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Exploratory factor analysis of a precollege quantum information science and technology survey: exploring career aspiration formation and student interest

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Abstract

The present study examined student outcomes from a quantum information science and technology (QIST) summer outreach program for U.S. secondary students. The program focused on foundational principles and skills from classical physics, quantum physics, and quantum computing. Students' attitudes towards QIST learning and careers were measured through a pretest/posttest research design. Exploratory factor analysis was utilized to identify latent attitudinal themes, followed by comparisons of means to measure changes in these factors and analysis of covariance to assess whether these changes were related to student demographics and prior academic coursework. Two latent themes were identified: (1) QIST career aspiration formation and self-concept, and (2) QIST interest and behavioral intentions. Results indicated that students improved their QIST career aspiration formation and self-concept with a medium to large effect size, yet their QIST interest and behavioral intentions were unchanged. These results were independent of student demographics (gender, ethnicity, grade level) and prior mathematics and computer science course enrollment; however, students who had previously taken chemistry and physics were more likely to improve QIST career aspiration formation and self-concept. Students also increased their intention to take four years of elective mathematics and science with a small effect size. These results suggest that early exposure to QIST principles, skills, and applications may increase students' consideration of related careers and academic coursetaking plans; however, their interest in QIST may be independent of career aspiration formation. Further research is needed to measure attitudinal sub-domains that may be influenced by early QIST education and specific programmatic elements.

Keywords: Analysis of covariance; Careers; Demographics; Education; Exploratory factor analysis; Outreach; Quantum information science and technology; Secondary; Self-efficacy; Workforce development

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1 Introduction

The global revolution in quantum computing capabilities has necessitated a focus on workforce development through precollege education pathways. Recent U.S. reports have called for informal outreach programs in quantum information science and technology (QIST) to develop pedagogical models that might be implemented in formal classroom settings. The *National Quantum Initiative Act* [1] called for the expansion of QIST education by investing in "activities to develop a quantum information science and technology workforce pipeline (p. 3)" and "leveraging the collective body of knowledge from existing quantum information science and engineering research and education activities (p. 8)." In 2023, the National Quantum Initiative recommended the expansion of the NQI Act, and the pending *NQI Reauthorization Act* includes provisions to strengthen workforce development and build testbed quantum applications of a larger scale [2]. Workforce coordination is a key aspect of this legislation to strengthen transitions from precollege and higher education into the quantum industry by initiating programs that broaden participation in QIST fields.

Despite considerable investment and rapid advances in QIST research and development, progress has been limited by a shortage of talent to meet workforce demands [3]. The Quantum Economic Development Consortium (QED-C), formed as part of the U.S. strategy for strengthening growth in the quantum industry workforce, analyzes global employment needs in QIST fields [4]. Their most recent *Quantum Technology Workforce Monitoring Report* indicated a 20% increase in new quantum technology job announcements in North America from July to August, 2024 [5]. These include positions that require high-level expertise (Ph.D.), QIST proficiency (undergraduate QIST-related major or minor), and science, technology, engineering, and mathematics (STEM) technical knowledge (for example, high school or associate degree-level expertise in programming, component fabrication, microelectronics, and cryogenic systems) [4, 6]. The *National Strategic Overview for Quantum Information Science* issued several recommendations to improve QIST workforce readiness, including comprehensive K-12 outreach and classroom-based learning opportunities [7].

Many precollege QIST outreach programs have been designed to teach QIST concepts and skills while promoting student interest and career intentions in the field. These included informal camps and extracurricular activities that introduce classical and quantum physics, differences between classical and quantum computing, and basic quantum computing [8–10]. Other out-of-school programs have included additional elements such as quantum key distribution [11] and quantum teleportation [12]. Formalized in-school programs have included full-year quantum computing coursework [13]. Aside from disciplinary content and applications, some programs have shared information on academic pathways into various QIST careers [8, 14]. The present study reports outcomes from an intervention that incorporated many of these thematic components in a streamlined effort to promote QIST knowledge, engagement, and career interest. However, this work is differentiated by an emphasis on measurement and inferential analysis of student affective outcomes. Measuring QIST-related attitudes is important since there are few valid and reliable instruments for this purpose, particularly at the precollege level [15]. The research questions for the present study were:

1. How might students' attitudes towards QIST be influenced and measured in a precollege outreach program?

2. How are students' attitudes toward QIST related to prior STEM coursetaking and demographic variables?

2 Theoretical framework

The theoretical framing for the present study is based upon psychosocial research in STEM self-efficacy and career aspiration development, which were considerations in the QIST outreach design. This program was designed to improve students' QIST self-efficacy, interest, confidence, and engagement, while also increasing QIST career awareness, knowledge of academic pathways to pursue these careers, and career intentions. Research has shown that self-efficacy in STEM has been influenced by engaging learning environments, collaborative discourse, and peer instruction [16–18]. Student interest and engagement may be facilitated by real-world applications, multiple representations of QIST phenomena, providing formative feedback, and emphasis on the social benefits of physical science and mathematical applications [19–21]. Research in QIST outreach has also shown that an emphasis on career awareness may lead to increased student interest in pursuing QIST-related post-secondary study [8]. This sense of identity and self-concept may also be increased by performance competence, a sense of recognition, and exposure to role models in the field [21–23].

Secondary students may have differential attitudinal outcomes in QIST outreach that are related to gender, ethnicity, and prior academic preparation in QIST-adjacent fields. There has been limited research at the secondary level in QIST-specific attitude formation, yet other STEM fields provide some insights. Research has shown that women tend to have less favorable views of mathematically intensive fields in which there is a presumed requirement of innate talent to participate [24]. These stereotypes may be formed as early as elementary school as many girls endorse gender stereotypes and perceive brilliance as a male quality [25, 26]. These views have often been shared by racialized minorities in STEM, whose STEM identity formation may be constrained by a lack of role models and the deficit mindsets of their instructors [27, 28]. Furthermore, students of color often have constrained access to physical science, computer science, and advanced mathematics in high school, since these are elective courses that are not offered in all U.S. secondary schools, particularly those of low socioeconomic status [29–31]. Students may be less confident about learning QIST concepts and skills if they have limited exposure to related concepts in the physical sciences and mathematics. The present QIST program was designed to appeal to diverse STEM learners, with the objective that they would improve their QIST interest, self-efficacy, and career aspiration formation.

