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Experimental Skills for Non-PhD Roles in the Quantum Industry

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Executive summary

As the quantum information science and engineering (QISE) workforce grows, there is an anticipated need for professionals with bachelor's and master's degrees who can fill a wide range of roles in the quantum industry [1]. This report identifies the **experimental skills** needed for individuals with bachelor's or master's degrees to succeed in quantum industry roles. Through semi-structured interviews with quantum industry employers, we gathered data on **22 distinct positions** spanning hardware, software, and business functions. While employers describe varying expectations of quantum expertise, the unifying requirement across these roles is proficiency in experimental skills, which fall into four key categories:

1. **Instrumentation**
2. **Computation and data analysis**
3. **Experimental and project design**
4. **Communication and collaboration**

Positions open to bachelor's and master's graduates use all four skill areas, but the balance of experimental skill set needed differs. Bachelor's roles lean toward **instrumentation**, **computation and data analysis**, as well as **experimental and project design** skills. Individuals in these roles build, operate, and troubleshoot hardware, and they gather and interpret data to design and carry out experiments. Master's roles stand out with the **communication and collaboration** skills needed on top of the other three skill categories. Individuals in these roles oversee experiments, coordinate teams, and align efforts with company and client needs. By articulating experimental skills needed for bachelor's and master's roles in the quantum industry, this report provides actionable insights for educators developing QISE courses and programs.

Recommendations:

1. **Prioritize the discussion of hardware in QISE theory courses**: Undergraduate programs should emphasize the theoretical foundations of quantum hardware within QISE courses to better prepare students for entry-level positions in the quantum industry. Currently, many introductory QISE courses focus solely on abstract theoretical concepts with limited time spent on theory underlying the experiments and devices [2]. Thus, shifting the focus of these courses to include discussions on theory behind hardware components will better align QISE education with industry needs.

2. **Increase experimental training through instructional labs**: Many of the experimental skills needed for non-PhD positions in the quantum industry overlap with general experimental skills that are valuable across a range of career paths. Many of these skills are already part

of the learning goals of existing lab courses, which makes this recommendation achievable with minimal additional resources. Increasing opportunities to engage in experimental skill development within existing labs would better prepare students for positions in the quantum industry, while simultaneously strengthening preparation for other career paths.

3. **Include professional skills in undergraduate QISE education**: Employers consistently identify communication and collaboration as critical skills. These skills should be embedded within QISE courses and programs to ensure students are prepared for industry roles.

Motivation

The quantum industry is growing with increasing need for talent at all educational levels. While PhD-level expertise remains important for research and development, there is an anticipated need for quantum industry professionals with bachelor's and master's degrees [1]. These roles are projected to be critical for the deployment of quantum technologies at scale. Despite this projected need, the specific skills required for these non-PhD roles remain underdefined, which makes it challenging to design courses and programs aligned with workforce needs [3]. Understanding which experimental skills employers desire can help align curricula with workforce needs.

Data collection and analysis

We conducted 37 semi-structured interviews with quantum industry employees based in the United States between December 2024 and May 2025.

Participants represented a range of perspectives and roles within the industry:

- Managers who provided a broad view of different roles in their company and associated knowledge, skills, and abilities (KSAs);
- Employees who described detailed tasks they engage in and associated KSAs.

Interviewees came from various company types and sizes as seen in Fig. 1, which allowed us to have insights into workforce needs from a variety of job roles in the quantum industry.

> **Key Question**
>
> **What experimental skills are needed for non-PhD roles in the quantum industry?**

To answer our key question, we analyzed our interview data to identify the knowledge and skills needed for each individual position in our dataset. A total of 70 individual positions were identified and filtered to 22 requiring associate's, bachelor's or master's degrees. Initial analysis used skill categories from the AAPT Recommendations for the Undergraduate Physics Laboratory

Curriculum framework [4], which we later refined to better reflect the pattern of skills found in our dataset.

