Title: Quantum Intuition XR (QIXR)

Team Members

- **Student Leads**

  Marven Wong (marven@terpmail.umd.edu)
  - Major: (BS) Immersive Media Design / Computer Science

  Jamie (Ngoc) Dinh (ngocdinh@terpmail.umd.edu)
  - Major: (MS- graduated) Information Science
  (one more student will be recruited since Jamie Dinh graduated)

- **Mentors**

  Charles Tahan, Ph.D. (ctahan@umd.edu)
  - Visiting Research Professor, Laboratory for Physical Sciences (LPS)
  - Role: Quantum physics advisor

  Myungin Lee, Ph.D. (myungin@umd.edu)
  - Lecturer, Immersive Media Design / Computer Science
  - Role: XR and HCI advisor

1. Project Description

1.1 Overview and Motivation

Quantum Intuition XR (QIXR) is a mixed reality (XR) experience that helps learners build an intuitive understanding of core concepts in quantum information science and engineering (QISE). The project is particularly inspired by the call to action in A Quantum Wish (*https://www.quantum.gov/a-quantum-wish/*), which emphasizes the need to advance quantum education in order to foster a skilled, diverse, and inclusive workforce for the quantum future. Instead of encountering superposition, entanglement, and measurement only as equations, participants interact with qubits as responsive three-dimensional objects in a shared physical space. The project responds to calls in the QISE community to expand quantum education and prepare a diverse, technically capable quantum workforce. QIXR is designed as an integrated artistic and educational module that can be deployed at outreach events, short courses, and workshops supported by CQN and Q^3.

1.2 Current system

In the earlier version used before the Qreate event, the system supported a single-player virtual reality experience on a Meta Quest headset via Oculus Link, streaming audio and 3D visuals from Unity3D. This setup required powerful hardware and wired or wireless network connections, which became a major obstacle for demonstration. Our team encountered these technical issues during the Qreate demonstration session.

In response, we implemented an on-device quantum computing library for the XR headset, which enables the current QIXR system to run as a stand-alone mixed reality application on a single XR headset. This allows QIXR to run on any Android-based device, including the Meta Quest series and newer XR platforms. Users see two Bloch spheres floating in the physical room, along with a small set of basic gates (X, Z, H, S). Using standard Quest controllers, they grab a qubit and move it through a gate object to apply the corresponding unitary, see the Bloch sphere rotate in real time to reflect the new state, bring two qubits together to increase coupling and visualize entanglement as connecting arcs, and press a measurement button to collapse the state and observe one of the classical outcomes.

The same underlying state drives both visuals and sound. Bloch sphere orientation, rim color, halo intensity, and the tension of arcs represent the state and correlations, while a simple sonification maps state parameters to pitch, timbre, and dynamics so that superposition and collapse are heard as well as seen. The current version supports short 5 to 10 minute sessions within a 10-meter footprint, fully offline, with optional casting to a large display for bystanders. The interaction loop is discrete, repeatable, and robust enough for public exhibitions.

1.3 Technical Core

At its core, QIXR maintains one or more qubits as density matrices and applies unitary gates and measurement operators. For the current two-qubit configuration, the system represents each qubit as a 2×2 complex density matrix, applies single qubit gates as $U\rho U^\dagger$, builds simple two-qubit states using tensor products, computes reduced states to derive a lightweight entanglement indicator, and uses distance between qubits to modulate coupling strength and drive entanglement cues. This implementation ensures that the visual and auditory feedback is not arbitrary animation but a consistent mapping from quantum state evolution.

2. Planned Future Work: Two-Semester Plan

Over the next two semesters, we will transform QIXR from a prototype into a reusable, student-led QISE learning module aligned with CQN goals. The work plan has three main thrusts: refinement of the existing mixed reality module, expanded quantum scenarios and interaction modes, and integration with QISE education and evaluation.

2.1 Refinement of the XR module

We will stabilize and optimize the current Quest 3 build for low latency and reliable tracking in varied environments, simplify onboarding with in-headset prompts, safety reminders, and a one minute tutorial sequence, and add an instructor overlay that can be mirrored on an external display to show gate labels, current states, and entanglement level.

2.2 Expanded quantum scenarios and interaction modes

We will extend from two qubits to three or four qubits in selected scenarios to illustrate richer quantum phenomena while keeping the interface accessible. Additional gates and simple multi-qubit operations, such as CNOT and CZ, will enable learners to create Bell states and GHZ-like configurations in the environment. Short scenario templates for basic quantum computing tasks will be implemented, including preparing and measuring Bell states, running simple interference experiments with different gate sequences, and exploring introductory quantum communication motifs that rely on shared entanglement. We will also design a multi-user mode where two or more learners share entangled qubits. In this mode, each participant controls one or more local qubits and must coordinate gate application and measurement choices to achieve a target configuration. The system will highlight how local actions affect joint outcomes, emphasizing the relational nature of entanglement and quantum networks.

2.3 Integration with QISE education and evaluation

Together with CQN experts, we will co-design learning objectives and activity scripts so that QIXR modules fit clearly within existing outreach and curricular efforts. We will develop short guided modes for different audiences, including a track for general public outreach, one for high school or early undergraduate learners, and one for introductory QISE courses. Small scale evaluations with pre and post concept questions, usability scales, and interviews will test understanding, engagement, and perceived accessibility. The module will be packaged with instructor documentation, including concept overviews, suggested discussion prompts, and deployment guidelines.