3 Methods

3.1 Research and program design

This study employed a pre-/post-survey design to measure potential changes in student attitudes before and after a summer QIST intervention. The QIST outreach program was a 25-hour summer camp experience for students in grades 10–12 (approximately ages 15–18) in the Southeast region of New York State. This program was characterized by QIST-related instruction in classical wave behavior, quantum mechanics, and basic quantum computing with IBM Composer [32]. Students also learned about the four pillars of quantum science (quantum communication, quantum computation, quantum simulation, and quantum metrology and sensing) and academic pathways that would best prepare

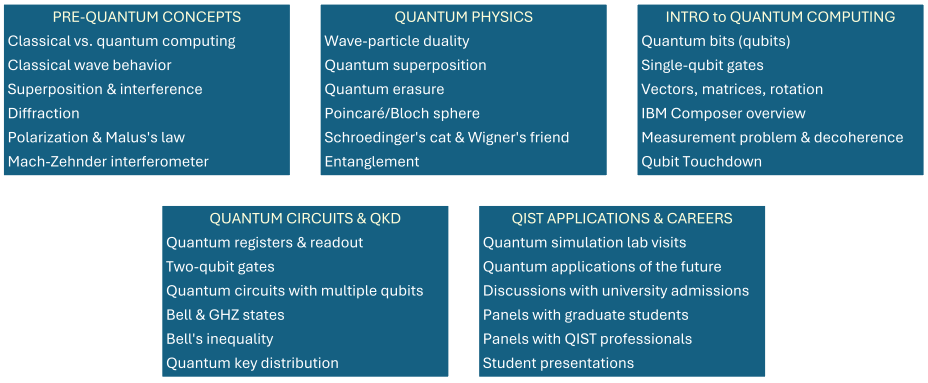


Figure 1 QIST Precollege Program Structure (One Week, 25 Hours)

them for careers in these fields. This occurred through panels with graduate students and career quantum physicists and computer scientists, visits to a quantum simulation laboratory, and interactive discussions with university admissions staff. Instructional strategies employed in the program included best practices from prior research in QIST outreach, including multiple representations of three-dimensional phenomena [9, 10], hands-on analogues [14], gamification [9, 12], advanced computational tools with IBM Composer [8, 12, 16], collaborative discussions of QIST applications with role models [8], as well as student presentations of key topics learned.

The main elements of the one-week program are represented in Fig. 1. Foundational QIST concepts and skills were drawn from the *Q-12 Frameworks for STEM Education* [33], which are aligned with the *Next Generation Science Standards* [34] to integrate QIST ideas with science content that is typically taught in U.S. high schools. More detailed descriptions of QIST disciplinary depth and student-centered activities are included in previous publications [35, 36].

3.2 Study context and participants

The QIST summer outreach program consisted of 25 hours of instruction over one week. The program was offered four times in 2023–2024, with a total of 131 students enrolled. Students came from diverse gender and ethnic groups, and they were entering grades 10-12 (approximately ages 15–17 years) in the fall following their participation. Recruitment letters were sent to regional high school STEM teachers, school counselors, and STEM directors. The enrollment was largely based on students' intrinsic interests and the majority of self-selected applicants were accepted into the program based on academic transcripts and teacher recommendations. The summer program was offered at two sites: Stony Brook University (a research university on Long Island in suburban New York State), and the New York Hall of Science (an informal science institution in New York City). The two locations allowed for diverse recruitment and multiple modes of travel to outreach sites; there was no cost to attend and meals and transportation were provided. There were no prerequisites established for program admission other than grade level. Student demographics are summarized in Table 1.

Table 1 Student Demographics

Camp session	Site	Enrollment (*n*)	Women (*n*)	Men (*n*)	URMS (*n*)	Non-URMS (*n*)
I	University	31	17	14	2	29
II	ISI	15	8	7	4	11
III	University	31	16	15	4	27
IV	ISI	54	18	36	22	32
TOTAL		131	59	72	32	99

ISI = informal science institution.
URMS = underrepresented minority in STEM (Hispanic, Black, Native American, Pacific Islander).
Non-URMS = non-underrepresented minority in STEM (Asian, White).

3.3 Quantitative analysis

This study employed a pretest/posttest design to collect the data utilized for exploratory factor analysis. A survey on student attitudes toward QIST was developed and validated by the researchers; some items were new and others were taken from previously published surveys. According to Mundfrom et al. [37], there is some disagreement on the minimum sample size required for exploratory factor analysis. However, they recommended that to achieve excellent-level criterion, a minimum sample size of 45 (high communality) to 70 (low communality) is necessary for a two-factor solution with an item-to-factor ratio of 7.5. This threshold suggests "excellent" agreement between the present sample and the population [37]. Other research has suggested a minimum of 150 subjects when there are high communalities [38]. The quantum camp intervention had enrolled 131 students to date, while some students did not complete both pre- and post-surveys or skipped some items, and others did not provide consent to participate in the research study. The final sample of 122 students was more than adequate using the Mundfrom et al. [37] criteria, yet small by other standards [38, 39]. An exploratory factor analysis with an oblique Promax rotation was conducted with survey data; this method was chosen since it allows for correlation among the factors. This research with human subjects was approved by the Stony Brook University Institutional Review Board (#2022–00244).

Once factors were identified, pre-/post-means comparisons were measured with paired samples t-tests. Analysis of covariance tests were conducted to see whether attitudinal outcomes differed when considering gender, ethnicity, and prior STEM coursetaking. Missing data were deleted listwise. All data were analyzed with SPSS v.29.

4 Results

4.1 Exploratory factor analysis of students' QIST-related attitudes

The original survey consisted of 25 items. Although this instrument was validated and demonstrated adequate reliability overall (α = 0.87) [35], the original intervention sample size in a previous study was limited (N = 77) and exploratory factor analysis did not yield reliable factors with sufficient items. Consequently, overall pre-/post-scores were analyzed with the smaller sample, yet nuanced analyses of attitudinal sub-domains were not explored [35]. When a larger sample was available from a combined control group and program expansion in 2024 (N = 189), several questions contributing to low reliability were removed, for example, items related to the role of mathematics in understanding QIST principles and skills. These questions were intended to assess whether students felt that quantum principles could be explained conceptually (for example, "It is possible to explain QIST without mathematical formulas" [40]), and whether they believed mathe-