Company Size

Company Type	1-20	20-50	50-100	>100	Unknown	Partial sum
Quantum computing hardware	5	2	2	9	0	**18**
Enabling Technologies	4	3	1	8	0	**16**
Quantum algorithms and software	1	2	1	7	0	**11**
Quantum networking and communication	1	1	0	3	0	**5**
Consultants	1	1	0	2	0	**4**
Quantum sensing	0	1	0	2	0	**3**
End users of quantum technology	0	0	0	0	1	**1**
Partial sum	**12**	**10**	**4**	**31**	**1**	

Figure 1. Distribution of interviewed companies by type and size. We did 37 interviews with professionals at 22 distinct companies. We had a few interviewees from the same company and most companies self-reported participation in more than one type of activity. We adopted definitions consistent with prior literature [5, 1] for company types. Company size corresponds to the range of employees working in quantum-related technologies in these companies.

Note on terminology

Job role often refers to a job family or title that multiple people may hold across different companies, even if their responsibilities may vary somewhat. This report focuses on individual *positions*, by which we mean a specific job at a particular company (e.g., quantum software developer at company X). When we use the term "role" in this report, it is for readability and should be interpreted as referring to a specific position unless noted otherwise.

Results

Experimental skills for quantum industry positions held by non-PhDs

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Main Takeaways

Our study identifies a set of experimental skills listed in Tables 1, 2, 3, 4 organized into four categories:

1. **Instrumentation**: Operating, maintaining, and troubleshooting scientific and engineering instruments and systems.
2. **Computation and data analysis**: Applying computational tools to acquire, process, and interpret data.
3. **Experimental and project design**: Planning, executing, and managing experiments.
4. **Communication and collaboration**: Sharing technical insights and coordinating with stakeholders.

The experimental skills identified from our data are listed by skill category in Tables 1, 2, 3, 4.

Table 1. Instrumentation skills (I1–I9) for quantum industry positions held by non-PhDs.

	Instrumentation Skills
I1	Able to operate basic test and measurement devices (e.g., power supplies, multimeters)
I2	Having hands-on experience with electronic systems and components
I3	Able to operate and fix laser systems
I4	Having hands-on experience with optical systems and optical alignment
I5	Able to operate interferometers to assess surface flatness
I6	Able to work with ultra-low temperature apparatus
I7	Able to work with vacuum systems
I8	Able to do basic troubleshooting with an iterative and logical approach
I9	General practical experimental skills (e.g. research experience, lab course)

Table 2. Computation & data analysis skills (D1–D6) for quantum industry positions held by non-PhDs.

Computation & Data Analysis Skills

D1 Able to interpret computational or measurement results to understand physical systems

D2 Able to do some programming generally, without specifying whether it is for data processing, data representation, or other purposes

D3 Able to select numerical algorithms or software tools based on problem requirements

D4 Able to troubleshoot code

D5 Able to use computers to collect and process data

D6 Able to perform data analysis including uncertainty analysis

Table 3. Experimental & project design skills (E1–E10) for quantum industry positions held by non-PhDs.

Experimental & Project Design Skills

E1   Able to integrate multiple scientific principles when designing experiments

E2   Able to integrate multiple scientific principles to translate findings into practical applications

E3   Able to design a procedure to test a model or hypothesis

E4   Able to effectively plan and carry out experiments

E5   Able to manage complex technical projects from formulation through testing to reporting

E6   Able to perform basic systems engineering tasks, including understanding requirements and determining acceptable performance thresholds

E7   Able to design and oversee construction of specialized scientific facilities, including cleanroom and chip fabrication facilities for quantum research

E8   Able to critically read scientific literature to refine research questions or optimize an experimental design

E9   Able to conduct an experiment in an open-ended and ill-defined context (e.g., working in ambiguity with emerging technology)

E10 Able to persist through experimental setbacks, including adapting approaches until reliable outcomes are achieved

Table 4. Communication & collaboration skills (C1–C5) for quantum industry positions held by non-PhDs.

Communication & Collaboration Skills
C1   Able to prepare and deliver presentations to multiple stakeholders
C2   Able to collaborate effectively with others
C3   Able to create and maintain clear and up-to-date technical documentation for experimental setups and procedures
C4   Able to write reports and proposals
C5   Able to critically assess both their own work and that of others to identify strengths and limitations

Overview of non-PhD quantum industry positions

Main Takeaways

- The **22 non-PhD positions** identified in our dataset span a wide range of job titles and disciplinary backgrounds, from highly hands-on technical positions (e.g., *lab technician, fabrication engineer, assembly technician*) to engineering roles (e.g., *research engineer, quantum engineer, nanofabrication engineer*) to more business-focused roles (e.g., *quantum business development specialist, product manager*).

