Quantum Education at Minority Serving Institutions: Insights from Faculty Perspectives

Shabnam Sodagari
Computer Engineering & Computer Science
California State University, Long Beach, CA, USA
shabnam@csulb.edu

Ali Rezaei
Advanced Studies in Education & Counseling
California State University, Long Beach, CA, USA
ali.rezaei@csulb.edu

***Abstract*—This study investigates the landscape of quantum computing education through the lens of higher education faculty at Minority Serving Institutions. By examining data from participants in a specialized quantum computing workshop, we identify key factors influencing both educator proficiency and pedagogical effectiveness. The study uses principal component analysis, exploratory factor analysis, and correlation analysis to reveal latent patterns and interconnections in quantum education practices. The findings of the principal component analysis highlight dimensions such as technical knowledge, instructional support, and hands-on experiential learning, while the exploratory factor analysis uncovers latent constructs related to mentorship, inclusive pedagogy, and technical mastery. Correlation analysis shows strong relationships between faculty confidence and their grasp of core quantum concepts, such as quantum gates, multi-qubit states, and quantum algorithms, emphasizing the cascading effect of mastering foundational topics. The workshop significantly enhanced participants' understanding of quantum frameworks and practical applications. Gender-based analysis revealed that male participants reported higher confidence boosts, suggesting the need for targeted support. This research also underscored the importance of industry collaborations and research integration in quantum curricula. These findings provide actionable insights for curriculum design and professional development, emphasizing the need to balance technical competencies, hands-on engagement, and sustained mentorship to foster a diverse quantum workforce.**

***Index Terms*—Quantum Education, Minority Serving Institutions, Faculty Perspectives, Higher Education**

INTRODUCTION

The goal of this research is to explore and enhance the effectiveness of quantum computing education by focusing on the experiences and perspectives of faculty members who are responsible for teaching at minority-serving institutions. By analyzing the outcomes of a specialized quantum computing workshop, this study aims to identify key factors that influence quantum teaching proficiency. The target audience for this research includes educators, curriculum developers, and policy-makers involved in quantum education, as well as institutions seeking to strengthen their quantum computing programs.

Research Question: *How do faculty perceptions of professional development workshops influence their confidence and effectiveness in teaching quantum computing concepts?*

As educational institutions strive to prepare the next generation of quantum computing professionals, understanding the perspectives of faculty becomes crucial. One of the significant challenges in quantum education is the inherently complex and counterintuitive nature of quantum mechanics, which underpins quantum computing [1]. This makes this subject challenging to teach at various educational levels. To address this, innovative educational approaches, such as the use of visual and hands-on learning, are being implemented to make quantum concepts more accessible [1].

Another critical aspect of quantum education is workforce development, i.e., the importance of building a quantum-smart workforce to meet the demands of the rapidly growing quantum industry [2]. Quantum education programs must be inherently interdisciplinary, combining elements of physics, engineering, and computer science to equip students with the necessary skills for the quantum era. There is a need for collaboration between academia, industry, and policymakers to create comprehensive and inclusive quantum education programs that can adapt to the evolving needs of the quantum industry.

While there is a significant push to develop quantum education programs, there remains a gap between the current educational offerings and the skills required by the quantum industry. This gap underscores the importance of ongoing curriculum development and the need for educational institutions to remain agile in response to the fast-paced advancements in quantum technologies [3].

Explorations of curriculum development for quantum computing education highlight the importance of integrating quantum mechanics, quantum algorithms, and quantum programming into educational frameworks [4], [5] with an emphasis on the need for a foundational understanding of quantum principles among students before they can effectively engage with more complex topics such as quantum cryptography and quantum algorithms. This foundational focus is supported by the argument that without a robust grounding in basic quantum mechanics, students struggle with the advanced concepts that are critical for proficiency in quantum computing.

Despite the progress in curriculum design, there are significant challenges in quantum education, particularly concerning the gap between theoretical knowledge and practical application. For instance, the difficulties students face in applying theoretical quantum knowledge to programming tasks suggest a need for more practical, hands-on experiences within the curriculum [5] and the importance of aligning educational content with

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industry demands to adequately prepare students for the practical realities of quantum computing careers.

The current study distinguishes itself from previous research by focusing specifically on the perspectives of faculty members involved in quantum computing education, a viewpoint that has been less explored in the literature. While much of the existing research centers on student experiences and curriculum development [6], [7], [8], this study provides a comprehensive analysis of faculty experiences and the challenges they face in teaching quantum concepts.

The insights gained from this research have the potential to inform the design of future faculty training programs and enhance the overall quality of quantum computing education.

The contributions of this paper, include, but are not limited to:

- Contribution to the broader field of quantum computing education by offering evidence-based insights that can inform curriculum development and teaching practices.
- Exploration of correlation analysis, principal component analysis, and exploratory factor analysis for various aspects of quantum education.

In the following sections, we detail our methodology, present the results of our analyses, and discuss the implications for curriculum development.

I. Methodology

A faculty professional development workshop in quantum sciences was organized which had several sessions on topics, such as fundamental principles & theoretical foundations of quantum computing, quantum cryptography, quantum network simulation, quantum algorithm, multi-qubit states, industry applications, etc.

Quantitative data were analyzed using principal component analysis (PCA), exploratory factor analysis (EFA), and correlation analysis. Participation in the survey was voluntary and respondents were informed of the confidentiality of their responses, through IRB approval [2122560-1]. The recruitment period for this study was conducted on May-June 2024. In the next section, we describe the results of the analysis.

