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BOARD # 385: ITEST Quantum Education for Students and Teachers (QuEST): Preparing the Next Generation of Global Technology Innovators

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ITEST Quantum Education for Students and Teachers (QuEST): Preparing the Next Generation of Global Technology Innovators

Abstract

Quantum Education for Students and Teachers (QuEST), a National Science Foundation (NSF)-funded Division of Research and Learning ITEST Developing and Testing Innovations partnership between a research university and an urban informal science institution, advances quantum education, physical science literacy, and the diversification of the science, technology, engineering, and mathematics (STEM) pipeline through improved quantum science and quantum computing access, teaching, and learning for precollege (grades 9-12) students and teachers. Student outcomes (*N*=262) include improved quantum information science and technology (QIST) knowledge and attitudes, as well as increased intentions to enroll in four years of mathematics and science in high school. Teacher outcomes (*N*=68) include improved QIST knowledge and pedagogical self-efficacy. This project is a replicable model of university-based QIST outreach to inspire the next generation quantum workforce in industry, research, and academia.

Introduction and Background

Recent reports have called for increased teaching, learning, and awareness of quantum information science and technology (QIST) principles and skills in precollege educational settings. Federal initiatives including the *National Strategic Overview for Quantum Information Science* have emphasized the need to develop the future quantum workforce through K-12 partnerships between academia and government agencies [1]. The *Quantum Information Science and Technology Workforce Development National Strategic Plan* suggested that early and sustained engagement in science, technology, engineering, and mathematics (STEM) fields such as QIST will help diversify the talent pool for related careers [2]. University-based outreach programs may provide expertise and facilitate access to quantum technologies, while promoting the incorporation of QIST in classroom-based STEM instruction [1]-[2].

Quantum Education for Students and Teachers (QuEST), a National Science Foundation (NSF)-funded Division of Research and Learning ITEST Developing and Testing Innovations partnership between a research university and an urban informal science institution, advances quantum education, physical science literacy, and the diversification of the science, technology, engineering, and mathematics (STEM) pipeline through improved quantum science and quantum computing access, teaching, and learning for precollege (grades 9-12) students and teachers [3]. The goals of the QuEST project include: (1) the development of classical and quantum science content knowledge and quantum computing practices that promote critical thinking, reasoning, and communication skills; and (2) increased student and teacher awareness, interest, and knowledge of QIST academic pathways and careers [3]. QuEST activities are aligned with the *Next Generation Science Standards* [4] and the *QIS K-12 Frameworks for STEM Education* [5].

The four-year program builds upon prior research in quantum education that established the need for research-based early access to QIST education to facilitate workforce readiness for the next generation of quantum science innovators. The National Science and Technology Council Subcommittee on Quantum Information Science suggested nine key concepts that provide a foundation for QIST outreach and curriculum design. These include: (1) quantum information science, (2) quantum states, (3) measurement, (4) the quantum bit (qubit), (5) entanglement, (6) coherence, (7) quantum computers, (8) quantum communication, and (9) quantum sensing [6]. This project embedded the majority of these core concepts, along with basic classical and quantum physics principles, in outreach activities that leveraged pedagogical strategies that research has shown to improve knowledge and/or engagement. Such strategies include multiple representations of complex concepts, participation in hands-on activities, learning and practicing with computing tools (IBM Composer), and exposure to QIST role models and careers [7]-[20]. The project is partly differentiated from previous works by the inclusion of mixed methods research to assess outcomes for students and teachers.

Student Outcomes

QuEST employs two approaches. First, the program in quantum teaching laboratories, *QuEST Lab*, educates high school students in school day and summer camp activities in classical and quantum physics and quantum computing. In its first two years, the program enrolled N=262 secondary students at a research university (n=180) and an urban informal science institution (n=82). The summer camp participants included 45% young women, 24% students of color, and 50% from high need schools [21].

Student outcomes were measured through newly developed pre-/post-QIST content knowledge surveys and pre-/post-QIST attitudes surveys, as well as interviews and focus groups. Results of comparisons of means tests indicated significantly improved student knowledge of classical physics (p<.001), quantum physics (p<.001), and quantum computing (p<.001) with large effect sizes; and improved student attitudes towards QIST, including career aspiration formation and self-concept (p<.001) with a medium to large effect size [21]-[23]. Analysis of covariance tests indicated that these results were unrelated to student demographics, although students who had previously taken physics (p<.05) and chemistry (p<.01) were more likely to strengthen QIST career aspirations, with small to medium effect sizes, respectively. Students also reported an increase in their intentions to enroll in four years of mathematics and science in high school (p<.01) with a small effect size [21]. However, students' QIST interest was unchanged from pre- to post-treatment (p=.218), possibly due to the self-selected nature of the outreach program [21]. Qualitative data indicated that students valued the hands-on activities, the explicit connections between prior science knowledge and quantum concepts, socialization with like-minded peers, and laboratory visits and interactions with QIST researchers [22].

Recent formative improvements in program design included more hands-on activities with a Mach-Zehnder interferometer [24]-[25] and Bell's inequality [24,26], as well as interactive panels with graduate students, and with quantum researchers working on solutions to technological challenges and associated improvements in global health [24].

Teacher Outcomes

The second program focus is quantum science and quantum computing professional development. *EduQation* educates middle and high school STEM teachers in QIST principles, skills, and curricular integration. This program has enrolled N=68 teachers (two-thirds from high need schools, 76% certified in physics) to participate in site-based quantum science workshops that focused on conceptual learning, applications, quantum industry career awareness, and QIST curricular planning with cross-disciplinary pedagogical approaches [27]. Teacher outcomes were measured with the same pre-/post-QIST content knowledge survey that the students took, and a newly designed pre-/post-QIST self-efficacy survey. Exploratory factor analysis revealed three distinct self-efficacy constructs. STEM teachers significantly improved their self-efficacy in knowledge about QIST academic pathways and careers (p<.001), self-efficacy in facilitating QIST learning (p<.001), and self-efficacy in QIST pedagogical fluency and STEM integration (p<.001) with large effect sizes [27]. Teachers also improved their knowledge of classical physics (p<.001) quantum physics (p<.01) with medium effect sizes, and knowledge of quantum computing (p<.001) with a large effect size [28].

Future Initiatives

The QuEST program will be complemented with two NSF-sponsored upcoming regional conferences to coincide with the International Year of Quantum (IYQ) in 2025 [29]. The first one-day conference, the *IYQ School District Leadership Conference*, will host 100 STEM leaders who serve as superintendents, assistant superintendents, and/or STEM directors. The project will strengthen their commitment to district-wide quantum education so they may facilitate QIST learning. The second one-day conference, the *IYQ Teacher Leadership Conference*, will host 120 K-12 STEM teachers and 40 high school students at a national laboratory in the region. This event is designed to engage, inspire, and motivate K-12 teachers and students in learning QIST research innovations and connection to STEM disciplinary content [29].

Conclusions

The broader impacts of this work relate to increased introductory quantum science and computing participation for students from diverse backgrounds, who may not have equitable access due to restricted school resources, lack of science course offerings, limited teacher knowledge about core quantum principles and applications, and infrequent advisement about QIST academic pathways and career opportunities. Mixed methods results and other findings demonstrate the promise of the *QuEST* initiative in improving and expanding QIST teaching and learning to educate the next generation quantum industries workforce.

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