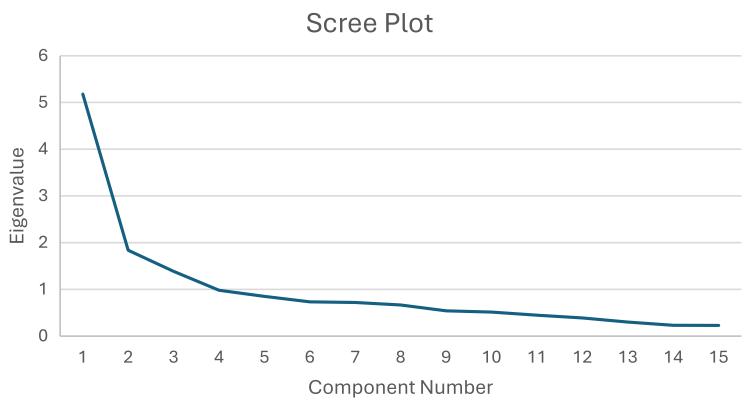


Figure 2 Exploratory Factor Analysis Scree Plot

matics was useful in expressing these principles (for example, "I do not expect equations to help my understanding of QIST; they are just for doing calculations" [40]). However, this dichotomy was not well differentiated by students, likely due to their limited linear algebra background. One purpose of the present study is to refine this survey instrument so it may be useful in other QIST outreach programs that aim to foster QIST interest, engagement, self-efficacy, and career aspirations. Furthermore, this instrument should indicate whether student differences in academic preparation influence attitudinal outcomes. The revised survey consisted of 15 items that demonstrated high reliability, thematically consistent factor constructs, and adequate model fit.

Based on the scree plot (Fig. 2), it appeared a two-factor to four-factor solution would be appropriate given the relative flattening of the curve after this point. A four-factor solution did not have at least three items on each factor. A three-factor solution did not have adequate reliability for each factor. The two-factor solution with a Promax rotation produced thematically consistent items on each of the two factors with primary factor loadings >.40 [41]; also, there were no cross-loaded items with factor loading differences <0.10. The total variance explained by the survey was 46.79%. The model was a good fit based on the sample size, as evidenced by Kaiser-Meyer-Olkin sampling adequacy of 0.84, which is considered good [42], and Bartlett's test of sphericity was significant ($\chi^2(105) = 997.48$, $p < 0.001$). The overall reliability of the survey was $\alpha = 0.85$, indicating high internal consistency. The communalities were acceptable and ranged from 0.25 to 0.74, a wide range for which a sample size of 55 is adequate for exploratory factor analysis with a two-factor solution [37].

The factor solution was characterized by two major constructs (Table 2). Factor 1 was identified as *QIST Interest and Behavioral Intentions*. These ten items had adequate reliability $\alpha = 0.80$ and explained 34.54% of the total variance. This sub-domain included items related to students' perceptions of QIST topics as interesting, engaging, and relevant in their everyday lives, and whether their curiosity about QIST would lead them to further explore current events and new discoveries in the field. This construct also included items on how confident students were in learning QIST skills, and their behavioral intentions of taking four years of mathematics and science. Research has suggested that engagement and interest are important predictors of student persistence in post-secondary study and careers [43], although career intentions items were distinct from this category. Recent re-

Table 2 Two-Factor Analysis of QIST Attitude Survey

		Factor loadings		Communality
Factor 1: QIST Interest and Behavioral Intentions (α = 0.80, 34.54% of variance)				
1.	Learning about QIST topics is interesting and engaging [44]	0.13	0.64	0.50
2.	Learning about QIST changes my ideas about how the world works [40]	0.15	0.48	0.32
3.	I enjoy learning about current events that involve QIST [45]	0.09	0.59	0.40
4.	I am curious about discoveries in QIST [46]	0.14	0.68	0.57
5.	I plan on taking four years of mathematics in high school	0.34	0.61	0.29
6.	Reasoning skills used to understand QIST can be useful in everyday life [40]	0.13	0.42	0.25
7.	In QIST, mathematics expresses meaningful relationships among measurable quantities [40]	0.13	0.51	0.34
8.	I want to learn more about QIST [45]	0.14	0.67	0.55
9.	I am not satisfied until I understand why something works the way it does [45]	0.06	0.70	0.45
10.	I plan on taking four years of science in high school	0.32	0.65	0.33
Factor 2: QIST Career Aspiration Formation and Self-Concept (α = 0.84, 12.26% of variance)				
11.	I am familiar with different types of QIST careers	0.66	0.19	0.36
12.	QIST will be part of my future after high school [45]	0.83	0.03	0.70
13.	I can see myself pursuing a QIST-related career after college	0.81	0.10	0.74
14.	Learning QIST will help me get a good job [46]	0.69	0.07	0.52
15.	I am interested in pursuing a QIST-related major in college	0.88	0.07	0.71

ports have called for quantum outreach programs that promote these attitudinal domains in precollege students to facilitate diverse workforce participation in the field [3, 7].

Factor 2 consisted of five items and was identified as *QIST Career Aspiration Formation and Self-Concept*. These five items had adequate reliability $\alpha = 0.84$ and explained 12.26% of the total variance. This construct included items on students' QIST-related academic and career intentions, and whether they viewed QIST knowledge and skills as advantageous in their general career pathways and everyday lives. One item asked students to report their understanding of precursor coursework that would prepare them for QIST study; this was intended as a measure of expectancy and behavioral intention, where students need to understand academic choices that will facilitate their career goals. Several items related to QIST self-concept, that is, their perceptions of themselves as belonging in the field. Sense of belonging and self-concept have been shown to predict the likelihood of students formulating STEM-related career goals [47].

The relationship between Factors 1 and 2 was measured with a bivariate Spearman correlation. *QIST Interest and Behavioral Intentions* and *QIST Career Aspiration Formation and Self-Concept* were correlated for both the pre-survey ($r = 0.46$, $n = 178$, $p < 0.001$) and post-survey ($r = 0.67$, $n = 112$, $p < 0.001$). This suggests QIST program designs might facilitate engagement while simultaneously promoting career awareness.

4.2 Means comparisons of pre- and post-QIST measures

The overall pre-/post-composite scores indicated significant gains in overall student attitudes from pre-survey ($M = 61.11$, $SD = 6.73$) to post-survey ($M = 63.57$, $SD = 8.00$) ($t(103) = 4.01$, $p < 0.001$, 95%CI[1.24, 3.68]), with a small to medium effect size (Cohen's $d = 0.39$). However, examining the factors individually provides more nuanced insights into specific affective domains influenced by the intervention. Descriptive statistics for individual survey questions are summarized in Table 3.