Correlation Analysis

This exploration will help us understand how different aspects of quantum education are interconnected from the viewpoint of faculty teaching at minority-serving institutions, which can be crucial for targeted improvements. Figure 1 presents a heatmap of Spearman's rank correlation coefficients relating boosted self-confidence of faculty at minority-serving institutions in teaching quantum to various concepts in the quantum science. The *Boosted confidence in teaching quantum information* shows positive correlations (≈ 0.7 to 0.83) with all other topics, supporting the idea that these curriculum topics are essential for professional development of faculty who later train quantum workforce among students.

The heatmap further reveals that foundational concepts, such as *Quantum algorithms* and Quantum gates & circuits, show a very high correlation (0.94), indicating that high confidence in one of these areas were likely to report high confidence in the other. *Industry applications of quantum utility* and *Quantum programming languages* also exhibit strong correlations with other topics (e.g., 0.83 with *Quantum computing foundations*), reflecting perceived interconnectedness between the practical applications and theoretical knowledge. In addition, *Quantum cryptography* and *Multi-qubit states* exhibit moderately strong correlations ($\approx 0.7 - 0.76$) with more general topics, such as *Superposition, entanglement, and measurement*.

The results suggest that participants' understanding and confidence in quantum computing topics are interconnected, highlighting the importance of reinforcing both fundamental and advanced topics to build overall competence. This analysis informs future curriculum design by identifying areas where improvements in one aspect may have cascading effects on others.

In the following, we present an interpretation of the results soliciting faculty perspectives on quantum education for students at minority serving institutions and faculty professional development. The analysis leverages principal component analysis and exploratory factor analysis to identify key themes and latent constructs that emerged.

Principal Component Analysis

The results from PCA reveal key dimensions that influence quantum education practices. PCA focuses on maximizing the variance explained by each principal component [9], making it a useful tool for summarizing broad faculty perceptions of quantum education.

Figs. 2, 3, 4, and 5 highlight the major contributors to the principal components (PC1, PC2, PC3, PC4), each representing a different dimension of variance in the perspectives of faculty.

More specifically, PC1 (Foundational and Technical Knowledge) in Fig. 2 sees strong contributions from categories such as *Multi-Qubit States*, *Quantum Computing Foundations*, and *Quantum Algorithms*. This reflects the importance faculty place on ensuring that students master core quantum concepts and technical skills. Furthermore, PC2 (Instructional Support and External Collaboration/Mentorship) in Fig. 3 includes categories such as *Guest Speakers' Proficiency*, *Integration of Content into Research*, *Inclusive & Supportive Pedagogy*, and *Project-Based Student Learning*. This highlights the role of external expertise, cross-disciplinary projects, and research integration in enhancing quantum education. Moreover, the prominence of *Boosted Confidence in Teaching Quantum Information* and *Guest Speakers' Proficiency* for PC3 (Quantum Teaching Confidence) in Fig. 4 suggests that professional development programs, particularly those involving external experts, significantly enhance faculty confidence in delivering quantum content. Finally, PC4 (Experimental and Conceptual Foundations) in Fig. 5 comprises contributions from *Superposition, Entanglement, Measurement*, *Quantum Network Simulation*, and *Industry Applications of Quantum Utility*. This indicates the importance of providing students with experimental resources and collaborative learning opportunities.

