# Preparing for the quantum revolution - what is the role of higher education?

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https://arxiv.org/abs/2006.16444

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# Outline of this talk

1. Motivation
2. What is the quantum industry?
3. Methodology
4. Research questions:
    a. What are the career opportunities?
    b. What skills are valued?
    c. What are the routes into specific jobs?
    d. What new training is needed?
    e. What are the hiring challenges?
5. Discussion and Conclusions

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# Motivation

## The National Quantum Initiative Act

Public Law 115–368
115th Congress

An Act

Dec. 21, 2018
[H.R. 6227]

To provide for a coordinated Federal program to accelerate quantum research and development for the economic and national security of the United States.

*Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled,*

National Quantum Initiative Act. 15 USC 8801 note.

**SECTION 1. SHORT TITLE; TABLE OF CONTENTS.**

(a) SHORT TITLE.—This Act may be cited as the "National Quantum Initiative Act".

(b) TABLE OF CONTENTS.—The table of contents of this Act is as follows:

**SEC. 3. PURPOSES.**

The purpose of this Act is to ensure the continued leadership of the United States in quantum information science and its technology applications by—

(1) supporting research, development, demonstration, and application of quantum information science and technology

(A) to expand the number of researchers, educators, and students with training in quantum information science and technology to develop a workforce pipeline;

Higher-education institutions have a key role

Our first question is:
What is quantum information science and technology in this context?

*Hence,* ***what is the "quantum industry"****?*

# What is the Quantum Industry?

1. Quantum information science:

   *"the use of the laws of quantum physics for the storage, transmission, manipulation, computing, or measurement of information."*

   (National Quantum Initiative Act)

2. The quantum industry:

   *All companies engaged in activities that either apply quantum information science for their product to function or provide technology that enables such a product.*

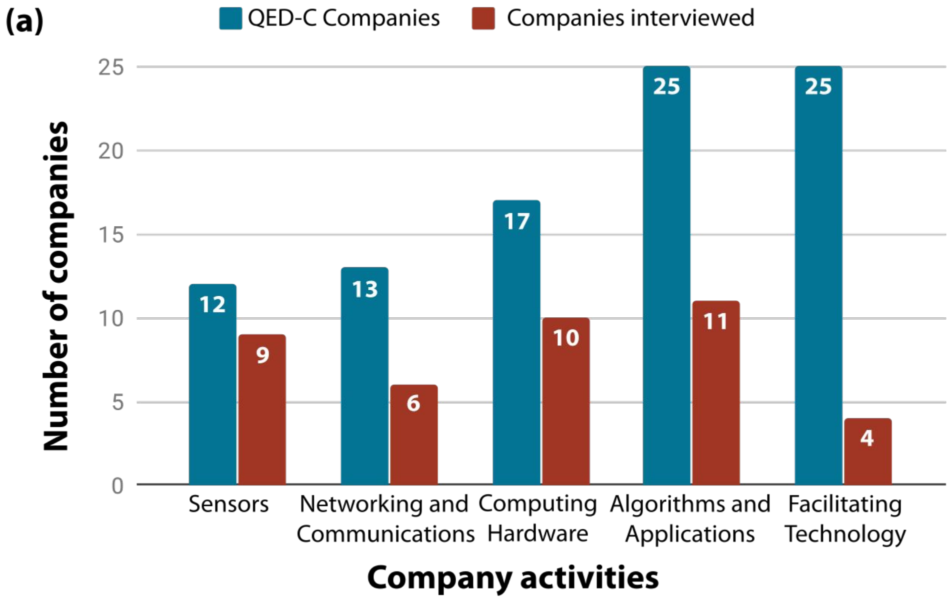
**Five types of activities**

1. Quantum sensors
2. Quantum networking & comms
3. Quantum computing hardware
4. Quantum algorithms & applications
5. Facilitating technologies

# Methodology

Interview study of 21 companies from across the different activities of the Quantum Industry.

Recruited through the Quantum Economic Development Consortium (QED-C) mailing list and snowball sampling.