- The unifying feature of most non-PhD positions is their **reliance on experimental skills**: whether the day-to-day tasks involve assembly of optical systems, troubleshooting, developing research software, or presenting results, most rely heavily working knowledge and skills in **instrumentation**, **computation and data analysis**, **experimental and project design**, and **communication and collaboration**.

Table 5. Overview of the 22 individual positions, including education, discipline, quantum expertise, and mapping to the four experimental skill categories (refer to Tables 1, 2, 3, 4 for exact skill).

Title of Individual Positions	Education	Discipline	Quantum Expertise	Instrumentation	Computation & Data Analysis	Experimental & Project Design	Communication & Collaboration
Lab technician	Associate, Bachelor	Engineering (Eng.), Other	Aware	I9	D2, D5		
Fabrication engineer	Bachelor	Physics, Math	Conversant, Proficient	I1–I8	D1, D5	E1, E2, E5, E10	C5
System operator	Bachelor	Physics, Engineering	Conversant	I1, I8	D1	E1, E2, E6	C1, C3
Photonics assembly technician	Bachelor	Physics, Engineering	Conversant, Proficient	I2, I4, I9	D2, D6	E5	C5
Assembly technician	Bachelor	Physics	Aware, Conversant	I2, I3, I4, I9	D2, D6	E5	C1, C2, C5
Quantum R&D engineer	Bachelor	Engineering Physics	Proficient	I2, I4, I8	D2	E3, E4, E6, E8	C1, C2, C3
Laser and optics engineer	Bachelor	Physics, Chemistry	Proficient	I4, I5, I8, I9	D2		
Quantum software developer 1	Bachelor	Computer Engineering	Conversant		D1, D2, D3, D4	E10	C1, C2, C3, C5
Quantum software developer 2	Bachelor	Computer Science (CS)	Conversant		D1, D4		C1, C2, C5
Quantum software engineer 1	Bachelor	CS, Engineering, Math	None, aware		D1, D2, D4	E10	C1, C2, C5
Quantum software engineer 2	Bachelor	CS, Physics, Math	Conversant		D1, D2, D4		C1, C2, C5
Chief Operating Officer	Bachelor	Engineering, Other	Aware	I8		E5	C1
Construction specialist	Bachelor	Other	Aware			E5, E7	C1
Research engineer	Bachelor, Master	Physics, Chemistry, CS, Eng.	Conversant	I3, I4, I8		E5	C2
Research scientist / quantum systems engineer	Bachelor, Master	Physics, Thermal Eng., Mech. Eng.	Proficient	I8, I9		E10	C2, C5
Algorithm developer 1	Bachelor, Master	CS, Physics, Math, Other	Proficient		D1, D2, D3, D4, D6	E3, E8, E10	C1, C2, C5
Algorithm developer 2	Bachelor, Master	Physics, CS	Proficient		D1, D3, D4		C5
Quantum engineer	Bachelor, Master	Engineering, Eng. Physics	Conversant, proficient	I3		E6	
Test and integration engineer	Master	Electrical Engineering	Conversant	I5, I6, I7, I8	D3	E6, E9	C1, C2, C5
Nanofabrication engineer	Master	Physics	Aware	I8			C5
Quantum business development specialist	Master	Physics	Expert		D6	E5	C1, C4
Product manager	Master	Engineering	Conversant			E5	C1, C5

Legend: "Other" denotes that no specific discipline is required according to the interviewee. "Quantum Expertise" describes the level of quantum knowledge the interviewee believes the position requires. Definitions provided to interviewees were adapted from the CUbit Quantum Initiative's report on the quantum workforce [6]:

Quantum Aware: those who are new to quantum concepts and simply have general awareness of the subject matter;

Quantum Conversant: those may or may not hold a traditional four-year degree, but should be able to have a conversation in quantum information science topics;

Quantum Proficient: those who may hold physics or engineering degrees in quantum-specific topics at either the undergraduate or master's degree levels;

Quantum Expert: those who may typically hold a PhD in physics, engineering, computer science, or other subjects connected to the basic study of quantum phenomena.