Table 3 Descriptive Statistics of QIST Attitude Survey Items

		Pre-survey mean (SD)	Post-survey mean (SD)
Factor 1: QIST Interest and Behavioral Intentions			
1.	Learning about QIST topics is interesting and engaging [44]	4.50 (0.64)	4.39 (0.93)
2.	Learning about QIST changes my ideas about how the world works [40]**	4.19 (0.79)	4.47 (0.83)
3.	I enjoy learning about current events that involve QIST [45]	4.20 (0.84)	4.31 (0.96)
4.	I am curious about discoveries in QIST [46]	4.60 (0.60)	4.51 (0.75)
5.	I plan on taking four years of mathematics in high school*	4.67 (0.77)	4.82 (0.61)
6.	Reasoning skills used to understand QIST can be useful in everyday life [40]	4.22 (0.69)	4.06 (0.90)
7.	In QIST, mathematics expresses meaningful relationships among measurable quantities [40]***	4.00 (0.81)	4.29 (0.82)
8.	I want to learn more about QIST [45]**	4.65 (0.57)	4.38 (0.90)
9.	I am not satisfied until I understand why something works the way it does [45]	4.44 (0.77)	4.50 (0.68)
10.	I plan on taking four years of science in high school*	4.71 (0.70)	4.86 (0.47)
Factor 2: QIST Career Aspiration Formation and Self-Concept			
11.	I am familiar with different types of QIST careers***	2.61 (0.99)	4.34 (0.74)
12.	QIST will be part of my future after high school [45]	3.56 (0.84)	3.68 (1.01)
13.	I can see myself pursuing a QIST-related career after college	3.63 (0.93)	3.58 (1.04)
14.	Learning QIST will help me get a good job [46]***	3.64 (0.78)	3.94 (0.90)
15.	I am interested in pursuing a QIST-related major in college	3.44 (0.92)	3.49 (1.09)

*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

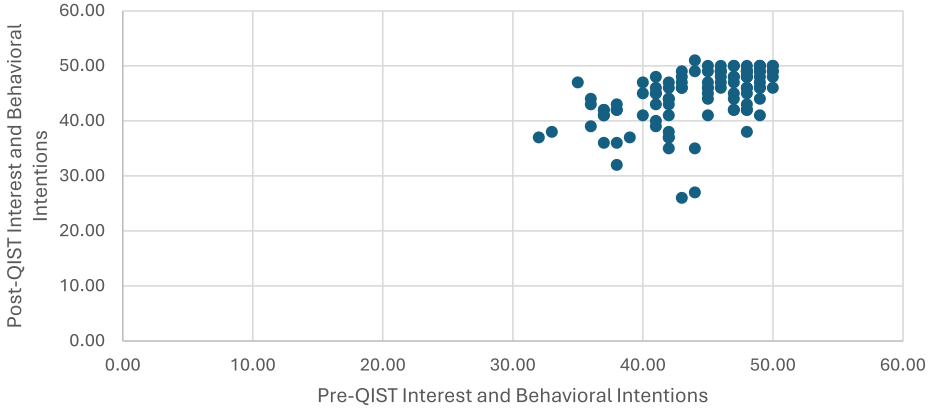


Figure 3 Scatter Plot of Pre- and Post-Factor 1 Scores: QIST Interest and Behavioral Intentions

Paired-samples t-tests were conducted to assess whether students' QIST-related attitudes improved when considering each of the two factors. Students significantly improved their *QIST Career Aspiration and Self-Concept* from pre-survey ($M = 16.88$, $SD = 3.47$) to post-survey ($M = 19.00$, $SD = 3.82$) ($t(105) = 7.38$, $p < 0.001$, 95%CI[1.55, 2.69]), with a medium to large effect size ($d = 0.72$). However, students did not improve their *QIST Interest and Behavioral Intentions* from pre-survey ($M = 44.18$, $SD = 4.41$) to post-survey ($M = 44.54$, $SD = 4.97$) ($t(103) = 0.78$, $p = 0.218$, 95%CI[−0.55, 1.26]). It is notable that the pre-survey mean was already quite high (44.18 out of a maximum of 50), so there may be a ceiling effect in that significant improvement was unlikely. The pre- and post-factor scores are represented in scatterplots in Figs. 3 and 4.

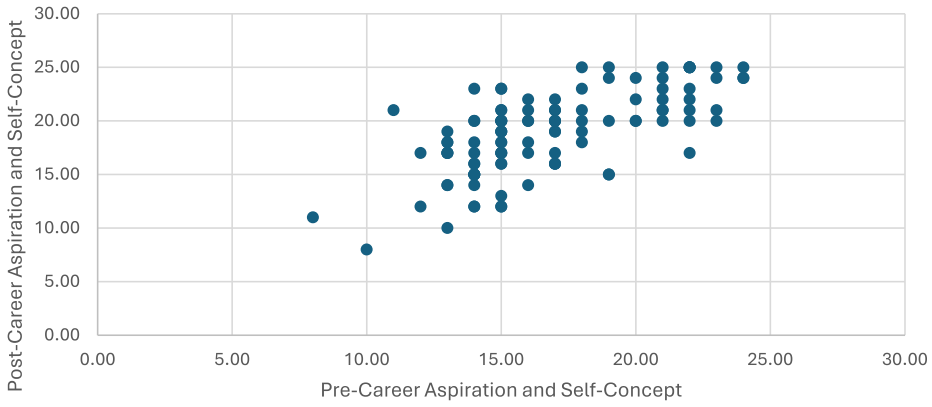


Figure 4 Scatter Plot of Pre- and Post-Factor 2 Scores: QIST Career Aspiration and Self-Concept

As part of the survey, students were asked to report their intention to take four years of mathematics and science during their time in high school, which is often not the case for students in U.S. secondary education. Although many of the self-selected students in the camp already intended to take four years of mathematics and science, there was still an increase. Students overall increased their intention to take four years of mathematics from pre-survey ($M = 4.67$, $SD = 0.77$) to post-survey ($M = 4.82$, $SD = 0.61$) ($t(106) = 2.53$, $p = 0.006$, 95%CI[0.03, 0.27]), with a small effect size ($d = 0.25$). They were also more likely to complete four years of science, increasing their reported intention from pre-survey ($M = 4.71$, $SD = 0.70$) to post-survey ($M = 4.86$, $SD = 0.47$) ($t(106) = 2.60$, $p = 0.005$, 95%CI[0.04, 0.26]), with a small effect size ($d = 0.25$). However, the effect size should be interpreted with caution since most students had already entered the program with the intention of taking four years of mathematics and science.

These data provide evidence that participation in the QIST outreach program was related to improvement in students' career aspirations and self-concept, but not their interest and engagement. Furthermore, students were more likely to enroll in mathematics and science coursework that would prepare them for post-secondary majors in STEM, including QIST-related fields.