Find out more about the QED-C: www.quantumconsortium.org

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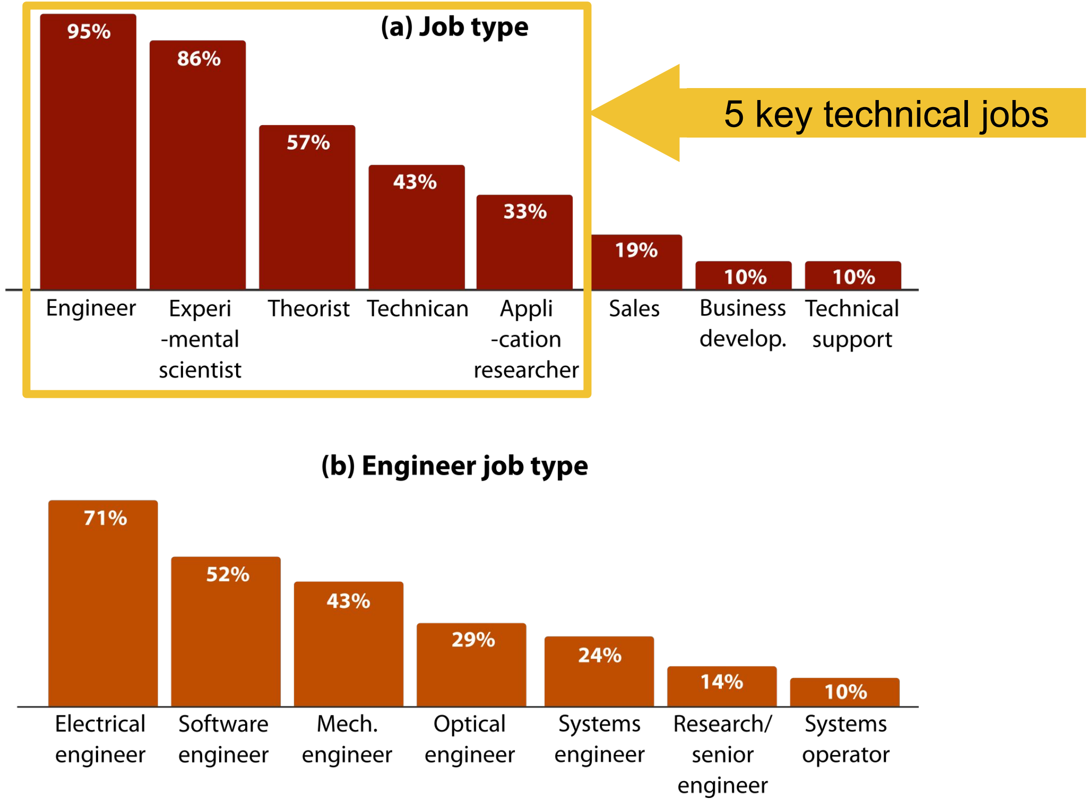
# What are the career opportunities?

