Quantum Awareness for Post-Secondary Students

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***Abstract*—Quantum Information Science is a new and growing field. Significant growth in the quantum workforce has been called for by some in the quantum industry. Supporting this growth will require engaging the best and brightest. However, most students do not know what quantum information science entails or what jobs are available. We present a workshop model that we have developed to build quantum awareness among post-secondary students. These workshops have been effective in raising awareness and increasing interest in the field among students at a range of educational levels, including community college, undergraduate, and graduate students. All of the students who attended these workshops attended minority serving institutions, and most attended historically black colleges and universities. These workshops are only a first step towards building the quantum workforce. We still need to define pathways that allow students to take the next steps toward entering the workforce if they are interested in pursuing the field after one of these workshops.**

***Index Terms*—quantum information science, education, workforce development, undergraduate education, graduate education**

I. Introduction

As quantum technologies that harness the power of superposition and entanglement improve, companies are calling for more students to be prepared for jobs in this area [1], [2]. The jobs that need to be filled span disciplines and education levels. They range from technicians to the PhD scientists who are developing these technologies.

Currently, several challenges hinder the growth of the quantum-prepared workforce: (1) students don't know what quantum information science (QIS) is or what a career related to quantum could be; (2) from the little that they know, students believe that QIS is very difficult and only accessible to geniuses; and (3) students feel that there is a risk to going into quantum because it is such a new field [3].

QIS is not part of the curriculum or the standards across most K-12 institutions, so students do not know what it is beyond the little that they hear from the media or pursue on their own [3]. Even at the university level, programs that introduce students to quantum technologies outside of the traditional quantum mechanics courses for upper-level physics students only exist at a subset of universities. Most of the universities at which these courses exist are research-intensive universities, leaving behind the majority of students who do not attend these institutions [3]–[6].

Growing an equitable and inclusive domestic quantum workforce to support the growth that has been projected [1], [2] will require targeted efforts to reach students who have been significantly underrepresented in physics, engineering, and computer science. These fields are the ones from which most of the quantum workforce is currently being drawn, yet they have some of the lowest percentages of women and people from minoritized groups. Preparing a growing quantum workforce will require raising interest and awareness among students along the educational pipeline and supporting their interest in pursuing QIS education into a career in the field. Getting students from an interest in QIS to a job in the workforce will require connecting programs aimed at raising awareness to more in-depth opportunities like courses, certificates, and degree programs.

We present data collected as part of the Quantum Pathways program. This program aims to raise awareness of QIS among post-secondary students with a focus on students at minority-serving institutions (MSIs) and other institutions where there is not significant QIS research and programs. Understanding the knowledge and interest in QIS among students at these institutions will be important for the development of courses and programs. This work examines the background and interests of a subset of students at these institutions, but it does not provide information about whether the background and interests are different from those at other institutions.

II. Data and Methods

This study used a qualitative approach [7] to understand how participation in workshops related to QIS impacted students' thinking about quantum careers. Multiple sources of data were collected from the students who participated in the workshops. These participants comprise a diverse group of undergraduate and graduate students from MSIs.

A. Study Context: Quantum Pathways Workshops for Post-secondary Students

The authors developed the Quantum Pathways workshops to introduce QIS concepts and quantum careers to students who did not have other avenues of exposure, particularly students from MSIs. The workshops were designed with research-based pedagogical practices [8] at their core and aimed to help

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TABLE I
PARTICIPANTS

Workshop	Pseudonym	AS/UG/Grad	Gender	Race/Ethnicity	First Gen?
Bowie State			Male	Black Af.	No
Bowie State		UG	Female	Af. Amer.	
Bowie State		Grad	Male	Brown	No
Bowie State			Male	Black	No
Bowie State		Grad	Male	Lafrican Am.	No
Bowie State			Male	Hispanic/Latino	Yes
Bowie State			Female	Hispanic	Yes
Bowie State		UG	Male	Af. Amer.	No
Howard U.					
Howard U.		UG	Female	Black	No
Howard U.		UG	Female	Af. Amer.	Yes
Howard U.		UG	Male	Af. Amer.	No
Howard U.		UG	Male	Hispanic	Yes
Howard U.		Grad	Male	Black	No
Howard U.		Grad	Male	Black	
George Mason	Vincenzo	AS	Male		
George Mason	Salvador	AS	Male		
George Mason	Kerim	UG	Male		
George Mason	Lamar	Grad	Male	Black	No

students understand basic QIS concepts [9], what quantum career pathways exist, and how to pursue them.