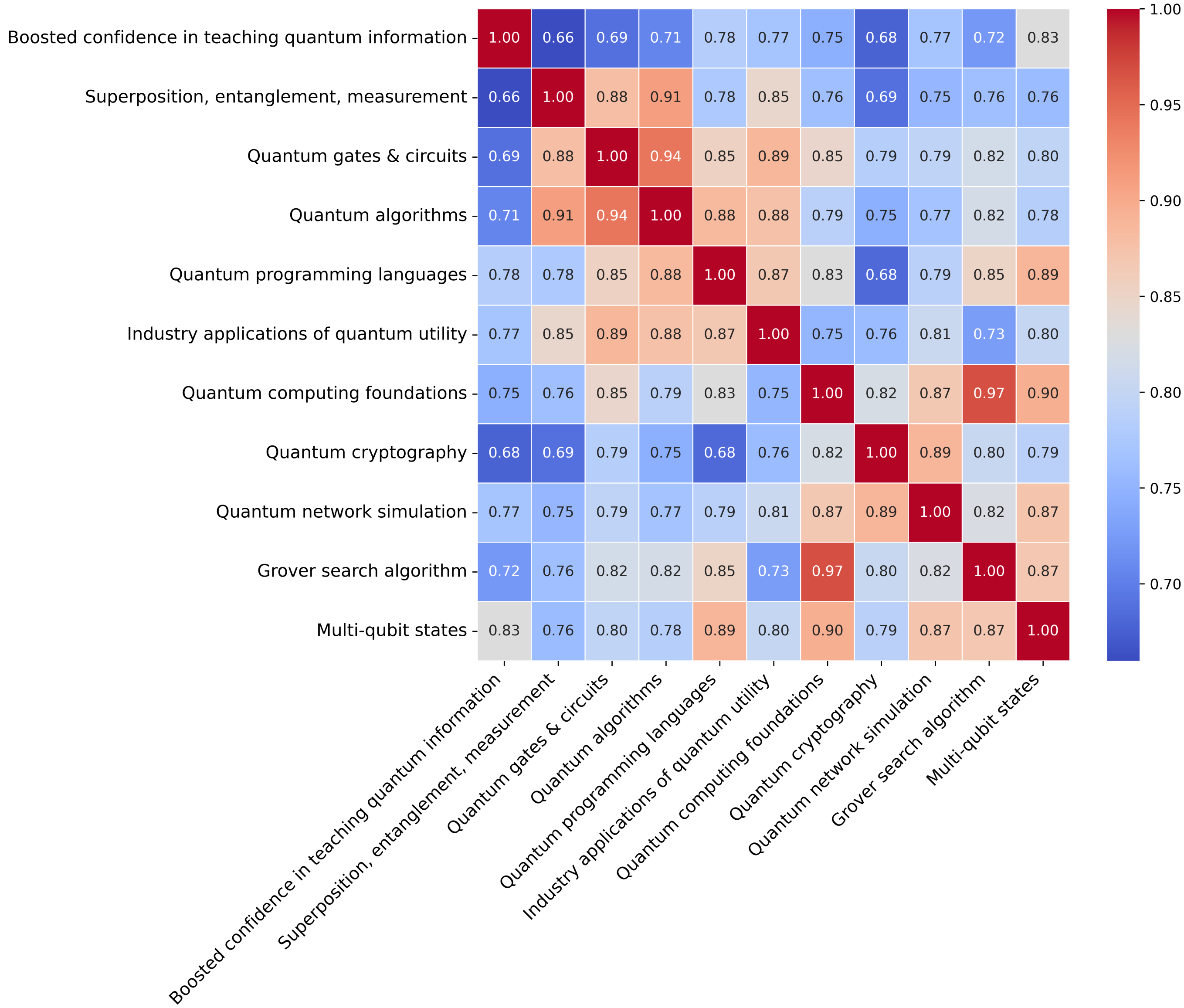

Fig. 1: Spearman correlation heatmap of various quantum concepts, showing the relationships between boosting confidence levels of faculty at minority serving institutions and key quantum computing topics.

II. Exploratory Factor Analysis

EFA attempts to uncover underlying latent factors, making it more effective for identifying the specific constructs that faculty associate with effective quantum instruction and professional growth.

The factor loadings (or top contributors for each factor) are plotted in Figs. 6, 7, 8, and 9. The EFA results offer insights into how faculty perspectives on quantum education at minority-serving institutions align with specific underlying constructs related to their teaching approaches, perceived challenges, and areas for professional growth. More specifically, Factor 1 (Technical Proficiency and Content Knowledge) in Fig. 6 emphasizes categories such as *Quantum Computing Foundations*, *Quantum Cryptography*, and *Multi-Qubit States*. It suggests that faculty prioritize technical mastery and foundational knowledge as essential for effective quantum education. Furthermore, Factor 2 (Pedagogy and Instructional Support) in Fig. 7 highlights elements such as *Quantum Pedagogy for Diverse Students*, *Quantum Teaching Capability Improvement*, and *Inclusive and Supportive Pedagogy*. This indicates that faculty value instructional tools and methods that improve student engagement and support diverse learners. Additionally, Factor 3 (Experimental Learning and Industry Relevance) in Fig. 8 includes categories such as *Superposition, Entanglement, Measurement*, *Quantum Gates & Circuits*, and *Industry applications*, which point to the importance of presenting these topics to minoratized students through hands-on experience and experimentation in quantum learning. Finally, Factor 4 (Professional Development

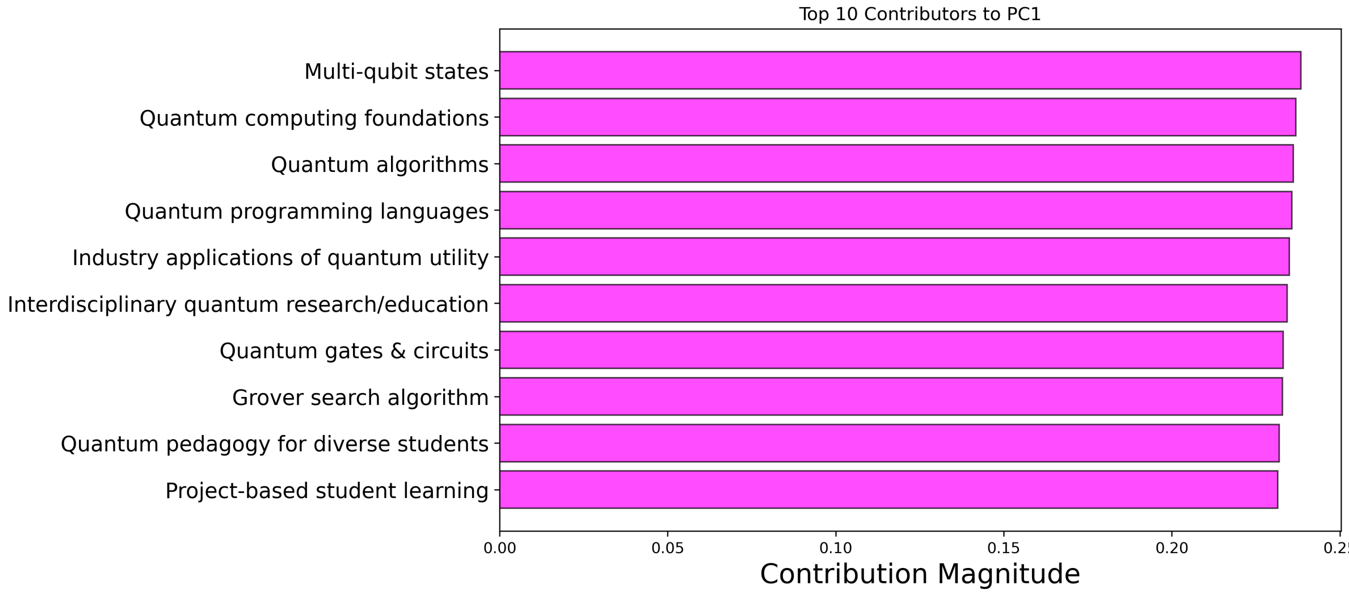

Fig. 2: Major contributors to principal component 1 (PC1)

