# [NumFOCUS / toqito] GSoC 2025 Proposal: Creating and Expanding an Example Gallery for Toqito

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### Abstract

This proposal is submitted under the NumFOCUS umbrella for Google Summer of Code 2025, specifically for the `toqito` project—an open-source Python library for quantum information theory. The goal is to develop a structured, visually engaging example gallery that demonstrates `toqito`'s functionality through reproducible Python scripts. These examples will serve as both pedagogical tools for newcomers and practical demonstrations for researchers. Modeled after the `scikit-learn` example gallery, the page will feature tiled thumbnails, annotated code snippets, and auto-generated outputs. At least five examples will be implemented, including new use cases for quantum key distribution, state antidistinguishability, and structured state preparation—helping lower the barrier to entry for the quantum information community.


## Technical Details

### Approach and Tools

I will implement a Sphinx-Gallery-based example gallery for the `toqito` library, modeled after projects like scikit-learn's gallery [1]. Each example will be a standalone Python script demonstrating a practical quantum information theory use-case using `toqito`, executed during documentation builds to ensure output reproducibility and accuracy.

Key technologies:

- `NumPy` for numerical computation.
- `Matplotlib` for visualizations.
- `CVXPY` (with solvers like SCS or MOSEK) for semidefinite programming where applicable.
- `Sphinx-Gallery` for auto-generating HTML documentation and example thumbnails.

The examples will be pedagogically focused and designed for physics students with a basic background in quantum computing. Code will follow `toqito`'s conventions and be commented with theoretical annotations and educational explanations.

### Planned Example Gallery Content

The gallery will consist of 5–7 examples, including the following:

1. **Quantum Key Distribution via Extended Nonlocal Games:** Implements the BB84 protocol using `ExtendedNonlocalGame`. Theoretical values (e.g. $\cos^2(\pi/8) \approx 0.8536$ for unentangled strategies) will be reproduced and compared with entangled results [2,3].
2. **Quantum State Antidistinguishability:** Uses `state_opt.state_exclusion` to determine whether a set of quantum states is antidistinguishable [4, 5, 11]. Results will be visualized and linked to exclusion theory. This example draws inspiration from the work by Russo and Sikora [11], which explores conditions for antidistinguishability in terms of pairwise inner products.
3. **GHZ State Preparation and Verification:** Constructs a GHZ state via quantum gates, simulates measurements, and verifies entanglement properties using `toqito`'s metrics [6].
4. **Quantum Gate Decomposition (SWAP via CNOTs):** Demonstrates matrix decomposition of the SWAP gate using three CNOTs and verifies the equality via multiplication [7].
5. **Entanglement vs. Parameter:** Computes concurrence or entanglement of formation for the parametrized state $|\psi(\theta)\rangle = \cos\theta|00\rangle + \sin\theta|11\rangle$ and compares numerical results to the analytical $\sin(2\theta)$ curve [8].
6. **Mixed-State Entanglement: Werner States and PPT Criterion:** Uses `is_ppt` and `negativity` to demonstrate the entanglement-separability transition in noisy Werner states [9, 10].

Each script will be:

- Self-contained and reproducible.
- Narrated with theory explanations and references.
- Supplemented with plots (e.g. success probability, Bloch sphere, negativity vs. noise).

**Execution and Feasibility**

This plan fits within a 225-hour GSoC timeline. Initial work includes building the gallery framework and one example. Examples are modular and some (e.g., BB84, exclusion) are based on existing tutorials [1]. Code will be validated through test cases, version-controlled using GitHub, and reviewed with mentors. At the end of the project, the gallery will provide a rich set of examples for new users to explore quantum information theory interactively.

## Schedule of Deliverables

### Community Bonding Period (May 8 – June 1)

- Work on gallery architecture with Sphinx-Gallery.
- Prototype a minimal working example.
- Outline example plans with theoretical sources.

- *Note: I will be completing university exams until May 21. I will remain in light contact and resume fully after that.*

**Phase 1 (June 2 – July 14)**

- Deliver gallery infrastructure and working builds.
- Implement 3 examples:
  - BB84 QKD example
  - State exclusion example
  - GHZ state preparation
- Publish midterm report and blog post.

