Psychosocial factors in precollege learning of quantum information science and technology

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Recent federal initiatives have focused on workforce development in the rapidly advancing field of quantum information science and technology (QIST), which begins with precollege education to engage and inspire students. This paper will examine the integrated nature of QIST education (physics, computer science, engineering, mathematics) and its relationship with psychosocial domains including student interest, self-efficacy, normative comparison, recognition, belonging, and self-concept. The intervention that informed this work is a summer program for precollege students at a research university and an informal science institution, developed and taught by a quantum theorist, a quantum experimentalist, and a physics education researcher. This work suggests that QIST education may be uniquely accessible for all precollege students, leading to increased QIST self-concept and career aspiration formation. Implications for broader QIST participation and related attitudinal domains are discussed.

Keywords: affective domains; high school students; physics education research; psychosocial factors; quantum education research; quantum information science and technology

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I. INTRODUCTION

The International Year of Quantum Science in 2025 [1] presents a unique opportunity for raising public awareness of how quantum information science and technology (QIST) will transform computing capabilities and applications, and how precollege education might be reformed to inspire students and meet QIST workforce demands. The rapid global expansion of QIST research and industrial innovation has resulted in numerous calls for education and workforce expansion. The 2024 revenue from the global quantum industry market reached approximately $1.07B in quantum computing and $375M in quantum sensing, with an expected annual growth rate of 27% over the next three years [2]. The number of quantum-engaged workers is approximately 200,000 people, including physicists, engineers, computer scientists, mathematicians, and software developers, and the need for these workers will rise in tandem with industry advancement and expansion [2]. For example, IBM recently announced that their high-performance quantum processor (IBM Quantum Heron) can accurately "run certain classes of quantum circuits with up to 5,000 two-qubit gate operations" [3]. As this capacity builds, use case development and workforce needs will increase in tandem. QIST education should continually evolve to reflect changing global workforce needs as quantum technologies become more advanced [4,5].

The U.S. government passed legislation aimed specifically at promoting QIST education throughout the academic pipeline, with the precollege level cited as an important time for informing students about the exciting possibilities associated with QIST careers [6,7]. It is essential for physics educators to approach QIST education from an interdisciplinary perspective to reflect the integrated nature of QIST-adjacent content, skills, and best practices [8]. QIST is an amalgamation of subdisciplines including physics, chemistry, mathematics, engineering, and computer science, and there are challenges associated with the complexity of this disciplinary content. These challenges might be mitigated by the consideration of psychosocial factors that influence students' attitudes towards QIST.

II. PSYCHOSOCIAL FACTORS IN QIST TEACHING AND LEARNING

Although several studies have disseminated best practices in designing QIST educational outreach for precollege students, particularly at the secondary level [9-17], few have explored psychosocial mechanisms for developing students' attitudes towards QIST [18]. These mechanisms are important since human behavior is often influenced by personal, environmental, and behavioral factors that may be difficult to observe and measure. Precollege science, technology, engineering, and mathematics (STEM) educators would benefit from awareness and understanding of psychological influences on QIST interest, persistence, and career choice, since their pedagogical choices may affect how students conceptualize QIST and their potential involvement in the field [19].

This work was informed by a precollege outreach program for students entering grades 10-12 (approximate ages of 14 to 17 years), offered at Stony Brook University and the New York Hall of Science. This program was designed and implemented by a quantum theorist, a quantum experimentalist, and a physics education researcher [20]. The enrollment in these 25-hour, one week programs was N=131 students over two years. Although students' affective and cognitive outcomes were documented from quantitative survey data [21,22], subsequent research will focus on qualitative analysis of interviews with program participants. Although this work has not yet been completed, a priori influences have been identified from prior literature to guide future analysis.

Psychological research has provided insights into factors that influence social and cognitive affective domains with regard to precollege students' attitudes towards QIST. These factors, arranged in a proposed conceptual continuum that contributes to career aspiration formation (Fig. 1), include (1) interest; (2) self-efficacy; (3) normative comparison; (4) recognition; (5) belonging; and (6) self-concept.

A. Interest

Student *interest* has been defined as the "psychological state of engaging or the predisposition to reengage with particular classes of objects, events, or ideas over time" [23, p. 112]. Factors that contribute to interest include both cognitive and affective domains, for example, QIST interest might be increased if students have an affinity for learning QIST topics (cognitive) and they feel as though they can understand them well (affective). Students may express *situational interest* if they have an opportunity to engage with QIST topics, which often occurs in outreach programs; however, this interest may be short-lived if students do not develop *individual interest,* which is a self-directed, sustained desire to reengage with QIST in their future [23]. Consequently, it is important for QIST educators to promote interest through strategies that include the use of authentic applications, explicit discussion of the societal benefits of QIST, and multiple representations of quantum concepts [18,20].