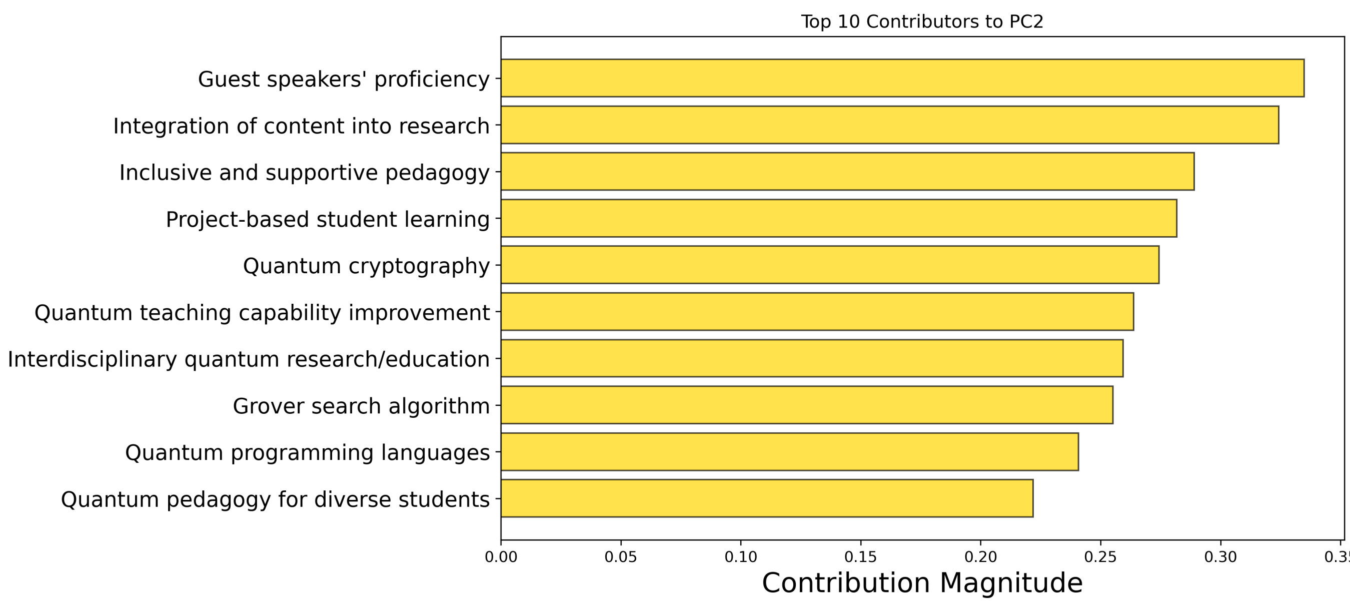

Fig. 3: Major contributors to principal component 2 (PC2)

and Mentorship) in Fig. 9 includes contributions from *Guest Speakers' Proficiency* and *Boosted Confidence in Teaching Quantum Information*, emphasizing the role of mentorship, professional development, and external resources in building faculty expertise.

Some categories appear across multiple factors, such as *Quantum Algorithms*, *Quantum Network Simulation*, *Hands-on Quantum Experiments*, and *Multi-Qubit States*, showing shared variance across different themes. This indicates overlap in how educational experience influences understanding.

Comparison of PCA and EFA Findings

The PCA and EFA reveal complementary insights into the structure of faculty perspectives on quantum education. Both analyses underscore the faculty's recognition of the importance of technical rigor, inclusive pedagogy, and professional development opportunities in delivering effective quantum education to students. More specifically, PC1 (Technical Foundations) emphasizes core technical topics, including *Quantum Computing Foundations*, *Multi-Qubit States*, *Quantum Algorithms*, and *Quantum Programming Languages*. This mirrors the technical focus seen in Factor 1 of EFA, indicating a shared