The key components of the workshop included:

- An introductory activity in which students collaboratively discussed questions they had about quantum
- An introduction to the QIS concepts of quantum states, probability, superposition, and entanglement
- A hands-on discussion of light polarization as an example of quantum states, superposition, and measurement
- A discussion of quantum careers, usually with a panel of people who are working in different quantum careers (the Howard University workshop was embedded in a program with talks from quantum professionals rather than a panel)

Three workshops were held between January and April 2024. The first workshop was at the George Mason University Arlington Campus in January 2024. This workshop drew students from around the DC metro region who were majoring in engineering, physics, and cybersecurity. The second workshop was at Bowie State University with students studying computer science, and the third was at Howard University with students studying computer science and engineering who were involved with the IBM Historically Black Colleges and Universities (HBCU) Quantum Center as part of their Building Community, Advancing Quantum event.

The workshops at Mason and Bowie State made use of the National Q-12 Partnership World Quantum Day video (https://youtu.be/q0fqxPUDVpw) to introduce students to QIS and quantum careers. All three workshops participated in an introductory activity in which students listed the questions they have about QIS. This activity provides an avenue to see what students are curious about with respect to QIS. After the students wrote their questions, they learned about some of the quantum key concepts drawn from the Q-12 framework, including quantum states, superposition, measurement, and entanglement [9]. Following the key concepts presentation, light polarization was used to illustrate the idea of quantum state, superposition, and measurement. The orthogonal components of a polarization vector were described and "measurement basis" was defined. Students were then asked to predict the effect of one polarizer before observing it and then to do the same for two and then three. After predicting and then examining the case of three polarizers, the effect was explained using the earlier polarization vector discussion and then what would happen in the case of single photons was discussed. At Howard University, this was followed by a discussion of quantum applications including computing and cryptography. At Mason, it was followed by a discussion of quantum careers and a career panel with people with different backgrounds. At Bowie State, it was followed by a discussion of quantum computing and how it works and then a career panel.

B. Participants

Participants in each of the three Quantum Pathways workshops were asked to fill out feedback surveys at the completion of the event. These surveys collected basic demographic data, asked about knowledge and interest in quantum and quantum careers before and after the workshop, how the workshop influenced their thinking about further education or career, and the most and least useful aspects of the workshop for students at the Bowie State and Howard workshops. After the Mason workshop, attendees who were willing to participate were interviewed in two groups.

Table 1 shows demographic data for all of the students who attended the events and consented to participate in the research. For all of the workshops, only a subset of the students who attended consented to the research. We include pseudonyms for the students who participated in the focus groups as we discuss their responses in more detail. We note whether students were pursuing their associate's degree (AS), bachelor's degree (UG), or a graduate degree (grad). The race and/or ethnicity column was a free-response question so the entries are what students wrote. Note that all of the students attended minority serving institutions and are from groups underrepresented in STEM, and 29% of the survey respondents were women. Just under 70% of the participants who responded to the questions are the first in their families to attend college.

The first workshop at George Mason University was attended by students from a variety of institutions and disciplinary backgrounds, and all of the participants identified as male. The second workshop was at Bowie State University, an HBCU, and had about 30 undergraduate and graduate student participants, most of whom were studying computer science. The third workshop was at Howard University, also an HBCU, as part of their Building Community, Advancing Quantum event run by the IBM HBCU Quantum Center. This workshop had about 10 undergraduate and graduate students who were mostly studying computer science, with a few studying engineering or other STEM disciplines.

C. Data Analysis

The data used for the analysis presented here include (1) the questions that students wrote at the beginning of the workshop when they were asked what questions they had about quantum, (2) their responses to the questionnaire described in the previous section, and (3) semi-structured focus group interviews conducted with four of the attendees at the George Mason workshop in which the authors each interviewed two students.

At each workshop students were asked to write their questions about quantum on large Post-it notes before any QIS content was presented. It was suggested that they could start with "How," "What," "Why" kinds of questions, but they were free to write whatever questions came to mind and were encouraged to write as many questions as they could think of. These questions provide data on what students are wondering about with respect to QIS when they arrive at the workshop. These responses were thematically grouped for the analysis.

Students were asked to fill out online surveys at the end of the Bowie State and Howard events. These surveys provided demographic data, feedback about the workshop, and answers to questions that asked them to rate their knowledge and interest in quantum (Figures 1 and 2).

The focus group interviews after the George Mason workshop provide additional insight into students' knowledge of an interest in quantum as well as their thinking about the utility of the workshop. Focus group interviews were transcribed for analysis and checked for accuracy. We employed thematic qualitative analysis techniques to address our research question, including constant comparative methods [10]. Both descriptive coding and in vivo coding methods were used in our analysis [11].