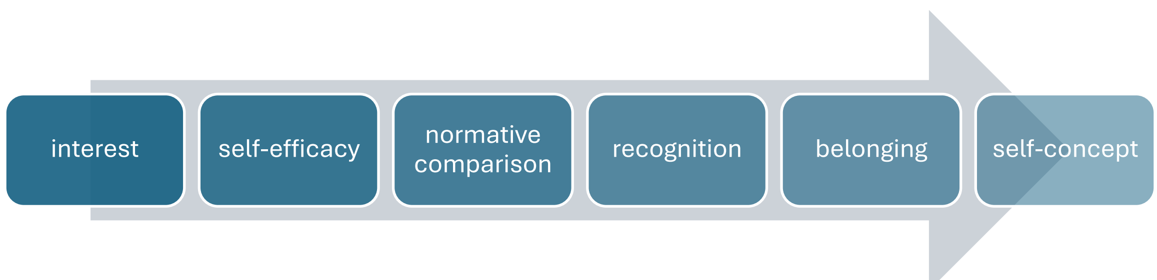

Fig. 1. Psychosocial considerations in QIST career aspiration formation.

B. Self-efficacy

Self-efficacy has been defined as "people's judgments of their capabilities to organize and execute courses of action required to attain designated types of performances" [24, p.391], for example, confidence that one can complete tasks that lead to task mastery or a degree in a field. QIST self-efficacy may be influenced by several factors including past academic performance in QIST-adjacent disciplines, observing role models in QIST, and socialized learning experiences [25]. QIST outreach programs should be carefully structured to provide students with opportunities to demonstrate task mastery and to observe faculty and graduate students doing the work of quantum scientists. Seeing QIST professionals in action creates a sense of expectancy of what a QIST career looks and feels like [26].

C. Normative comparison

Career aspiration formation has been linked to *normative comparison*, which is how an individual views their own QIST competence in relation to other disciplines and other students [27]. This construct has two perspectives. From an internal point of view, normative comparison is how one views their performance in relation to how well they do in other subjects. External normative comparison is how students compare themselves to their peers, for example, how their physics grades rank them in relation to other in the class [27]. Students are more likely to develop interest in careers where they feel they have the potential for competence, both in terms of their own performance and the performance of others around them. These psychological constructs dynamically develop as students engage in QIST learning and assess their competence.

D. Recognition

Recognition has been defined in prior STEM identity research as familial, peer, and role model expectations and encouragement in a particular domain [28]. Recognition is particularly powerful when received from individuals in positional authority, such and QIST faculty and researchers, who might promote student agency and offer critical feedback [29]. Recognition may be communicated by inviting students to participate in undergraduate research or encouraging them to pursue future study in a particular field such as QIST [29]. Recognition may also be embodied in communicating a growth mindset in interactions with students [30], for example, by explicitly expressing that all students can succeed in QIST study and careers.

E. Belonging

Sense of belonging reflects feelings of being welcomed in both the learning environment and the discipline itself [31]. Factors that contribute to one's sense of belonging in QIST might include social relationships within the field; patterns of demographic representation that match that of the individual; personal connection to QIST; and competence and individual interest [29,32]. QIST outreach programs might be structured to promote sense of belonging through team building, group tasks, and exposure to a diverse group of role models, both in terms of demographics and QIST subdomain focus.

F. Self-concept

Self-concept is the perception of one's competence and capability in a specific academic domain, for example, whether students view themselves as a "QIST person." Self-concept is influenced by many social and environmental experiences since actions and goal attainment influence how individuals perceive themselves [33]. Self-concept incorporates all of the previously discussed psychosocial domains, since it is reflective of whether an individual has formed a sense of identity and inherent connection with an academic domain. In the case of QIST learning in outreach programs, factors contributing to self-concept might include an awareness of QIST and QIST-adjacent career options, an understanding of what academic courses and extracurricular experiences will position a student for future QIST study and careers, and social interactions that communicate the norms and expectations of a QIST community of practice [29].

III. BROADENING QIST PARTICIPATION

The psychosocial considerations discussed here provide a meaningful framework for understanding how students might develop career aspirations in QIST fields. Prior research on student outcomes in our QIST outreach programs indicated high school students improved their QIST career aspiration formation from pre- to post-treatment [21,22], and this increase was unrelated to gender, ethnicity, and prior mathematics and computer science coursetaking. Students who had taken chemistry and physics were more likely to increase their QIST career aspiration formation [21]. However, this quantitative work did not address the underlying factors that influenced the attitudinal shifts. Perhaps prior mastery experiences in mathematically intensive sciences contributed to QIST self-efficacy, normative comparison, and self-concept. Interview data analysis will provide more nuanced insights into how psychosocial domains provide frameworks for understanding how precollege students might be inspired to pursue QIST study and careers.

To broaden opportunities for precollege QIST learning, outreach and formal classroom innovations must be designed to reach diverse groups of students. Future research in broadening QIST participation should consider psychosocial constructs and their role in influencing how students conceptualize QIST communities of practice. In doing so, students will gain quantum literacy and perhaps be inspired to join the rapidly growing QIST workforce.

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