**Percent of the 21 companies employing at least 1 person in these roles**



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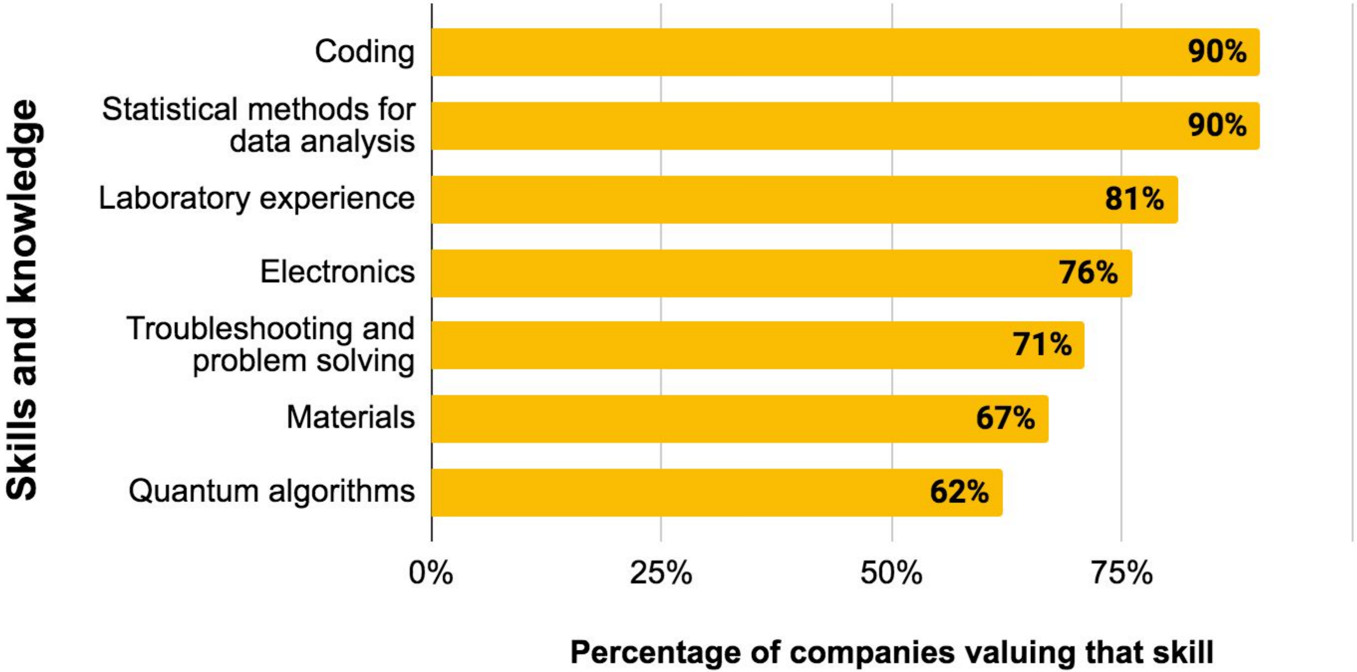
# What are the skills valued by the quantum industry?



# What are the skills associated with each job?

An example:

**Electrical engineer (N = 16)** The majority of the engineering jobs are electrical engineers. Electrical engineers form an important part of hardware teams and there is demand for different specialist knowledge depending on the specific hardware, such as the design and manufacture of microwave circuits that are used to manipulate qubits in superconducting hardware or radio frequency circuits to probe atomic transitions (38%). Electrical engineers play a role in constructing precision control and feedback systems (31%), so that measurements of delicate quantum states can be made, which requires an understanding of analog electronics (31%). Another example is the need for specialists in building low-noise power supplies for laser systems.

# Linking skills to future training

We have produced skills tables with the following course titles:

1. Traditional quantum theory
2. Quantum information theory
3. Real-world quantum information theory
4. Hardware for quantum information
5. Electronics
6. Mechanical engineering
7. Optics and opto-mechanics

| Real-world Quantum Information Theory | |
|---|---|
| **Skills** | **Examples** |
| Coding | "be able to **program based on established quantum algorithms**, be able to debug the quantum processor, be able to collect and analyze data and discuss the results back with me." |
| Statistics and data analysis | "Some of what we do is refining our processes and calibrations of [the computer] and that involves doing a bunch of experiments and understanding **if you've nullified your hypothesis or proven your hypothesis.**" "we have software engineers that contributed to the **statistical analysis** [of experiments]" |
| Troubleshooting (debugging) | "**totally different from debugging classical code** 'cause classical codes you can step through and quantum codes you can't do that because you'd have to measure and [when you measure] you just throw your information." |
| Noise sources | "what a gate model machine is, the principles on how it operates, **decoherence and noise mechanisms** and common failure mechanisms for both models of quantum computation." |
| Modeling | "understanding how to take noisy data, understanding what the underlying physical model of what is dragging that data, knowing how to fit that data and say something statistically meaningful: **whether your model is correct or not; or how to update your model**." |
| (De)coherence | "the decoherence mechanisms for the technology upon which the sensor operates" "it's important to know for a particular application **whether you want a system that has a longer coherence time** or a system that can easily be coupled to some other system. What are the limits of that kind of coupling?" |
| Error correction | "for **quantum error correction**, and device design, and simulation obviously need lots of physics" |
| Open system dynamics | "the Schrödinger equation drives the time evolution that we see or, hopefully even more than unitary dynamics, understanding **open system dynamics**" |
| Qubit hardware | "when you're talking about quantum computing and applications, you don't need to know a great deal about the base hardware except for **how it's going to propagate up in terms of decoherence mechanisms**" |
| Hamiltonians | "that sort of connection from some abstract **Hamiltonian** to actual physical reality is of course tenuous and needs to be carefully understood what the limitations are." |
| Quantum circuit design (physical) | "taking a specification of a quantum system in terms of a Hamiltonian and then **turning that into a design that will be fabricated**. And there's a lot of microwave engineering there, but also strong connections to quantizing microwave circuits." |