Patterns of experimental skills among non-PhD professionals in the quantum industry

> **Main Takeaways**
>
> - The **22 positions** require a mix of the four skill categories as illustrated in Fig. 2, though certain positions place greater emphasis on particular skills. Hardware focused positions emphasize **instrumentation** skills. Software and algorithm positions emphasize **computation and data analysis** skills. Customer and product development positions emphasize **experimental and project design**, and **communication and collaboration** skills.
> - These patterns reflect both the technical nature of the work in these positions and the **typical educational levels** of individuals filling them. Bachelor's level positions tend to focus on building and operating experimental setups, while master's level positions focus more on planning and optimizing those setups, as well as communicating effectively with various stakeholders.

Instrumentation

Instrumentation skills emerged as dominant desirable skills across a wide range of roles in our data and serve as a key differentiator between positions open to different degree levels. These skills range from foundational skills, such as operating basic test and measurement devices, to more specialized expertise, such as working with vacuum systems.

Some positions with an instrumentation focus are accessible to both bachelor's or master's degree holders such as the *quantum engineer* position. However, positions that require only a bachelor's degree tend to emphasize familiarity with common laboratory tools and systems. For instance, when discussing the knowledge and skills needed for a *fabrication engineer*, our interviewee explains the importance of being able to operate basic test and measurement devices. They say:

> *Understanding how a multimeter works and what impedance is — these basic things are helpful.*

Other essentials skills at this educational level include operating interferometers to assess surface flatness and be able to do basic troubleshooting of equipment. At the master's level, instrumentation skills shift towards integrating subsystems, and using advanced optomechanical and design tools. For example, when discussing the knowledge and skills needed for the *test and integration engineer* position, our interviewee highlights the need for candidates with more hands-on experience to build and maintain the structures that support optical systems. They explain:

> *The big one that we struggled to find are people with the optomechanical knowledge and tools such as CAD, [Computer-Aided Design] SolidWorks or Onshape that support making a system.*

