Quantum entanglement represents a nonclassical form of correlation that is useful for fundamental tasks such as quantum teleportation and quantum key distribution. Recent studies have underscored the critical role of catalytic effects for entanglement, opening up new avenues for research in this direction. This project aims to build on these developments, extending the catalytic framework to address key open challenges in quantum information science.

The goals of the project are:

- Explore the reversibility of entanglement theory by leveraging the frameworks of entanglement catalysis and entanglement batteries. The primary objectives include resolving open questions regarding the size and resource cost of the catalyst or battery required to enable reversible transformations.

- Advance the understanding of entanglement catalysis in multipartite settings by characterizing catalytic transformations between entangled states of multipartite systems. A central focus will also be the exploration of reversibility in multipartite entanglement theory, incorporating catalysis and entanglement batteries, with the goal of identifying the minimal resources necessary to achieve reversible transformations.

- Explore practical uses of catalysis in quantum communication and computing, concentrating on distributing entanglement via noisy channels, catalytic authentication methods, and the impact of catalysis on quantum computing performance.

This project presents a series of intriguing questions that will transform our understanding of entanglement in quantum information science. It raises the possibility of a resource-free quantum advantage, proposing that an entangled catalyst might trigger non-classical phenomena even if the underlying quantum system is not entangled. This concept, if proven, will fundamentally alter our perception of quantum entanglement, suggesting its utility without consumption. Exploring these and related questions will have a significant impact on the perceived role of entanglement in quantum technological applications.