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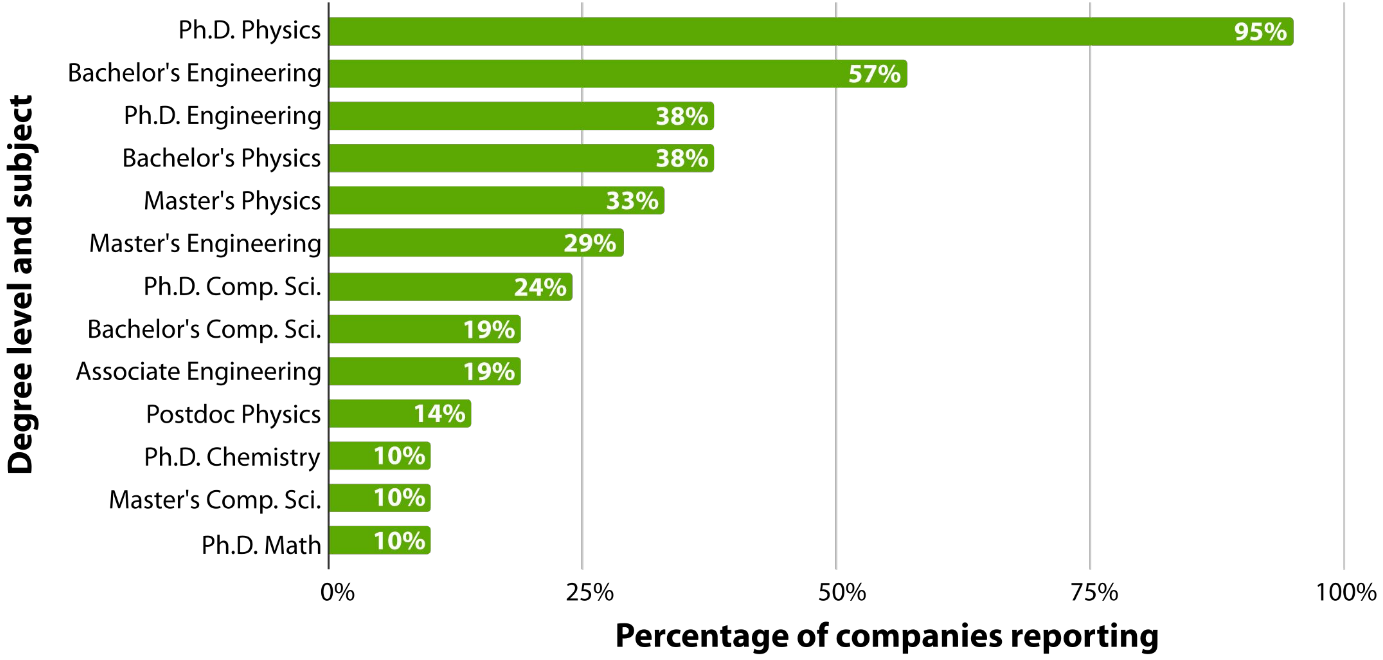
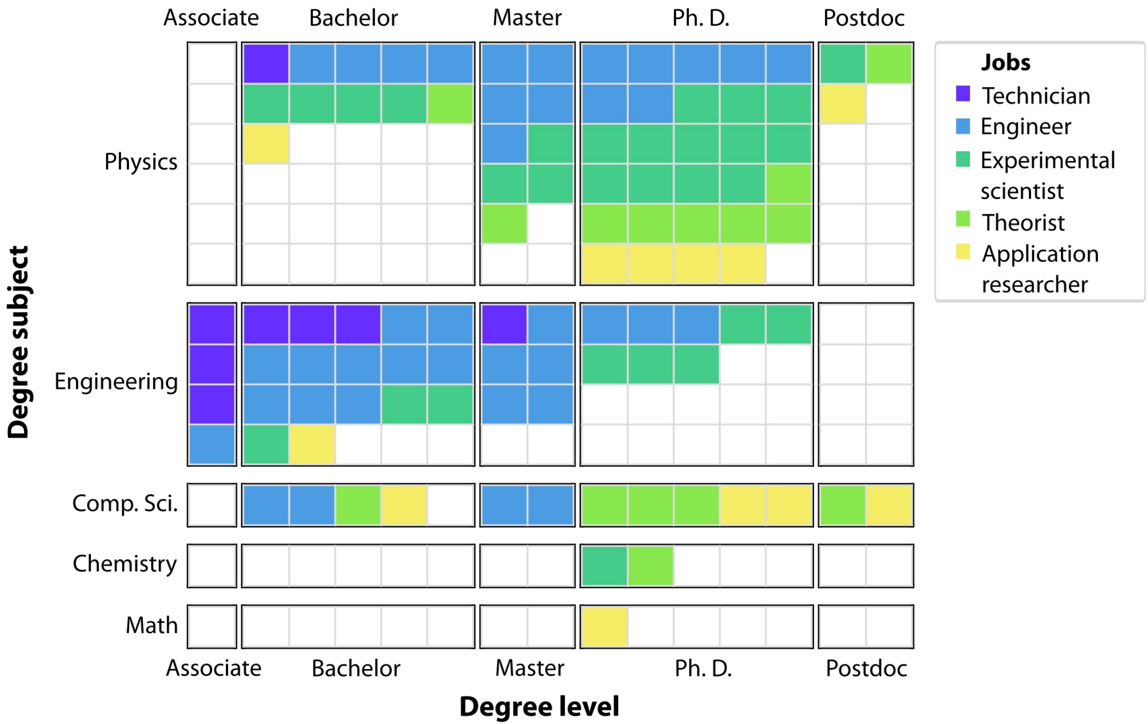
# What are the routes into specific jobs?