The breadth of these roles illustrates how proficiency with scientific instruments and systems
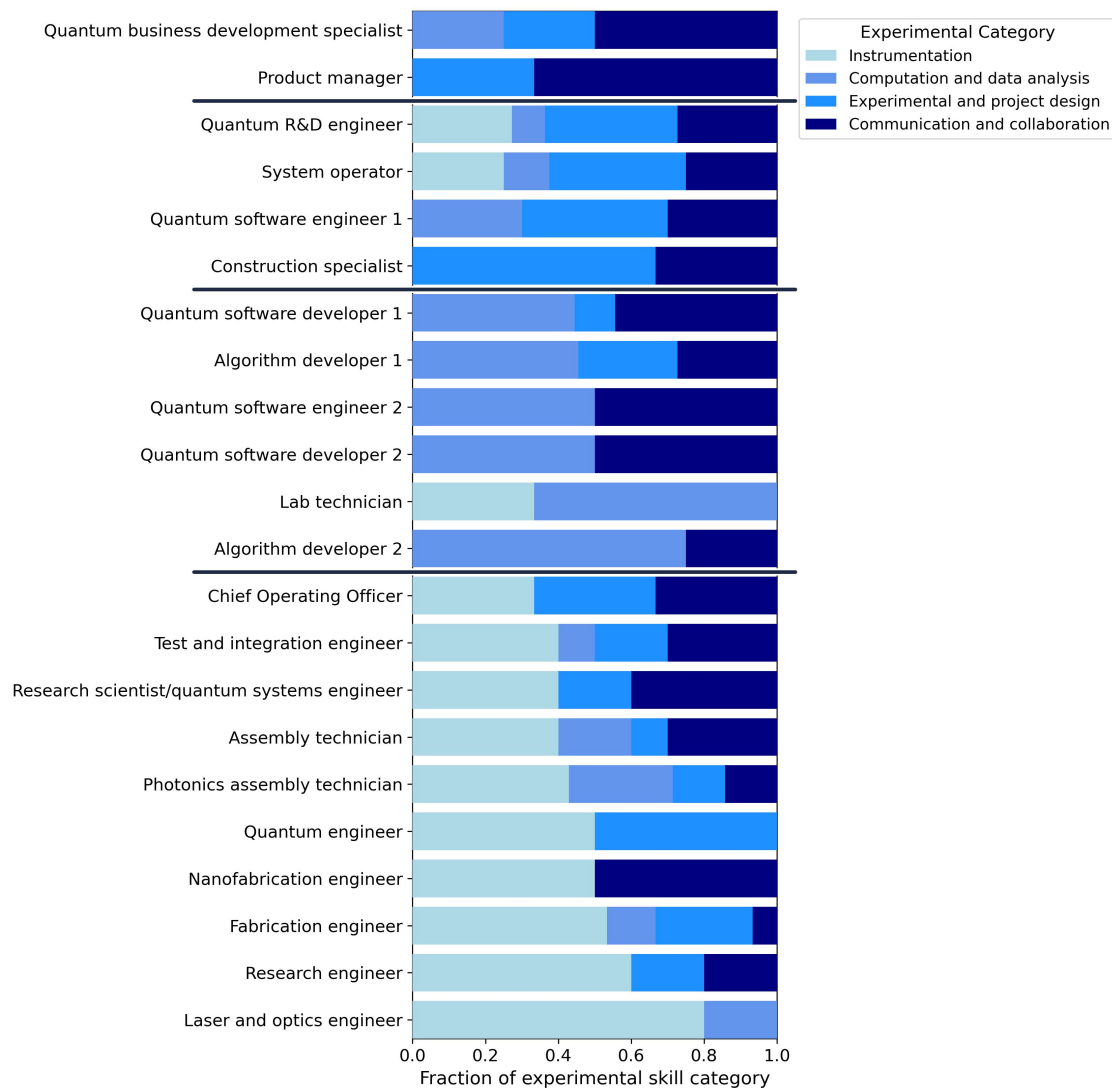
Figure 2. Distribution of experimental skills for each position grouped by dominant experimental skills category. The individual positions serving as starting and endpoint points for each category are: Chief Operating Officer → laser & optics engineer emphasize **instrumentation** skills. Algorithm developer 2 → software developer 1 emphasize **computation and data analysis** skills. Construction specialist → quantum R&D engineer emphasize **experimental and project design** skills. Product manager → quantum business development specialist emphasize **communication and collaboration** skills.

opens multiple opportunities. For *bachelor's graduates*, hands-on experience with laboratory equipment provides a foundation for technical positions focused on assembly, maintenance, and troubleshooting. For *master's graduates*, more advanced and specialized instrumentation skills enable individuals to take on system integration and optimization responsibilities.

Computation and data analysis

Computation and data analysis are critical for roles focused on software development. In our dataset, these positions are largely accessible to individuals with a *bachelor's degree* and emphasize the ability to interpret computational or measurement results to understand physical systems.

In these roles, employees are expected to have general programming skills that enable them to write code. When discussing knowledge and skills needed for the *quantum software developer 1* position, our interviewee states that familiarity with common programming environments is a baseline expectation:

> *It's expected that people are familiar with either Python or Conda, the Jupyter Notebook environment that type of R&D set.*

Beyond basic programming, these positions require the ability to select appropriate numerical algorithms or software tools based on problem requirement. Additionally, in these roles, employees need to perform data analysis, including uncertainty analysis, to inform experimental results or develop software tools that support quantum research and engineering. By combining programming expertise and data interpretation, individuals in these roles provide the software infrastructure and analytical skills that bridge the gap between experimental operations and computational modeling.

Experimental and project design

Several positions place experimental and project design skills at the core of their responsibilities, which require individuals to plan, execute, and manage experiments or experimental workflows. These positions emphasize the ability to design procedures to test models or hypotheses, and effectively plan and carry out experiments.