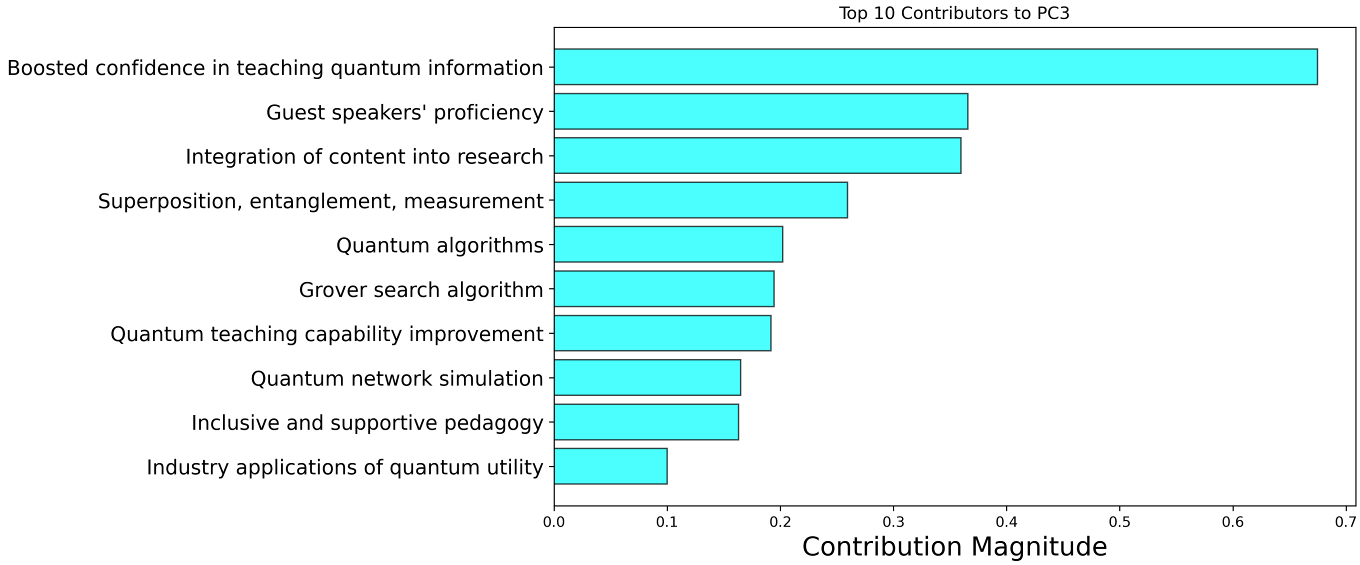

Fig. 4: Major contributors to principal component 3 (PC3)

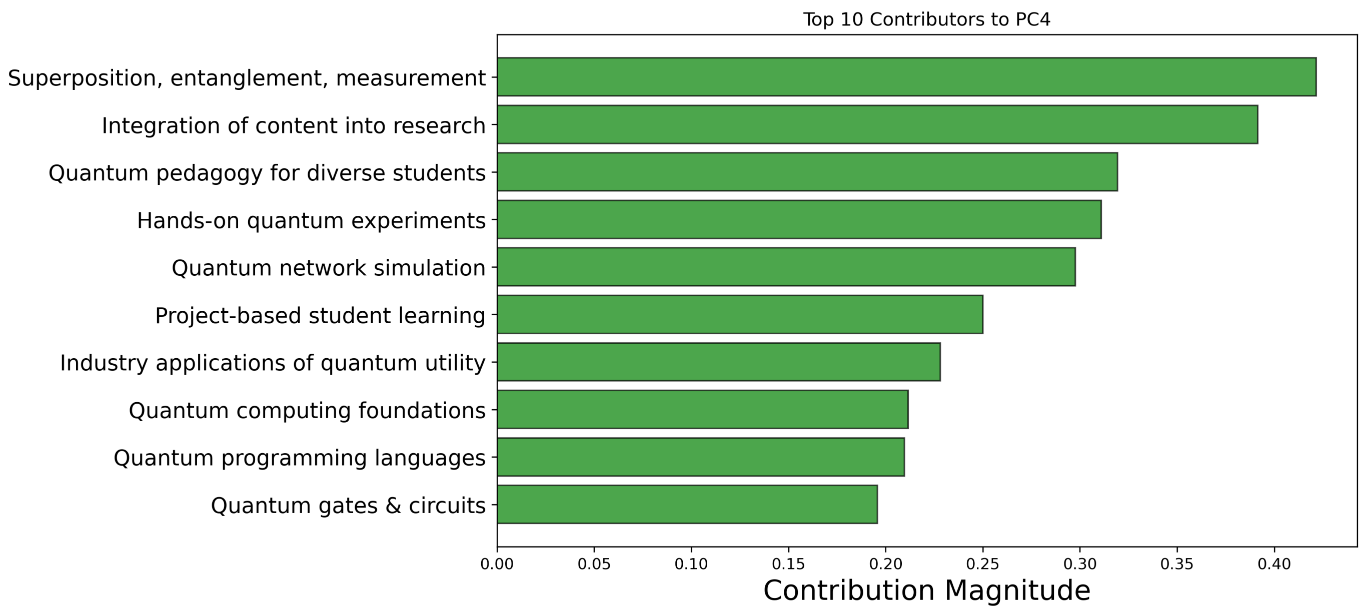

Fig. 5: Major contributors to principal component 4 (PC4)

focus on technical competency and suggesting that faculty consistently prioritize the foundational elements of quantum education. Moreover, key contributors to PC2 highlight the aspects of pedagogical support and collaboration, similar to the pedagogical emphasis in EFA Factor 2.

PC3 highlights the importance of *Boosted Confidence in Teaching Quantum Information*, aligning closely with mentorship and teaching support components in Factor 4 of EFA. Finally, topics like *Superposition, Entanglement, Measurement*, *Quantum Gates & Circuits*, and *Quantum Pedagogy for Diverse Students* in PC4 suggest a focus on both foundational concepts and experiential learning, reflecting elements in Factor 3 of EFA.

PCA provides a high-level view of the variance structure, identifying overarching themes like confidence, collaboration, and content knowledge. EFA, on the other hand, groups related survey questions into distinct latent constructs, offering insights into specific instructional strategies and professional support.

These findings provide valuable guidance for designing quantum curricula and faculty development programs that balance technical competencies, hands-on engagement, and professional mentorship.

