hold and drag the cursor to another square to perform a split move.

A superposition can be undone by performing a merge move and combining the two squares in the superposition by the same click-hold-drag motion and clicking the target square to merge.
Figure 11: Example of a knight in an uniform superposition between two squares (from the Quantum Chess online tutorial)

Figure 12: How to perform the merge move: click a square in the superposition, hold and drag the cursor to another square in the superposition; release and then select the square to complete the merge.
4 What to try beyond the workshop puzzles?

- The other quantum chess puzzles (1,4,6)
- Play quantum chess with your friends (select 'Sandbox', then press 'New', 'Play'; if the pieces appear all good to play other wise, press 'Stop' followed by 'New' and 'Play'
- Other quantum games,
  Quantum Checkers https://github.com/kartikeya-git/Quantum-Checkers
- Try quantum circuits online at the IBM Circuit Composer
  https://quantum-computing.ibm.com/composer

Figure 13: Example of a setup of a full game of quantum chess accessed via 'Sandbox' menu button and using 'New' to setup the board. Two attempts may be required for the pieces to persist upon pressing 'Play'.

Figure 14: Example of the Circuit composer interface. The circuit generated on the top has three wires and the gate operations indicated by H (Hadamard gate) generate a superposition. Bottom right: state obtained by measuring the outcome of the experiment once. Bottom left: Measurement statistics for 1024 experiments; a larger number of measurements would show that each state would have equal probability of being measured.
5 Solutions

- 1) \((Qb_3 + Qb_7) \to Qd_5\) (drag the two superposition sites for the queen into the target tile)

- 2) \(Kc_3 \to (Kb_5 + Ke_2)\) (click the knight initial position then drag-press on the two target tiles); one of the rooks will move, so try to capture the other with superposition knight in range. (win not guaranteed)

- 3) \(Ke_3 \to (Kc_4 + Kg_4)\) (click the knight initial position then drag-press on the two target tiles); one of the rooks will move, so try to capture the other with superposition knight in range. (win not guaranteed)

- 4) \(Bf_1 \to (Bb_5 + Bc_4)\) (click the bishop initial position then drag-press on the two target tiles); the queen will move to capture \((QxBb_5)\), so recapture by \(Bxb_5\) (win not guaranteed)

- 5) \(Kg_8 \to (Kh_7 + Kf_8)\) (click the king initial position then drag-press on the two target tiles)

- 6) \(Rh_1 \to (Rh_7 + Rh_8)\) (click the rook initial position then drag-press on the two target tiles) (win not guaranteed)

- 7) \(Kf_1 \to (Kg_7 + Kg_8)\) or \(Kf_1 \to (Ke_7 + Ke_8)\). Pawn will move to capture one of the kings on the 1st rank and promote to queen \((xe1=Q\) or \(xg1=Q)\). Capturing the opposing king with \(Kxf_3\) will force measurement, ending the game.