Building a Quantum Engineering Undergraduate Program

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Abstract*—*Contribution: **A roadmap is provided for building a quantum engineering education program to satisfy U.S. national and international workforce needs.**

Background: **The rapidly growing quantum information science and engineering (QISE) industry will require both quantum-aware and quantum-proficient engineers at the bachelor's level.**

Research Question: **What is the best way to provide a flexible framework that can be tailored for the full academic ecosystem?**

Methodology: **A workshop of 480 QISE researchers from across academia, government, industry, and national laboratories was convened to draw on best practices; representative authors developed this roadmap.**

Findings: **1) For quantum-aware engineers, design of a first quantum engineering course, accessible to all STEM students, is described; 2) for the education and training of quantum-proficient engineers, both a quantum engineering minor accessible to all STEM majors, and a quantum track directly integrated into individual engineering majors are detailed, requiring only three to four newly developed courses complementing existing STEM classes; 3) a conceptual QISE course for implementation at any postsecondary institution, including community colleges and military schools, is delineated; 4) QISE presents extraordinary opportunities to work toward rectifying issues of inclusivity and equity that continue to be pervasive within engineering. A plan to do so is presented, as well as how quantum engineering education offers an excellent set of education research opportunities; and 5) a hands-on training plan on quantum hardware is outlined, a key component of any quantum engineering program, with a variety of technologies, including optics, atoms and ions, cryogenic and solid-state technologies, nanofabrication, and control and readout electronics.**

***Index Terms*—Quantum engineering, quantum information science (QIS), undergraduate education.**

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I. Introduction to Quantum Engineering

QUANTUM information science combines the understanding of nature at its most fundamental level—quantum mechanics—with information theory. From an applications standpoint, advancements in this field now rely on incorporating an engineering approach to better design, integrate, and scale quantum technologies. For example, the landmark quantum advantage result achieved in 2019 [1], in which a quantum computer met a computational benchmark not achievable on the same time scale with present classical computing resources, made heavy use of a range of engineering disciplines to construct a machine capable of quantum speedup. This is one example of the many recent advances in quantum information science (QIS) spanning algorithms, architectures, and qubit technologies, including atoms and ions, semiconductors, superconductors, as well as supporting hardware in integrated optics, and microwave and RF control and readout [2]–[5]. This new chapter of discovery and innovation is centered on novel devices that employ nonclassical states, superposition, and entanglement to create technological advantage over classical systems. In addition, devices based on these aspects of quantum physics