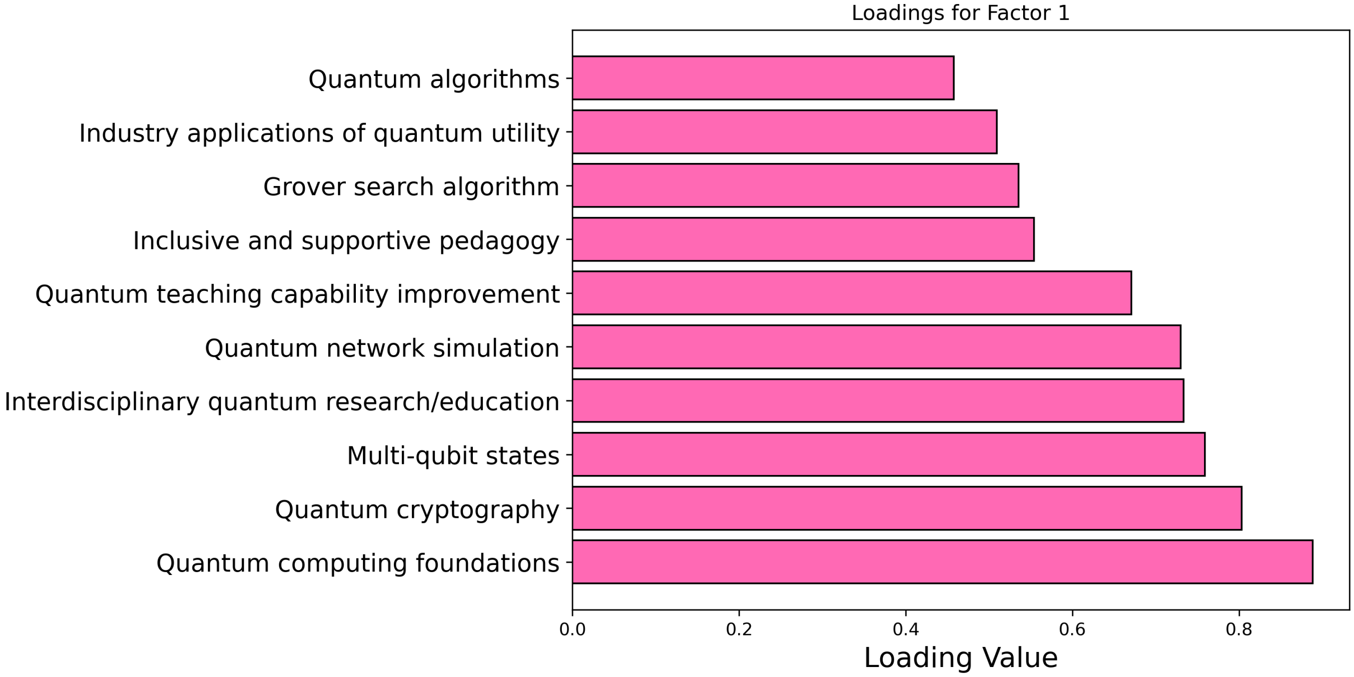

Fig. 6: Top ten loadings for factor 1 of EFA

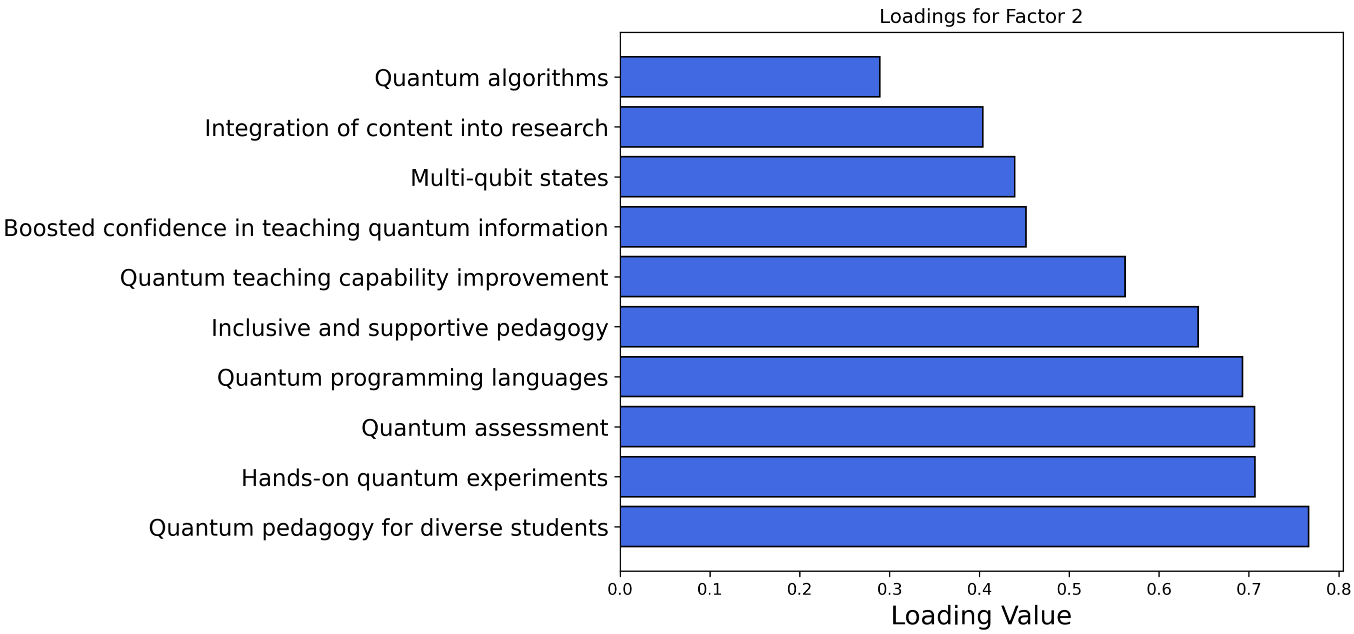

Fig. 7: Top ten loadings for factor 2 of EFA

ADDITIONAL INSIGHTS

Some results of Likert-type questions are summarized in Table I. Two significant gender differences were observed. The results showed that in comparison with female faculty, male participants were more satisfied with the topic of Multi-qubit states. Male faculty also reported a higher confidence in teaching quantum information after the workshop. 59% of the participants were male, 36% were female, and 5% preferred not to disclose their gender. In terms of ethnicity, 68% were white, 5% was Black or African American, 23% were Asian, and 5% identified as both Latino and Native Hawaiian or Pacific Islander. Among the faculty 55% had 1-5 years of teaching experience, 27% had 6-10 years of teaching experience, and 18% had more than 10 years of teaching experience. Most faculty members (82%) were new