# What are the routes into specific jobs?



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# What new training is needed?

**Generally:**

- Satisfied with skills and knowledge of physics Ph.D. graduates.
- High value associated with hands-on experience.

**For undergraduate engineers** - a basic course in quantum information:

1. Software track: in software and algorithms
   - for CS and Software Engineers
2. Hardware track: in device physics, qubits, and control electronics
   - for Electrical, Mechanical, and Optical Engineers

**For physics students** - value associated with:

1. working collaboratively on software (e.g. Git) and
2. engineering and system design skills

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# What are the hiring challenges?

1. 33% of companies reported finding quantum information theorists a challenge (though not all!):

   *"a lot of the theory positions have been the hardest... it's very specialized as far as the number of groups in the world that focus on things like quantum computing algorithms or quantum error correction"*

2. 29% of companies reported:

   *"what's challenging is finding people with relevant electronics expertise, and by relevant I mean sort of a good blend of analog and digital."*

# Discussion

<u>What is a quantum engineer?</u>

- A Ph.D. physicist gone into industry?
- A bachelor’s electronic engineer working on quantum hardware?
- A software engineer, with some QIS knowledge, writing quantum algorithms?

These are all quantum engineers!
It depends on who you ask.

# Conclusions

Today, we have answered the following questions:

1. What are the career opportunities?
2. What skills are valued?
3. What are the routes into the quantum industry?
4. What new training is needed?
5. What are the hiring needs?

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And we **provide resources**
to help identify the relationship **between these skills**
and **courses that are currently being taught** or are planned for the future.

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