4.3 Attitudinal comparisons based on prior coursework

The last research question was explored with ANCOVA comparisons of student outcomes based on prior science and mathematics course completion. Descriptive statistics were first generated to examine prior coursetaking trends (Fig. 5). Most students with complete survey data had completed Algebra II and Trigonometry (62.50%), with some students only completing Geometry (23.21%) and others Precalculus or higher (14.29%). In terms of physical science preparation, 68.87% had taken Chemistry and 41.51% had taken Physics. Many high schools in the region offered science research coursework, and 30.19% had enrolled in one or more of these courses. Finally, 34.91% of students had taken one or more computer science courses. Course enrollments varied in some inferential tests due to missing data that were deleted listwise.

To ascertain whether prior science and mathematics coursework influenced attitudinal outcomes, ANCOVA models were generated to compare outcomes by student group. There was homogeneity of variance between the two groups of students for each science

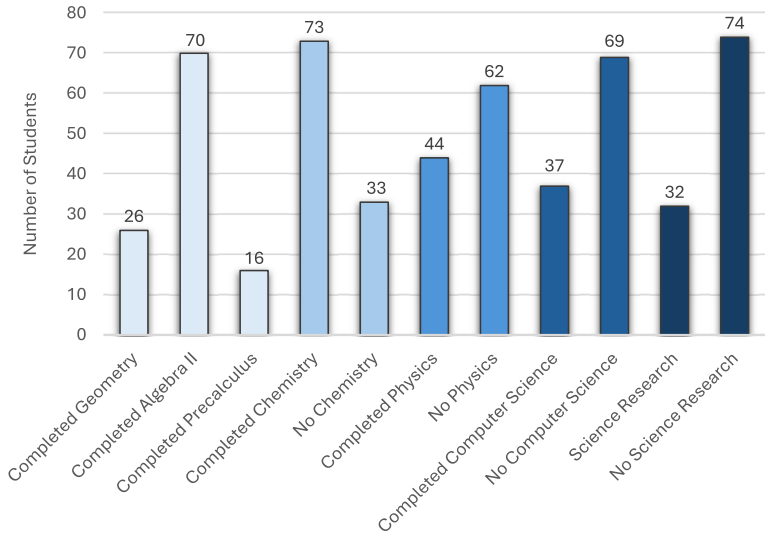


Figure 5 Student Preparation in Mathematics, Science, and Computer Science

and computer science course type as measured by Levene's test ($p > 0.05$). For *QIST Career Aspiration Formation and Self-Concept*, student attitudes were more positive for students who had taken Chemistry ($F(1, 103) = 7.65$; $p = 0.007$, $\eta_p^2 = 0.069$, medium to large effect) and Physics ($F(1, 103) = 4.23$; $p = 0.042$, $\eta_p^2 = 0.039$, small to medium effect). However, student outcomes did not depend upon prior course completion in Science Research ($F(1, 103) = 1.09$; $p = 0.299$), or Computer Science ($F(1, 103) = 1.95$; $p = 0.166$). No interaction effects were observed among various combinations of prior courses ($p > 0.05$).

The mathematics level of students was classified as one of three variables (completing Geometry, Algebra II, or Precalculus). Since there was no homogeneity of variance in attitudinal outcomes among students in the three levels of mathematics (Levene's test $p = 0.031$), nonparametric analysis was performed to identify potential differences among the three groups. A Kruskal-Wallis H test indicated that there was no significant difference in *QIST Career Aspiration Formation and Self-Concept* between students with different levels of mathematics preparation, $\chi^2(2) = 2.44$, $p = 0.296$. For the analyses of prior science and mathematics coursetaking, the mean scores are similar for some tests and the statistically significant difference is partly attributed to the difference in standard error, although the sample is adequately powered (80%) for ANCOVA. In future research, a larger sample may yet improve the clarity and generalizability of the results. Descriptive statistics are summarized in Table 4.

4.4 Attitudinal comparisons based on demographics

ANCOVA analyses were also explored to determine whether there were differences in student outcomes based upon demographics (gender, ethnicity, grade level). Homogeneity of variance for student outcomes was indicated for each set of comparisons ($p > 0.05$). There was no difference between women and men in *QIST Career Aspiration Formation and Self-Concept* ($F(1, 104) = 0.67$; $p = 0.414$); and no difference between students in racialized minority groups vs. students of White and Asian ethnicities ($F(1, 104) = 0.67$; $p = 0.414$). To compare outcomes by grade level, ANOVA with post hoc Tukey comparisons were

Table 4 Descriptive Statistics of QIST Career Aspiration Outcomes by Prior STEM Course Completion

Discipline	Status	*N*	Estimated marginal mean	*SE*	95% confidence interval	
					Lower	Upper
Post-Survey *QIST Career Aspiration Formation and Self-Concept*						
Chemistry**	Completed course	73	19.50	0.32	18.86	20.14
	Did not complete course	33	17.90	0.48	16.95	18.85
Physics*	Completed course	44	19.66	0.42	18.83	20.50
	Did not complete course	62	18.53	0.36	17.83	19.23
Science Research	Completed course	32	19.44	0.50	18.44	20.44
	Did not complete course	74	18.81	0.33	18.15	19.47
Computer Science	Completed course	37	19.53	0.46	18.60	20.44
	Did not complete course	69	18.72	0.34	18.05	19.39
Mathematics	Completed Geometry	26	18.04	0.94	16.10	19.98
	Completed Algebra II	70	19.07	0.40	18.26	19.88
	Completed Precalculus	16	20.31	0.93	18.34	22.28

*$p < 0.05$; **$p < 0.01$.

Table 5 Descriptive Statistics of QIST Career Aspiration Outcomes by Demographic

Demographic	Descriptor	*N*	Estimated marginal mean	*SE*	95% confidence interval	
					Lower	Upper
Post-Survey *QIST Career Aspiration Formation and Self-Concept*						
Gender	Female	48	18.75	0.41	17.94	19.57
	Male	58	19.21	0.37	18.47	19.95
Ethnicity	URM	26	19.13	0.32	18.50	19.76
	Non-URM	80	18.60	0.56	17.49	19.71
Grade Level	10	29	17.83	0.83	16.12	19.54
	11	41	19.05	0.55	17.93	20.16
	12	42	19.81	0.53	18.73	20.89

URMS = underrepresented minority in STEM (Hispanic, Black, Native American, Pacific Islander).
Non-URMS = non-underrepresented minority in STEM (Asian, White).

run. There were no differences by grade level ($F(1, 109) = 1.57$; $p = 0.200$). No interaction effects were observed among demographic characteristics ($p > 0.05$). Descriptive statistics are summarized in Table 5.