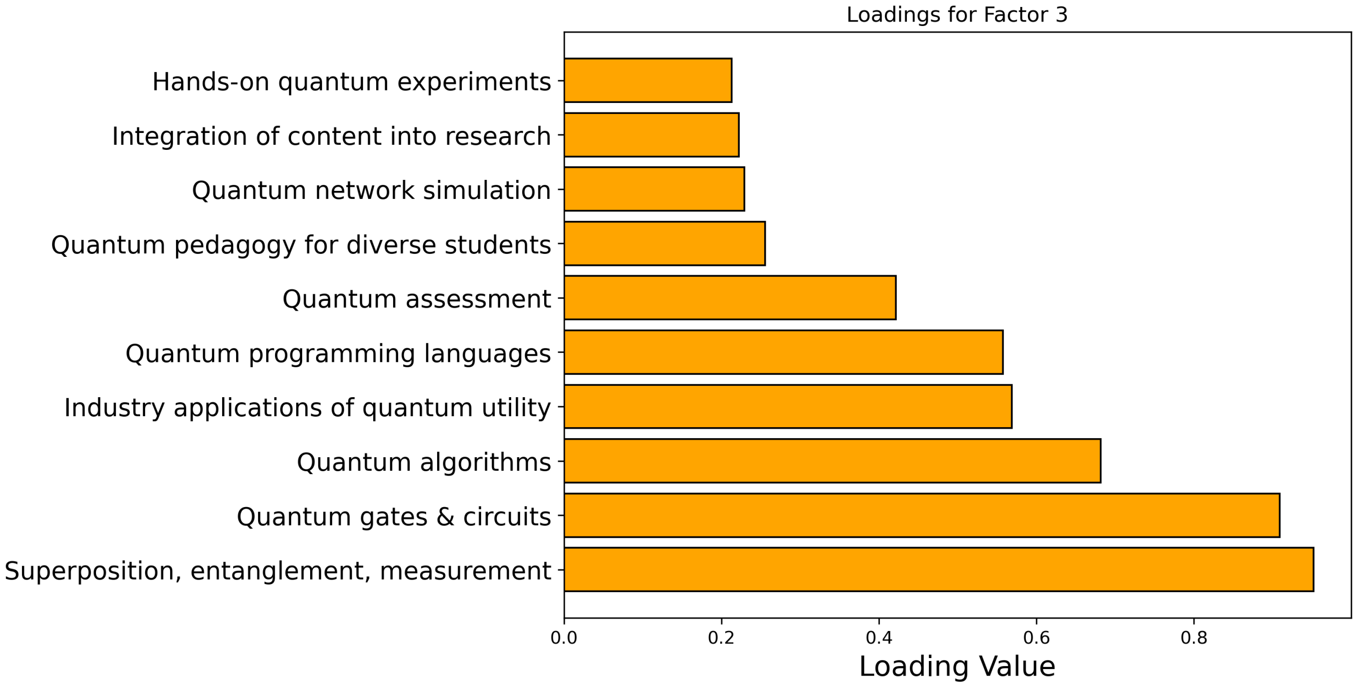

Fig. 8: Top ten loadings for factor 3 of EFA

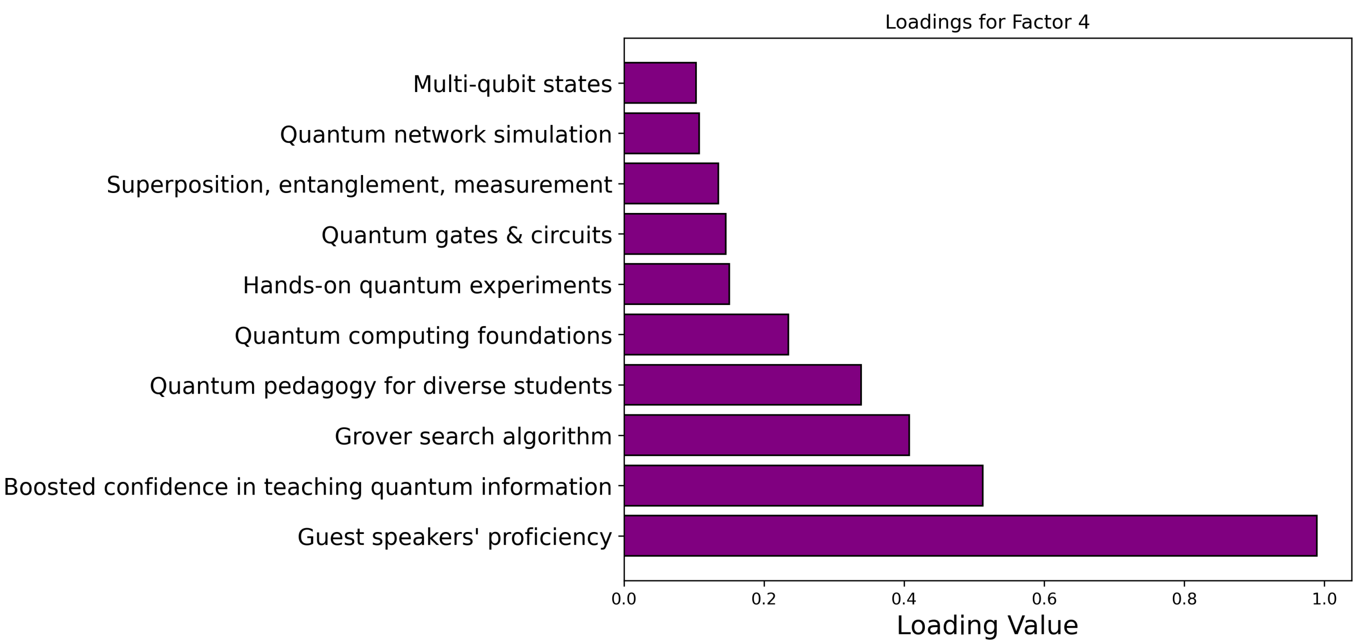

Fig. 9: Top ten loadings for factor 4 of EFA

to quantum information, while 14% identified as having an intermediate level of knowledge, and only 4% considered themselves advanced in quantum information.

The majority of participants (81.8%) were beginners in quantum information, making the workshop's foundational focus highly relevant. The workshop significantly enhanced their understanding of quantum mechanics principles like superposition, entanglement, and measurement, with 72.7% agreeing or strongly agreeing that their understanding improved. Additionally, familiarity with quantum gates & circuits saw substantial gains. Furthermore, 90.9% of participants indicated an enhanced understanding of quantum programming frameworks and languages such as Qiskit. This indicates the workshop's success in addressing key technological competencies.

TABLE I: Group Statistics Comparing Male and Female Responses to Various Aspects of a Quantum Computing Faculty Development

	Gender	Mean	Std. Deviation	Std. Error Mean
Fundamental principles and theoretical foundations of quantum computing.	Male	4.85	0.376	0.104
	Female	4.38	1.061	0.375
Quantum Cryptography	Male	4.23	0.725	0.201
	Female	4.25	1.035	0.366
Quantum Networking	Male	3.92	1.038	0.288
	Female	3.50	1.690	0.598
Advanced topics such as the Grover Search Algorithm	Male	4.85	0.376	0.104
	Female	4.75	0.463	0.164
Multi-qubit states.	Male	4.77	0.439	0.122
	Female	4.00	1.069	0.378
Rate the knowledge and proficiency of the guest speakers.	Male	4.92	0.277	0.077
	Female	4.88	0.354	0.125
Did the hands-on activities offer a valuable learning experience?	Male	4.77	0.439	0.122
	Female	4.25	1.035	0.366
Were networking opportunities adequate?	Male	2.83	0.389	0.112
	Female	2.63	0.744	0.263
Is your confidence in teaching Quantum Information boosted?	Male	2.75	0.452	0.131
	Female	1.88	0.835	0.295
Likelihood of workshop content integration into teaching or research	Male	6.00	1.477	0.426
	Female	5.13	2.100	0.743