Positions emphasizing these skills are filled by bachelor's level graduates who must be able to integrate multiple scientific principles to translate findings into practical applications. These individuals balance theoretical concepts with practical considerations. For example, when discussing knowledge and skills needed for the *quantum R&D engineer* position, our interviewee describes that part of managing a complex technical projects includes:

> *Translating a quantum experimental plan into requirements for a control system such as resolution, or number of channels of a certain output type.*

Employees in these roles that emphasize experimental and project design also highlight the importance of adaptability and problem-solving when conducting experiments in open-ended

and ill-defined contexts. Individuals in these positions play a key role in shaping experimental processes and adapting them to evolving project needs.

Communication and Collaboration

Positions that emphasize communication and collaboration are essential for bridging technical work with strategic decision-making. These positions tend to be filled by individuals with a *master's degree*, which reflects the advanced experimental skills needed to communicate and collaborative effectively with multiple stakeholders. For example, when discussing the skills needed for the *product manager* position, our interviewee highlights how a deep understanding of experiments helps in navigating conflicting technical requirements:

> *When I have a customer interaction, when the customer stipulated two seemingly unrelated technical requirements, but in actual implementation, when you understand how the experiment works, they are actually contradictory to each other, you have to bring it up to the customer and say, "Hey, if we're going to implement to fulfill your requirement A, we need to do this. When doing this, that's actually contradicting requirement B that you just stipulated, even though on the surface, these two don't seem related to each other." That's definitely a very important skill set that I would say that really helps out in my line of work.*

In addition to external communication, these positions require strong internal communication practices, such as creating and maintaining clear and up-to-date technical documentation for experimental setups and procedures. Professionals in these positions focus on translating complex technical results into actionable business strategies that ensure projects move forward smoothly. Ultimately these roles that emphasize communication and collaboration skills serve as a vital link between experimental teams and strategic leadership.

Recommendations and conclusions

> **Main Takeaways**
>
> - Non-PhD roles in the quantum industry are unified by an emphasis on experimental skills across four areas: **instrumentation**, **computation and data analysis**, **experimental and project design**, and **communication and collaboration**.
> - Bachelor's roles emphasize a range of skills in **instrumentation**, **computation and data analysis**, and **experimental and project design**, while master's roles place greater weight on **communication and collaboration** on top of the other three skill categories.

These findings point to concrete steps educators can take to align QISE courses and program with workforce needs:

1. **Prioritize the discussion of hardware in QISE theory courses**: Undergraduate programs should emphasize the theoretical foundations of quantum hardware within QISE courses to better prepare students for entry-level positions in the quantum industry. Currently, many introductory QISE courses focus solely on abstract theoretical concepts with limited time spent on theory underlying the experiments and devices [2]. Thus, shifting the focus of these courses to include discussions on theory behind hardware components will better align QISE education with industry needs.

2. **Increase experimental training through instructional labs**: Many of the experimental skills needed for non-PhD positions in the quantum industry overlap with general experimental skills that are valuable across a range of career paths. Many of these skills are already part of the learning goals of existing lab courses, which makes this recommendation achievable with minimal additional resources. Increasing opportunities to engage in experimental skill development within existing labs would better prepare students for positions in the quantum industry, while simultaneously strengthening preparation for other career paths.

3. **Include professional skills in undergraduate QISE education**: Employers consistently identify communication and collaboration as critical skills. These skills should be embedded within QISE courses and programs to ensure students are prepared for industry roles.

Limitations

Our findings should be interpreted with the following limitations in mind:

- *Sample and scope:* We interviewed 37 professionals at 22 companies. Thus, the sample is not intended to be representative of all roles in the quantum industry.
- *Time-bounded snapshot:* The report presents the first set of findings based on interviews conducted

with quantum industry professionals in the first half of 2025. Workforce needs may evolve as quantum technologies becomes more mature.

Future work

Building on these initial results and addressing the limitations above, we plan to:

- Further refine the experimental skills taxonomy as we collect more data;
- Provide a detailed account of the extent and type of QISE content knowledge expected at the bachelor's and master's levels as we conduct more analysis.

Acknowledgments

About the project

This report is part of a collaborative project between researchers at the University of Colorado Boulder & Rochester Institute of Technology to advance quantum information science education and strengthen the quantum workforce. Learn more about the broader effort at rit.edu/quantumeducationandworkforce.

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