With these data we address the **research question:**

> How does a workshop focused on quantum concepts and careers influence undergraduate and graduate student thinking about their future career path?

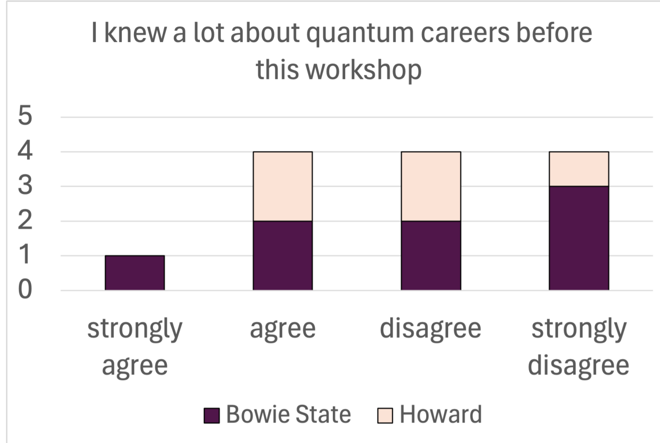

Fig. 1. Student feedback survey responses to the statement, "I knew a lot about quantum careers before this workshop." The responses are color-coded by workshop, but we do not have any responses to this question from the Mason workshop.

We have analyzed the data for the purpose of understanding how these workshops have influenced students' thinking about QIS and QIS careers. We analyzed the quantum questions posters by grouping the questions into thematic areas and noting common questions among the different groups.

In the discussion of the findings, all names are pseudonyms.

III. Findings

When asked what questions they have about "quantum" at the start of the workshops, most of the groups of students (each poster was created by 2-5 students) included questions related to quantum computing. Of the eleven posters of questions from three events, all but one had at least one question about quantum computing. This is likely because most of the students were studying CS and had an interest in computing. The Bowie State students, who were almost all computer science undergraduate majors or graduate students, asked questions that were almost exclusively about quantum computing. The quantum computing questions included "what is quantum computing," "what are the applications of quantum computing," "what are careers in quantum computing," and "how much do they cost." Even CS students who were taking a class with or working with a faculty member who is collaborating on a quantum computing project (this was the case for most of the Bowie State students), had basic questions about quantum computing.

While students at all of the workshops asked about quantum computing, the kinds of questions at each of the workshops were different. At the Mason workshop, which had a different mix of majors, in addition to the quantum computing questions, there were quite a few very broad, almost philosophical questions like "how did it come to be?" and "what would change if quantum was fully understood?" At the Howard workshop, there were several questions about education and inclusion, "what would change if quantum computing was accessible to the common (non-STEM) person?" and "suppose

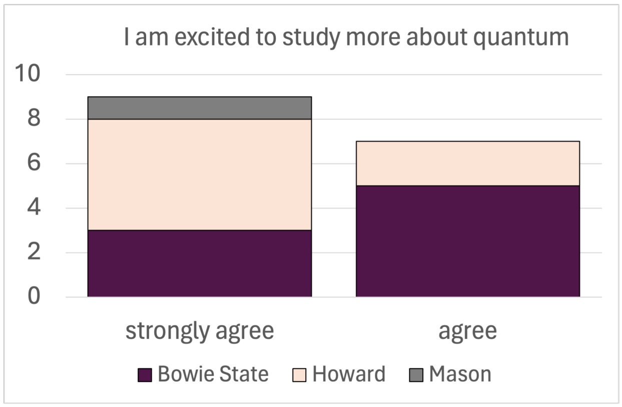

Fig. 2. Student feedback survey responses to the statement, “I am excited to study more about quantum.” The responses are color coded by workshop.

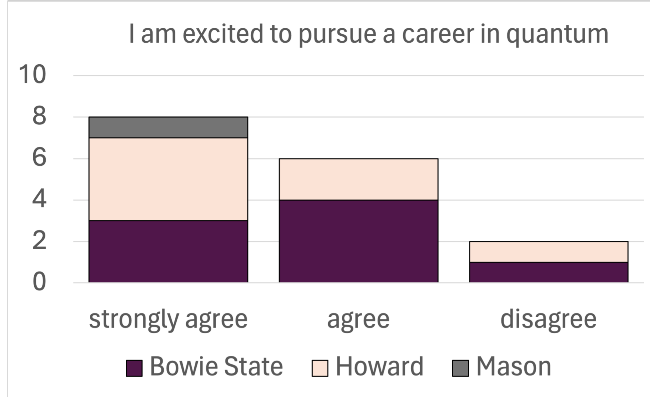

Fig. 3. Student feedback survey responses to the statement, “I am excited to pursue a career in quantum” The responses are color coded by workshop.

black people are not part of the quantum revolution how does that change quantum future?” and “How do you get more children involved in quantum computing?” and “how are we actively making the quantum workforce more inclusive - micro/macro levels?” While the questions differed, they emphasize that most of the students, regardless of level, are wondering about what QIS is as a field and where it is going in the future.