**Phase 2 (July 15 – August 25)**

- Add 2–3 more examples:
  - SWAP decomposition
  - Parameterized entanglement
  - Werner state + PPT test
- Complete thumbnails and visual layout improvements.
- Link examples to API documentation and polish narrative.

**Final Week (August 25 – September 1)**

- Finalize deliverables and submit gallery.
- Complete contributor documentation and styling guide.
- Submit final blog post and evaluations.

## Development Experience

- Strong Python programming background
- Built a Givens-rotation-based framework for quantum state preparation, including circuit decomposition and visualization in Qiskit.
- Organized and ran UCL's Qiskit Fall Fest 2024, delivering quantum computing tutorials to over 150 students.
- Developed deep learning models using PyTorch and TensorFlow/Keras for physics-focused problems:
  - Used a GNN-based LundNet architecture for jet classification (W/Z/QCD) with performance analysis via ROC curves and background rejection.

- Built CNN classifiers for fire detection in aerial imagery with Monte Carlo dropout, label smoothing, and MobileNetV2 fine-tuning.

- Experienced with high-performance computing (SLURM), model reproducibility, and evaluation under domain shift.

## Other Experiences

- Conducted a quantum state preparation research project involving a review of Divide-and-Conquer strategies for optimal arbitrary state generation.
- Tutor for Oxford's COMPOS program, mentoring students in physics and mathematics.
- Transition mentor at UCL for incoming undergraduate physics students.
- Worked on multiple group research projects applying machine learning to particle physics and environmental monitoring.

## Why This Project?

Toqito is a powerful quantum information toolkit with great potential for educational use. This project aligns perfectly with my passion for quantum computing, teaching, and documentation. My goal is to build high-quality examples that lower the learning curve and inspire students and researchers to explore quantum information using open-source tools.

## References


[1] V. Russo et al., "Toqito GSoC 2025 Ideas," https://github.com/vprusso/toqito/wiki/GSoC-2025

[2] C. H. Bennett and G. Brassard, "Quantum Cryptography: Public Key Distribution and Coin Tossing," Proc. IEEE Int. Conf. Computers, Systems and Signal Processing, 1984.

[3] J. Watrous, *The Theory of Quantum Information*, Cambridge University Press, 2018.

[4] T. Heinosaari, L. Mazzarella, and M. M. Wolf, "Antidistinguishability of Pure Quantum States," J. Phys. A: Math. Theor., vol. 43, no. 6, p. 065301, 2010.

[5] M. F. Pusey, J. Barrett, and T. Rudolph, "On the Reality of the Quantum State," Nature Physics, vol. 8, pp. 475–478, 2012.

[6] M. A. Nielsen and I. L. Chuang, *Quantum Computation and Quantum Information*, Cambridge University Press, 2000.

[7] A. Barenco et al., "Elementary Gates for Quantum Computation," Phys. Rev. A, vol. 52, no. 5, pp. 3457–3467, 1995.

[8] W. K. Wootters, "Entanglement of Formation of an Arbitrary State of Two Qubits," Phys. Rev. Lett., vol. 80, no. 10, pp. 2245–2248, 1998.

[9] R. F. Werner, "Quantum States with Einstein–Podolsky–Rosen Correlations Admitting a Hidden-Variable Model," Phys. Rev. A, vol. 40, no. 8, p. 4277, 1989.

[10] A. Peres, "Separability Criterion for Density Matrices," Phys. Rev. Lett., vol. 77, no. 8, pp. 1413–1415, 1996.

[11] V. Russo and J. Sikora, "Inner products of pure states and their antidistinguishability," *Phys. Rev. A*, vol. 107, no. 3, p. 032207, 2023.


## Appendix

**GitHub:** https://github.com/ianalaman
*Note: While my GitHub does not currently showcase public contributions, it reflects my exploration history and familiarity with open-source repositories.*
**LinkedIn:** www.linkedin.com/in/ianalaman
**Availability:** Full-time during the GSoC period. No academic conflicts.
**Blogging:** I will submit biweekly updates and final reflections.