5 Discussion and implications

5.1 Instrument development and attitudinal outcomes

The goals of this work were to create a valid, reliable instrument for measuring QIST attitudes and latent constructs, and to measure how these attitudes may have changed as a result of participation in a QIST outreach intervention for high school students. Research has shown that there is a need for assessments to measure outcomes of precollege QIST education [15]. The attitudinal survey was first designed and tested with 25 items, yet after several iterations, 15 remaining items were sorted into two distinct and stable attitudinal factors – (1) QIST interest and behavioral intentions, and (2) QIST career aspiration formation and self-concept. This instrument is a promising tool for assessing QIST attitudes in formal and informal education programs, although more research is needed to consider additional factors such as understanding the relevance of QIST. Such factors would ideally increase the variance explained by the treatment. Additional research would also shed light upon the specific programmatic elements that influenced QIST career aspiration formation, such as engaging with multiple representations of QIST phenomena, interacting

with role models, learning about the societal benefits of QIST applications, facilitating communities of practice, and receiving critical feedback from QIST experts, all of which are common elements in precollege QIST outreach [8–10, 12–15, 35, 36, 48, 49].

Once the survey was validated and reliability was established, the data analysis suggested mixed student attitudinal outcomes from participation in the summer QIST outreach program. Data indicated that students improved their overall attitudes with a small to medium effect size, however, this was not true for both constructs. Students improved their career aspiration formation development with a medium to large effect size but their QIST interest did not improve. Students were also more likely to elect advanced courses in mathematics and physics with a small effect size. These results have several implications. The increase in career aspirations was a positive outcome, suggesting that several programmatic aspects were effective – including the career panels, graduate student panels, university admissions sessions, and quantum experimental laboratory tours. This aligned with students' improved intentions to take as much mathematics and science as possible in high school. These changes indicated that students successfully learned about academic choices that would best prepare them for STEM and QIST career intentions, consistent with research that suggested students require knowledge of academic pathways and vocational choices to align their personal ambitions with career intentions [47, 50, 51]. However, these results should be interpreted with caution, since most students had already intended to take four years of mathematics and science.

Students' unchanged QIST interest suggests two possibilities. First, students entered the program with a high level of QIST interest and there was not much room for improvement. This "ceiling effect" has been identified in STEM programs in which students self-select based on prior interest and curiosity [50]. Secondly, other program components may have had limited effectiveness in this domain. The emphasis on relevant QIST applications and computer skills may not have inspired students' engagement in QIST beyond their baseline. The intrinsic value of a discipline has been shown to predict STEM interest [52]. This is a consideration in future outreach programs, which may be improved with additional applications that have explicit societal benefits, which have been shown to facilitate interest [19–21]. The exploratory factor analysis provided the researchers with more nuanced information on where programmatic improvements might be targeted, however, future research will explore how specific program elements may have influenced student outcomes.

5.2 Relationship of student outcomes to demographic and academic variables

Changes or stability in QIST attitudes were independent of students' gender, ethnicity, grade level, and academic background. This result is promising since research has suggested that self-efficacy and interest in QIST-adjacent fields such as physics, mathematics, engineering, and computer science are often related to demographic variables. Women are less likely to formulate career intentions in mathematically intensive fields, often due to chilly academic climates, lack of role models, or the perception that these disciplines are for the academic elite [19, 21, 24–26]. Similarly, ethnic minorities underrepresented in STEM have been less likely to aspire to STEM careers than White high school students [53]. The present study contradicts much of this prior work, suggesting that the opportunity to participate in QIST secondary outreach programs results in equitable attitudinal outcomes when considering gender and race. This is an important consideration since QIST-adjacent fields typically employ fewer women and students of color [21, 54].

Prior mathematics, science research, and computer science coursetaking did not influence students' QIST attitudes; however, QIST career aspiration formation was more pronounced for students who had taken chemistry and physics. This is important since QIST may have an elitist connotation that suggests only the brightest and most accomplished students may pursue careers in the field [55]. Research has shown that exposure to advanced STEM coursework in high school influences career intentions, particularly for students of color [56]; however, the present study found that prior coursetaking was often not a limiting factor in QIST career aspiration formation. This study demonstrated that QIST precollege interventions may be designed to overcome the inherent limitations of prior exposure to computer science and advanced mathematics with an emphasis on multiple representations of complex ideas [9, 10, 13, 14]. In doing so, more students could envision themselves in QIST careers.

5.3 Limitations and future research

This study had several limitations. Students self-selected into the summer program, so they may not have been representative of the general high school population. The sample size was somewhat small given the varying thresholds for exploratory factor analysis recommended by researchers. Future studies might further develop this instrument with a larger sample and additional items to capture other affective constructs. An additional sample of students is also needed for confirmatory factor analysis, which could validate the exploratory factor analysis and provide causal models for relationships between cognitive and affective variables [57]. Longitudinal studies would provide insights into how participation in QIST precollege outreach might influence the choice of college major and persistence towards QIST careers. This instrument could also be used with QIST educational programs that do not involve self-selected students, since changes in QIST interest may be more pronounced. Since students were self-selected, this many limit the generalisability of the results to other high school populations. Future iterations of the QIST outreach program will include more qualitative research through interviews and focus groups to identify nuanced perspectives of how students form attitudes towards QIST learning.

This study is one of the first of its kind to develop an instrument for measuring QIST attitudes in precollege outreach. Furthermore, data analysis indicated growth in QIST career aspiration formation, regardless of gender, ethnicity, or mathematics and computer science background. QIST interest remained unchanged. This research suggests that QIST precollege education is accessible to students of all backgrounds, which is promising given the increasing need to develop a diversified talent pool of QIST workers to meet global demands for these revolutionary technologies.

Abbreviations

ANCOVA, analysis of covariance; ANOVA, analysis of variance; CI, confidence interval; DRL, Division of Research and Learning; ISI, informal science institution; Non-URMS, non-underrepresented minority in science, technology, engineering, and mathematics (Asian, White); QIST, quantum information science and technology; QKD, quantum key distribution; SE, standard error; STEM, science, technology, engineering, and mathematics; URMS, underrepresented minority in STEM (Black, Hispanic, Native American, Pacific Islander).

Supplementary information

Supplementary information accompanies this paper at https://doi.org/10.1140/epjqt/s40507-025-00313-w.

Additional file 1. (DOCX 20 kB)

Author contributions
AMK: conceptualization (lead and corresponding); writing – review and editing (lead); data collection and analysis (lead).
TCW: conceptualization (supporting); writing – review and editing (supporting); data collection and analysis (supporting).
DS: conceptualization (supporting); writing – review and editing (supporting); data collection and analysis (supporting).
MD: conceptualization (supporting); writing – review and editing (supporting); data collection and analysis (supporting).
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Data availability
Student data that support the results are not available due to restrictions designated by Institutional Review Board approval of research with human subjects (IRB #2022-00244).