3. Educational Framework

3.1 Embodied and enactive learning

Learners physically move qubits, decide when to apply gates, and choose how close to bring qubits together. These sensorimotor activities create bodily traces for concepts like superposition and entanglement, which are otherwise difficult to imagine.

3.2 Multimodal representation and dual coding

The same quantum state has multiple representations: spatial orientation and color on Bloch spheres, connecting arcs for correlations, and audio cues for stability, tension, and collapse. This multimodal design supports dual coding and can help a wider range of learners make sense of the dynamics.

3.3 Immediate feedback and exploratory learning

Gate applications lead to clear and immediate changes in visuals and sound. Learners can run short experiments by trying different gate orders, distances, and measurement patterns, then comparing the outcomes. This supports exploratory learning and strengthens intuition.

3.4 Relational and collaborative framing

Entanglement and multi-user scenarios emphasize relations rather than isolated objects. In the planned multi-user mode, two or more people coordinate to reach a target state, mirroring the collaborative nature of quantum networks and encouraging social sensemaking.

3.5 Goal oriented but low stakes interaction

Light gamification, such as preparing a target state or creating a maximally entangled pair, gives structure and a sense of accomplishment but does not penalize failure. This encourages curiosity and risk taking while keeping focus on understanding rather than competition.

4. Intended Usage and Outcomes

QIXR is designed for CQN and Q^3 outreach events, short workshops or summer programs, and introductory QISE or physics courses. At outreach events, participants can cycle through six to eight minute sessions and observe each other on an external display. In workshops or courses, QIXR serves as an intuitive grounding activity before formal instruction on complex numbers and Dirac notation.

After a short QIXR session and debrief, participants should be able to describe in everyday language what a qubit is and how basic gates like X, Z, H, S, and CNOT transform its state, explain qualitatively what superposition and interference mean and recognize them in the visual and auditory cues, articulate a basic understanding of entanglement as correlation in joint measurement outcomes, recognize that measurement is an active process, and report increased interest in quantum technologies and a sense that quantum information science is approachable. For classroom or workshop deployments, simple pre and post concept questions, a short usability and engagement survey, and optional follow up interviews will assess these outcomes.

5. Budget and Budget Justification

We request a total of 10,000 USD, with emphasis on student leadership and on making QIXR a sustainable asset for CQN and Q³ events.

Category	Amount (USD)	Description / Justification
Student personnel	6,000	Two student leads (Marven and a new student) as primary developers and evaluators, approximately 150 hours per student over two semesters at an average rate of 20 USD per hour. Responsibilities include mixed reality development, implementation of multi-qubit and multi-user modes, study design, data collection and analysis, documentation, and coordination with CQN.
Hardware & software	2,000	Two additional Meta Quest 3 headset and comfort accessories for higher throughput and duet or multi-user testing, replacement controllers and minor hardware as needed, and small storage or PC upgrades and project specific assets not covered institutionally.
Outreach and workshop materials	1,000	Printing of quick start guides, concept sheets, and reflection handouts, simple physical props and signage for exhibition setups, and light participant incentives for user study or refreshments where allowed.
Travel and dissemination	1,000	Local travel and registration support for students to present QIXR at CQN related events and Q³ activities, and production of a short, captioned demo video.
Total	10,000	Total requested budget for the project.

This allocation supports intensive student involvement, robust mixed reality deployment, and effective outreach and dissemination.

6. Project Organization and Timeline

Student technical lead Marven Wong will focus on Unity and XR development, performance optimization, and the implementation of new gates and multi-qubit logic. Student UX and evaluation lead Jamie Dinh will focus on onboarding flow, activity design, survey instruments, data analysis, and documentation. Quantum physics advisor Charles Tahan will guide physics validation, scenario selection, and alignment with QISE concepts and CQN priorities. XR and HCI advisor Myungin Lee will advise on interaction design, mixed reality deployment, and integration into courses and outreach formats.
The timeline below outlines key phases and milestones over two semesters. Tasks can be shifted slightly to match CQN event schedules.

Month	Phase	Milestones
1	System review & planning	Review existing QIXR build and source code. Confirm learning goals with CQN mentors. Define target audiences and deployment contexts.
2	Mixed reality refinement	Stabilize Quest 3 standalone build. Improve onboarding and safety prompts. Test performance in a small lab setting.
3	Core guided mode	Implement a short guided sequence: initialize qubits, apply basic gates, create and measure an entangled pair. Add instructor overlay for casting.
4	Expanded gates & scenarios	Add CNOT and additional gates as needed. Implement Bell state preparation and simple interference scenarios. Pilot test with a small group of students.
5	Multi-qubit & multi-user mode	Extend the state engine to support selected three or four qubit scenarios. Implement early multi-user mode where two participants share entangled qubits and coordinate actions.
6	Evaluation preparation & deployment	Finalize activity scripts and survey instruments. Obtain IRB approval if required. Conduct a first evaluation with a course or workshop cohort.
7	Refinement & outreach package	Refine interaction design and visuals based on evaluation results. Prepare instructor documentation, quick start guides, and outreach materials.
8	Dissemination and handoff	Record and edit a demo video. Present QIXR in at least one CQN or Q^3 event. Prepare final report, usage guide, and repository for continued use.

Project Demo
Video:
https://drive.google.com/file/d/1BxwMKsm9v0Saz9HJJNp9nxpuGOeLPlmP/view?usp=sharing