The feedback forms were only completed by a limited set of the students, but they give us some information on student knowledge and interests. As seen in the questions that students asked, the feedback survey question “What quantum topics do you still want to learn more about and/or wish we had covered?” response from a majority of students included an aspect of quantum computing (or quantum computing generally).

Figure 1 shows student responses with respect to what they knew about quantum careers before the workshop. The majority of students knew little about careers in this field. All students agreed or strongly agreed with the statement, “I learned something new about careers in quantum,” and Figure 2 shows that students left the workshop interested in learning more and, for most of the participants, Figure 3 shows that they left with an interest in pursuing a career in quantum.

One of the open ended feedback survey questions was,“In what ways has the workshop influenced your thinking about further education or your career?” Several of the students responded about ways it motivated them to do more in quantum, “It helps me think about doing more research about quantum computing.” For about half of the students who responded to this question, it increased their interest in a quantum career, “It makes me be more open like a career in quantum.”

One of the findings of this project is that raising awareness about QIS, how it might be useful, and what careers exist in this area is important even for graduate students. This is a new field, and those not working directly in it do not know what it is and what they might be able to do with it. While we expected that the graduate students at our events would be knowledgeable about quantum and that the material we were delivering would be at too basic a level, this was, for the most part, not the case. There was one Bowie State student who wanted to know more about decoherence (a topic beyond the scope of what was presented at the workshop), but she was the exception. Kerim, a University of Maryland Baltimore County student at the Mason workshop, had done a lot of work on his own to learn about quantum computing and how to use Qiskit, including attending a quantum hackathon. Even with this level of background knowledge, he found the workshop valuable. Kerim talked about gaining a better understanding of measurement, “Yeah, I got a lot more insight on measurement today than I did before. I didn’t really quite understand. And when I read or watch videos, I struggle a lot, but today it was kind of a bit eye-opening.”

These workshops were effective at getting students to think about how they might get involved in QIS careers. They came in with a lot of questions but left with more of a sense that this might be something that they wanted to pursue. Vincenzo noted “Seeing quantum is kind of an interesting subject. I don’t know what I can do with it in terms of being a mechanical engineer, but being in this workshop kind of makes me feel like, oh, maybe I can do something with it.” Lamar, the PhD student who attended the workshop at Mason, still came out of the workshop feeling like he clarified his understanding of superposition and measurement and learned something about careers in quantum.

IV. Conclusions

Our previous survey of STEM students at George Mason University showed that undergraduates, even those at an R1 institution that has a Quantum Science and Engineering Center, do not know much about QIS, but there is a lot of interest, particularly from those in engineering, CS, and the physical sciences [3]. This work continues to emphasize the same basic point. Students at all levels do not know what QIS entails, but they are curious to learn more. These workshops also emphasized the interest in quantum computing among the different aspects of QIS, as seen in most of the questions asked at the beginning of the workshops and in the feedback survey question about what students wanted to know more about.

This study does not indicate that what students who attend HBCUs and MSIs know about quantum is any different from what students at primarily white institutions know about it. However, most of the existing QIS courses and programs are at R1 institutions [5], [6]. In order to increase access and build a diverse student pipeline into QIS, it is going to be important to bring these ideas to a larger audience. These workshops provide a first step and show that just a few hours can raise awareness and interest. However, to be effective, these kinds of programs are going to have to build on-ramps into programs that can support students' pursuit of QIS. A student who gets interested while at an institution with an existing QIS program has a much easier path to pursuing a career in the field.

While these workshops have shown that a short engagement with students can raise their interest in QIS, they left important questions to be answered. In particular, they did not provide any information on how to support the growth of the students' understanding of QIS and continue to engage these students' interests. It did not provide any information on the kinds of programs that would be most useful to help these students pursue a QIS career.

Future research in quantum education at the undergraduate and graduate level should consider questions at both program and individual levels. College and university faculty should explore how to build programs that offer access to quantum careers for students beyond R1 institutions. At the same time, future research should examine how individual students develop an interest in quantum and a robust STEM identity that will help them persevere in this challenging but rewarding field.

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