Declarations

Competing interests
The authors declare no competing interests.

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References

1. H.R. 6227 – National Quantum Initiative Act [Internet]. 2018 [cited 2024 Oct 14]. https://www.congress.gov/bill/115th-congress/house-bill/6227/text.
2. H.R. 6213 – The National Quantum Initiative Reauthorization Act [Internet]. 2023 [cited 2024 Oct 14]. https://science.house.gov/bills?ID=5DA4C2C3-2C01-44CD-B548-F1D2CEEBCA02.
3. National Science and Technology Council, Subcommittee on Quantum Information Science. Quantum information science and technology workforce development national strategic plan [Internet]. 2018 [cited 2024 Oct 14]. https://www.quantum.gov/wp-content/uploads/2022/02/QIST-Natl-Workforce-Plan.pdf.
4. QED-C. Quantum Consortium. Enabling the quantum ecosystem [Internet]. 2024 [cited 2024 Oct 14]. https://quantumconsortium.org/.
5. QED-C. Quantum Technology Workforce Monitoring Report [Internet]. September 5, 2024 [cited 2024 Oct 15]. https://quantumconsortium.org/blog/quantum-technology-workforce-monitoring-report-2/.
6. QED-C. Guide to Building a Quantum Technician Workforce [Internet]. October 23, 2023 [cited 2024 Oct 15]. https://quantumconsortium.org/workforce23/.
7. Subcommittee on Quantum Information Science, National Science and Technology Council. National strategic overview for quantum information science [Internet]. 2018 [cited 2024 Oct 15]. https://www.quantum.gov/wp-content/uploads/2020/10/2018_NSTC_National_Strategic_Overview_QIS.pdf.
8. Ivory M, Bettaale A, Boren R, Burch AD, Douglass J, Hackett L, Keifer B, Kononov A, Long M, Metcalf M, Porpp TB, Sarovar M. Quantum computing, math, and physics (QCaMP): Introducing quantum computing in high schools. 2023. arXiv:2309.16788.
9. Economou E, Rudolph T, Barnes E. Teaching quantum information science to high-school and early undergraduate students. 2020. arXiv:2005.07874.
10. Satenassi S, Fantini P, Spada R, Levrini O. Quantum computing for high school: an approach to interdisciplinary in STEM teaching. J Phys Conf Ser. 2021;1929:012053. https://doi.org/10.1088/1742-6596/1929/1/012053.
11. Akdemir Z, Menekse M, Hosseini M, Nandi A, Furuya K. Introducing quantum key distribution to high school students. Sci Teach. 2021;88:44–51. https://doi.org/10.1080/00368555.2021.12293585.
12. Hughes C, Isaacson J, Turner J, Perry A, Sun R. Teaching quantum computing to high school students. Phys Teach. 2022;60:187–9. https://doi.org/10.1119/10.0009686.
13. Walsh J, Fenech M, Tucker D, Riegle-Crumb C, La Cour BR. Piloting a full-year, optics-based high school course on quantum computing. Phys Educ. 2022;57:025010. https://doi.org/10.1088/1361-6552/ac3dc2.
14. Angara PP, Stege U, Maclean A, Muller HA, Markham T. Teaching quantum computing to high-school-aged youth: a hands-on approach. IEEE Trans Quantum Eng. 2022. 1–15. https://doi.org/10.1109/TQE.2021.3127503.
15. Darienzo M, Kelly AM. Review of literature on quantum information science and technology programs for high school students. In: Quantum Sci Eng Educ Conf. (QSEEC 2024). Montreál, QC, Canada. 2024. p. 96–103. https://doi.org/10.1109/QCE60285.2024.20464.
16. Labudde P, Herzog W. Girls and physics: teaching and learning strategies tested by classroom interventions in grade 11. Int J Sci Educ. 2000;22(2):143–57. https://doi.org/10.1080/095006900289921.
17. Alexoopoulou E, Driver R. Gender differences in small group discussion in physics. Int J Sci Educ. 1997;19(4):393–406. https://doi.org/10.1080/0950069970190403.