In terms of pedagogical skills, 86.4% of participants felt better equipped to convey quantum concepts to students with diverse backgrounds, and 90.9% reported improved ability to design engaging learning activities. Proficiency in assessing student learning and fostering an inclusive learning environment also saw positive feedback, with 90.9% agreeing or strongly agreeing.

The workshop motivated 90.9% of participants to pursue continuous learning and engage in interdisciplinary research and education in quantum computing. Inclusivity and diversity were effectively promoted, with 90.9% of participants rating the efforts as effective or very effective. The workshop significantly boosted participants' confidence in teaching quantum information, with 81.8% feeling more confident.

Conclusion

By juxtaposing the findings from the faculty quantum computing workshop, this study provides a comprehensive analysis of faculty experiences in quantum computing education. Our findings highlight that quantum algorithms, quantum gates & circuits, mutli-qubit states, as well as industry applications of quantum utility play pivotal roles in improving teaching proficiency. Correlation analysis reveals strong interconnections between faculty confidence in teaching at minority-serving institutions and their grasp of core concepts, indicating that building expertise in one area can bolster understanding across related topics. Both Principal Component Analysis (PCA) and Exploratory Factor Analysis (EFA) underscore the importance of instructional support, mentorship, hands-on experiential learning, and research integration, with PCA capturing broader dimensions such as mentorship and instructional confidence, while EFA identifies specific constructs like inclusive pedagogy and technical mastery. These findings provide actionable insights for designing faculty training programs that address gaps in technical preparation and pedagogical support. By fostering inclusive quantum education frameworks, institutions can better prepare educators to meet the challenges of this evolving field, ultimately contributing to the development of a robust and diverse quantum computing workforce.

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