18. Watkins J, Mazur E. Retaining students in science, technology, engineering, and mathematics (STEM) majors. J Coll Sci Teach. 2013;42(5):36–41. https://www.jstor.org/stable/43631580.
19. Koul R, Lerdpornkulrat T, Chantara S. Relationship between career aspirations and measures of motivation toward biology and physics, and the influence of gender. J Sci Educ Technol. 2011;20:761–70. https://doi.org/10.1007/s10956-010-9269-9.
20. Smit R, Dober H, Hess K, Bachmann P, Birri T. Supporting primary students' mathematical reasoning practice: the effects of formative feedback and the mediating role of self-efficacy. Res Math Educ. 2023;25(3):277–300. https://doi.org/10.1080/14794802.2022.2062780.
21. Wang MT, Degol JL. Gender gap in science, technology, engineering, and mathematics (STEM): current knowledge, implications for practice, policy, and future directions. Educ Psychol Rev. 2017;2017(29):119–40. https://doi.org/10.1007/s10648-015-9355-x.
22. Dou R, Cian H. Constructing STEM identity: an expanded structural model for STEM identity research. J Res Sci Teach. 2022;59(3):458–90. https://doi.org/10.1002/tea.21734.
23. Singer A, Montgomery G, Schmoll S. How to foster the formation of STEM identity: studying diversity in an authentic learning environment. Int J STEM Educ. 2020;7:57. https://doi.org/10.1186/s40594-020-00254-z.
24. Leslie SJ, Cimpian A, Meyer M, Freeland E. Expectations of brilliance underlie gender distributions across academic disciplines. Science. 2015;347(6219):262–5. https://doi.org/10.1126/science.1261375.
25. Master A, Meltzoff AN, Cheryan S. Gender stereotypes about interests start early and cause gender disparities in computer science and engineering. Proc Natl Acad Sci. 2021;118(48):e2100030118. https://doi.org/10.1073/pnas.210003011.
26. Bian L, Leslie SJ, Cimpian A. Gender stereotypes about intellectual ability emerge early and influence children's interests. Science. 2017;355(6323):389–91. https://doi.org/10.1126/science.aah6524.
27. Lee H, Hernandez PR, Tise JC, Du W. How role models can diversify college students in STEM: a social-cognitive perspective. Theory Pract. 2023;62(3):232–44. https://doi.org/10.1080/00405841.2023.2226554.
28. Richardson DS, Bledsoe RS, Cortez Z. Mindset, motivation, and teaching practice: psychology applied to understanding teaching and learning in STEM disciplines. CBE–Life Sci Educ. 2020;19(3):ar46. https://doi.org/10.1187/cbe.19-11-0238.
29. Weissman H, Glennon M, Twarek B, Dunton S, Childs J. State of Computer Science Education [Internet]. Seattle: Code.org, CSTA, ECEP Alliance; 2023 [cited 2024 Nov 3]. https://advocacy.code.org/2023_state_of_cs.pdf.
30. National Science Board. Science and Engineering Indicators 2018: Elementary and Secondary Science and Mathematics Education [Internet]. Washington, DC: National Science Foundation; 2018 [cited 2024 Nov 3]. https://www.nsf.gov/statistics/2018/nsb20181/report/sections/elementary-and-secondary-mathematics-and-science-education/high-school-coursetaking-in-mathematics-and-science#science-coursetaking-by-high-school-completers.
31. White S, Tyler J. Underrepresented Minorities in High School Physics [Internet]. College Park, MD: AIP Statistical Research Center. 2015 [cited 2024 Nov 3]. https://www.aip.org/sites/default/files/statistics/highschool/hs-underrepmin-13.pdf.
32. IBM Quantum Composer. https://quantum.ibm.com/composer/.
33. National Q-12 Education Partnership. QIS Key Concepts for Early Learners: K-12 Frameworks. National Q-12 Education Partnership. 2023 [cited 2024 Nov 3]. https://q12education.org/learning-materials-framework.
34. NGSS Lead States. Next Generation Science Standards: by States, for States. 2013 [cited 2024 Nov 3]. https://www.nextgenscience.org/.
35. Darienzo M, Kelly AM, Wei TC, Schneble D. Students' attitudes toward quantum information science and technology in a high school outreach program. Phys Rev Phys Educ Res. 2024;20(2):020126. https://doi.org/10.1103/PhysRevPhysEducRes.20.020126.
36. Schneble S, Wei TC, Kelly AM. Quantum information science and technology secondary outreach: conceptual progressions for introducing principles and programming skills. Am J Phys. 2025;93(1):88–97. https://doi.org/10.1119/5.0211535.
37. Mundfrom DJ, Shaw DG, Ke TL. Minimum sample size recommendations for conducting factor analyses. Int J Test. 2005;5(2):159–68. https://doi.org/10.1207/s15327574ijt0502_4.
38. Henson RK, Roberts JK. Use of exploratory factor analysis in published research: common errors and some comment on improved practice. Educ Psychol Meas. 2006;66(3):393–416. https://doi.org/10.1177/0013164405282485.
39. Worthington RL, Whittaker TA. Scale development research: a content analysis and recommendations for best practices. Couns Psychol. 2006;34(6):806–38. https://doi.org/10.1177/0011000006288127.
40. Adams WK, Perkins KK, Podolefsky NS, Dubson M, Finkelstein ND, Wieman CE. New instrument for measuring student beliefs about physics and learning physics: the Colorado learning attitudes about science survey. Phys Rev ST–PER. 2006;2(1):010101. https://doi.org/10.1103/PhysRevSTPER.2.010101.
41. Pituch KA, Stevens JP. Applied multivariate statistics for the social sciences. Analyses with SAS and IBM's SPSS. London: Routledge; 2015.
42. Leech NL, Barrett KC, Morgan GA. SPSS for intermediate statistics 2nd ed: Use and Interpretation. J Chem Inf Model. 2005.
43. Kelly AM. Social cognitive perspective of gender disparities in undergraduate physics. Phys Rev Phys Educ Res. 2016;12(2):020116. https://doi.org/10.1103/PhysRevPhysEducRes.12.020116.
44. Pintrich PR De Groot EV. Motivational and self-regulated learning components of classroom academic performance. J Educ Psychol. 1990;82(1):33–40.
45. Lockhart ME, Kwok OM, Yoon M, Wong R. An important component to investigating STEM persistence: the development and validation of the science identity (SciID) scale. Int J STEM Educ. 2022;9(1):34. https://doi.org/10.1186/s40594-022-00351-1.
46. Glynn SM, Brickman P, Armstrong N, Taasoobshirazi G. Science motivation questionnaire II: validation with science majors and nonscience majors. J Res Sci Teach. 2011;48(10):1159–76. https://doi.org/10.1002/tea.20442.
47. Ajzen I. Perceived behavioral control, self-efficacy, locus of control, and the theory of planned behavior. J Appl Soc Psychol. 2002;32(4):665–83. https://doi.org/10.1111/j.1559-1816.2002.tb00236.x.

48. Tappert CC, Frank RI, Barabasi I, Leider AM, Evans E, Westfall L. Experience teaching quantum computing. Assoc Supporting Comp Users Educ. (ASCUE) Proc. 2019:46–60. https://eric.ed.gov/?id=ED597112.
49. Matsler KJ, Lopez R, Singh C. Applying classroom practices learned from virtual professional development during a pandemic. Phys Teach. 2024;62(1):41–6. https://doi.org/10.1119/5.0107084.
50. Bugallo MF, Kelly AM, Ha M. Impact of a university-based electrical and computer engineering summer program for high school students. Int J Eng Educ. 2015;31(5):1419–27.
51. Gearns R, Kelly AM, Bugallo MF. School counseling practices related to postsecondary STEM participation. Career Dev Q. 2024;72(1):2–17. https://doi.org/10.1002/cdq.12338.
52. Ball C, Huang KT, Cotten SR, Rikard RV. Pressurizing the STEM pipeline: an expectancy-value theory analysis of youths' STEM attitudes. J Sci Educ Tech. 2017;26:372–82. https://doi.org/10.1007/s10956-017-9685-1.
53. Mau WC, Li J. Factors influencing STEM career aspirations of underrepresented high school students. Career Dev Q. 2018;66(3):246–58. https://doi.org/10.1002/cdq.12146.
54. Policy, Global Affairs, Committee on Science, Public Policy, Committee on Underrepresented Groups, the Expansion of the Science, Engineering Workforce Pipeline. Expanding underrepresented minority participation: America's science and technology talent at the crossroads. National Academies Press; 2011.
55. Johansson A, Nyström AS, Gonsalves AJ, Danielsson AT. Performing legitimate choice narratives in physics: possibilities for under-represented physics students. Cult Stud Sci Educ. 2023;18(4):1255–83.
56. Wang X. Why students choose STEM majors: motivation, high school learning, and postsecondary context of support. Am Educ Res J. 2013;50(5):1081–121. https://doi.org/10.3102/0002831213488622.
57. Cabrera-Nguyen P. Author guidelines for reporting scale development and validation results in the Journal of the Society for Social Work and Research. J Soc Soc Work Res. 2010;1(2):99–103. https://doi.org/10.5243/jsswr.2010.8.

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